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Automatic Steering For Conventional Truck Trailers: Development and Assessment of Operating Concepts for Improving Safety, Productivity and Pavement Durability

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**Automatic Steering For Conventional Truck
Trailers: Development and Assessment of
Operating Concepts for Improving Safety,
Productivity and Pavement Durability**

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Joseph Benjamin Zeta and Lihong Zhou
San Jose State University

**California PATH Research Report
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The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California. This report does not constitute a standard, specification, or regulation.

Final Report for Task Order 5201

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**AUTOMATIC STEERING FOR CONVENTIONAL TRUCK TRAILERS:
DEVELOPMENT AND ASSESSMENT OF OPERATING CONCEPTS FOR
IMPROVING SAFETY, PRODUCTIVITY AND PAVEMENT DURABILITY
(TASK ORDER NO. 5201)**

FINAL REPORT

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AUTOMATIC STEERING FOR CONVENTIONAL TRUCK TRAILERS: DEVELOPMENT AND ASSESSMENT OF OPERATING CONCEPTS FOR IMPROVING SAFETY, PRODUCTIVITY AND PAVEMENT DURABILITY

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ABSTRACT

Trucking productivity can be significantly increased by moving freight with longer combination vehicles (LCVs). However, LCV operations not only raise safety concerns for the surrounding traffic and the LCV drivers themselves but also can damage roadways and bridges not equipped to support the operations. All the discussion about truck size and weight limitations or about the pros and cons of LCV operations is predicated on the use of conventional tractors and trailers. We however observed that a root cause of several major issues associated with LCV operations is the problem of off-tracking. Through this one-year \$58K project, we have demonstrated that this off-tracking problem can be drastically reduced with a new partial-automation technology: automated trailer steering (ATS).

ATS can provide safety benefit for all existing large-truck operations, including non-LCVs and LCVs. However, the degree of the benefit is difficult to assess. Perhaps a real potential of ATS lies in the expansion of LCV operations. Although ATS can reduce the cost of infrastructure modification, it may significantly increase the safety of LCV operations in denser-traffic areas or non-Interstate roadways. If nationwide LCV use is proven safe, the estimated total public cost for a 20-year planning horizon (excluding the undetermined trucking-company equipment-upgrade cost) will be \$7,652 billion. Although the saving of \$53 billion from the estimated total cost of \$7,705 billion of a base case is less than 1%, the cost saving of \$568 billion for shippers (from \$4,980 billion to \$4,412 billion) is almost 15%.

ATS can be used to create a new mode of operations in which a tractor can pull a larger number of short trailers - Shorter Trailer Combination Vehicles (STCVs). We demonstrated the benefit of STCV operations for the household-goods moving industry.

Key Words: Benefit-cost Analysis, Commercial Vehicle Operations, Computer Simulation, Lateral Control, Safety, Vehicle Dynamics.

EXECUTIVE SUMMARY

Faced with the rising fuel cost, labor shortage and cost of health care for its labor force, the trucking industry is in urgent need for a significant increase of equipment and driver productivity, and a major method for achieving such an increase is to transport freight with large trucks, particularly with a group of large trucks known as the longer combination vehicles (LCVs). Longer combination vehicles include three major configurations: Rocky Mountain Double (a tractor-semitrailer combination plus an additional trailer up to 28 feet), Turnpike Double (a tractor hauling two trailers up to 48 feet each), and Triple (a tractor hauling three trailers up to 28 feet each).

However, LCV operations not only raise safety concerns for the surrounding traffic and the LCV drivers themselves but also can damage roadways and bridges not equipped to support the operations. Size and weight limits on trucking operations have long been imposed and were motivated to limit the possible safety hazards and the possible damage to the roadway infrastructure. The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) (P.L. 102-240) imposed an “LCV freeze” prohibiting all 50 states from allowing any expansion of LCV operations either in terms of routes upon which LCVs may operate or the vehicle weights or dimensions that may be allowed. The Transportation Equity Act for the 21st Century (TEA-21) (P.L. 105-85) did not lift that LCV freeze. 2003 Senate Joint Resolution No. 7 of the State of California “respectfully memorialize the President and the Congress of the United States to maintain the current federal truck size and weight limitations and to oppose proposals to experiment with longer and heavier trucks on public highways in the reauthorization of the federal Transportation Equity Act for the 21st Century (Public Law 105-178). Note the objection to further experimentation aimed to gain understanding of the pros and cons of expansion of LCV operations in the U.S. The railroad industry also voiced its strong opposition to relaxing the size and weight limits for fear that such relaxation may lure business away from the railroad; it views trucking industry’s use of the national highway system as governmental subsidy of the trucking industry. Several activist alliances have been formed to oppose relaxation of limitations on truck size and weight. With all these opposing forces, expansion of LCV operations for the purpose of a significant increase of productivity appears to be very difficult, at a time when such an increase seems to be needed more so than ever.

All the discussion about truck size and weight limitations or about the pros and cons of LCV operations is predicated on the use of conventional tractors and trailers. The industry and the research community seem to have resigned to the status quo of the current LCV equipment and have not begun to explore the use of modern vehicle automation technology to improve the LCV operations. We however observed that a root cause of several major issues associated with LCV operations is the problem of off-tracking, either during low-speed or high-speed travel. Moreover, we believe that this off-tracking problem can be drastically reduced with a new operational concept and the corresponding partial-automation technology: automated trailer steering. With respect to the “dumb” trailers being used today, the trailers equipped with such automated trailer steering may be called “intelligent trailers.” This one-year \$58K project was motivated

to study the potential of automated trailer steering for LCV and other large-truck operations, particularly from the perspectives of productivity, safety and roadway geometry. The background information and project description are summarized in Part I of this report.

In this research, we studied the pros and cons of current LCV operations. We focused on those aspects that may benefit from automated trailer steering and address in detail these aspects in this report, e.g., low-speed off-tracking on city streets and medium-speed off-tracking on interchange ramps (including freeway-to-freeway and city-street-to-freeway ramps). We developed operational concepts and selected one that, we believe, is the most promising. We then developed vehicle-dynamics models to show the potential of the operational concept in drastically reducing off-tracking for several critical scenarios. Our systems-analysis results are summarized in Part II of this report while the vehicle-dynamics models are summarized in Part III.

Low-speed off-tracking occurs when the wheels of the rearmost trailer axle traverse a path inside the path of the tractor's front steering axle. We examined low-speed off-tracking for articulated systems with 1, 2 and 3 trailers at a low speed of $V_x = 5$ ft/sec (or 3.4 miles/hour) during a 90-degree turn. For a case of three trailers, offtracking is reduced from 3.7 ft to 0.6 ft. We also examined high-speed off-tracking for 1-, 2-, and 3-trailer systems with a forward speed of $V_x = 50$ ft/sec (or 34.2 miles/hour) during a 90-degree turn. In high-speed off-tracking, the trailer units move outward due to lateral accelerations. For a case of three trailers, the severe off-tracking of 22 ft is reduced significantly to 4 ft. These drastic reductions of off-tracking can benefit the operations of all large trucks, including the ubiquitous tractor-semitrailer combinations, STAA doubles and LCVs. It is well known that low- and high-speed off-tracking for Rocky Mountain doubles and turnpike doubles is more severe than that for tractor-triple-trailer combinations. We expect that automated trailer steering is even more beneficial for these two categories of two-trailer LCVs.

Automated trailer steering can provide safety benefit for all existing large trucks, including non-LCVs and LCVs. However, the degree of the benefit is difficult to assess. The reason is that current data about traffic accidents, particularly the data maintained by the Fatality Analysis and Reporting System (FARS), do not pinpoint the root cause of the accidents. Our data analysis produced 5% (out of all fatal accidents involving large trucks) as a preliminary upper bound for the percentage of the fatal accidents whose occurrence may be avoided or whose effect may be reduced by the new technology of automated trailer steering.

Perhaps a real potential of the new technology of automated trailer steering lies in the expansion of LCV operations. Although virtually all analyses of existing data on the safety of current LCV operations (taking place within the roadway network in which LCVs are currently permitted to operate) concluded that LCV operations are no more unsafe than non-LCV operations, it is impossible to predict what the LCV crash rates will be when LCVs are allowed to operate on lower-quality roads or in denser vehicular traffic. It is entirely possible that expansion of LCV operations into non-Interstate and

non-primary state routes or into urban or suburban areas may lead to significantly higher LCV crash rates if the expanded operations are based on the current fleet technology. However, advanced technologies like automated trailer steering may make a big difference in LCV operational safety.

The non-safety potential of automated trailer steering for expansion of LCV operations is perhaps more tangible. A primary source of non-safety benefits of automated trailer steering is reduction in cost for infrastructure modification. Major sources of infrastructure costs for expansion of LCV operations include bridge replacement, modification of existing interchanges and intersections, provision of staging areas at highway entrances and exits, provision of truck lanes on steep hills, etc. Automated trailer steering can help reduce the costs associated with modifying existing interchanges and intersections because such modifications are needed primarily due to LCV offtracking. It can also help reduce the costs associated with the provision of the staging areas because, with automated trailer steering, LCVs can travel beyond highways and reach freight facilities without requiring major modifications of roadway geometry.

In response to a U.S. GAO request for an estimate of the total infrastructure cost required for nationwide use of LCVs, FHWA projected \$248 million for bridge replacement on rural interstates and \$1.1 billion for bridge replacement on urban interstates and also provided the range of \$750 million to \$2.2 billion for access improvement (including interchange improvement and staging area construction). We believe that, with the technology of automated trailer steering, access improvement will not be needed and hence only \$1.3 billion is required. The range of savings will be from \$750 million to \$2.2 billion, i.e., from 36% to over 60% of the total infrastructure improvement cost. This potential saving is drastic.

However, according to estimates provided by the 2000 Comprehensive Truck Size and Weight Study, this percentage of such savings with respect to the total infrastructure cost is much less significant. Despite the \$7.9 billion saving potential of automated trailer steering for infrastructure modification, it becomes much less significant when the estimated bridge replacement cost of \$206 billion, the estimated cost of \$266 billion due to traffic delay during bridge construction and the estimated pavement cost of \$196 billion are considered. Moreover, when the operational cost for a 20-year planning horizon (including recurrent congestion cost and fuel cost) is also considered, the estimated total cost of nationwide LCV use becomes a whopping \$7,654 billion. As a result, the \$7.9 billion potential saving due to automated trailer steering barely accounts for 1% of the total cost.

This again argues that the major contribution of automated trailer steering and other advanced vehicle control technologies may lie mostly in their enabling a safe nationwide use of LCVs, particularly on lower-quality roads and in dense vehicular traffic. If nationwide LCV use is proven safe, the estimated total cost for a 20-year planning horizon will be \$7,652 billion. Although the saving of \$53 billion from the estimated total cost of \$7,705 billion of a base case is less than 1%, the cost saving of \$568 billion

for shippers (from \$4,980 billion to \$4,412 billion) is not only significant in terms of the large quantity but also in terms of large percentage – almost 15%.

The new technology of automated trailer steering will not only drastically reduce off-tracking but may also improve trailer handling. A major problem reported by a 1984 Caltrans operational test of LCVs is the constant swaying of triples, and the potential benefit of automated trailer steering for solving this problem is a worthy subject for future research. This technology also has the potential of reducing the effect of rearward amplification of lateral acceleration, which is a major cause for vehicle instability in general and for rollover after a sudden evasive maneuver in specific. High-speed off-tracking is not a big issue for LCVs if the driver can position the tractor appropriately in the lane. However, this assumption may not be realistic. We demonstrated in Part III that this technology can drastically reduce high-speed off-tracking. A more useful result of this technology at high speeds than reduction of off-tracking may be better vehicle stability and reduced rollover hazards. This is a worthy subject for future research.

The proposed technology of automated trailer steering can be used to create a new mode of operations in which a tractor can pull a larger number of short trailers. We refer to such combination vehicles as Shorter Trailer Combination Vehicles (STCVs) and the corresponding operations as STCV operations. Such operations can be used not only for trucking on the nation's roadway systems but also for other operations involving towed vehicles, e.g., warehouse operations where a tractor pulls a number of vehicles carrying merchandize for storage or dispensing. For the purpose of this research, we focused on its potential benefit for the household-goods moving industry, i.e., the van lines. In this portion of the study, we do not explicitly address the LCV operations, but such operations can be a special case. The current van-line operations involve packing goods of multiple households into one large truck and therefore incur much delay to the goods' delivery due to the necessity of loading/unloading and packing/unpacking for one household and, in the meantime, keeping the goods of other households and even the driver waiting. We developed a simulation model and a simulator to analyze the efficiency potential of this version of the STCV operations. The results are summarized in Part IV of this report.

The productivity gains of the STCV mode of operation versus the conventional mode of operation is a function of the system capacity (number of available trucks in system) and the inter-arrival time of the orders (demand pattern). These are scenarios where system truck capacity is limited, and hence freeing the trucks from the loading and unloading tasks will have a significant productivity gain. However, in scenarios where truck capacities are sufficient to meet the expected demand pattern, the conventional mode may outperform the SCTV mode of operation since the extra travel time from the hub to the pickup location and the random waiting time for two different types of trucks can offset the productivity gained from freeing the truck from the loading and unloading task.

TABLE OF CONTENTS

ABSTRACT	iii
EXECUTIVE SUMMARY	v

PART I: BACKGROUND AND PROJECT DESCRIPTION.....I-1

1. BACKGROUND	I-3
1.1 Motivation for the Research.....	I-3
1.2 Problem Statement.....	I-5
2. PROJECT DESCRIPTION	I-6
2.1 Scope of the Research.....	I-6
2.2 Related Research.....	I-6
2.3 Related PATH Research.....	I-7
2.4 Research Approach.....	I-8
2.5 Organization of this Report.....	I-8
REFERENCES	I-8

PART II: SYSTEMS ANALYSIS FOR THE POTENTIAL OF AUTOMATIC TRAILER STEERING FOR OPERATION OF LARGE TRUCKS: PRODUCTIVITY, SAFETY AND ROADWAY GEOMETRY

1. INTRODUCTION	II-3
1.1 Scope of Study: All Large Trucks, Not Just Longer Combination Vehicles.....	II-3
1.2 Goals of Study: Improving Operations for All Large Trucks and Developing a New Model of Freight Transportation.....	II-3
1.3 Study Approach.....	II-4
1.4 Organization of This Part (Part II).....	II-5
2. ANALYSIS: NEEDS AND OPPORTUNITIES FOR STAKEHOLDERS	II-6
2.1 Needs.....	II-6
2.2 Opportunities.....	II-9
3. ANALYSIS: VEHICLE OPERATING REQUIREMENTS AND DESIGN OPTIONS, TECHNOLOGY SELECTION, COMPARISONS	II-13
3.1 Options Regarding the Basic Needs for Automated Trailer Steering.....	II-14
3.2 Design Options Regarding Opportunities for Capitalization on Automated Trailer Steering.....	II-15
4. SYNTHESIS: PROMISING OPERATING CONCEPT	II-16
5. SYNTHESIS: DEMONSTRATION OF TECHNOLOGICAL FEASIBILITY - VEHICLE DYNAMICS AND PHYSICAL IMPLEMENTATION	II-17
5.1 The Scope of Our Study and the Existing Literature.....	II-17
5.2 Our Study Approach.....	II-17
5.3 Major Problem with Operations of Large Trucks.....	II-18

5.4 Quantitative Characterization of Off-Tracking: High-Speed and Low-Speed.....	II-20
5.5 Other Studies.....	II-22
5.6 Our Study of the Dynamics and Control of Multi-Trailer Large Trucks.....	II-23
5.7 Physical Implementation.....	II-24
6. SYNTHESIS: EARLY ADOPTERS FOR INCREMENTAL DEPLOYMENT.....	II-26
7. EVALUATION: NON-SAFETY COSTS AND BENEFITS.....	II-27
7.1 Roadway Geometry As The Primary Source of Cost Savings for LCV Expansion.....	II-27
7.2 Impact of Automated Trailer Steering on the “Nationwide LCV Scenario” of The 2000 Comprehensive Truck Size And Weight Stud.....	II-29
8. EVALUATION: SAFETY.....	II-29
8.1 Current Status and Trend of Large-Truck Accident Rates.....	II-30
8.2 Safety Comparison Among Truck Configurations.....	II-31
8.3 Safety Comparison Between LCVs and Non-LCVs.....	II-32
8.4 The 2000 Comprehensive Truck Size and Weigh Study.....	II-33
8.5 An FHWA Study Entitled “Longer Combination Vehicles Involved In Fatal Crashes, 1991 – 1996”.....	II-35
8.6 An FHWA Study Entitled “Accident Rates For Longer Combination Vehicles”.....	II-37
8.7 A Canada Safety Council Study Entitled “Literature Review of The Safety of Long Combination Vehicles and Their Operation in Canada”.....	II-38
8.8 Safety-Improvement Potential of Reduction of Off-Tracking Through Automated Trailer Steering.....	II-38
9. CONCLUSION.....	II-44
REFERENCES.....	II-46

PART III: EFFECT OF MULTI-AXLE STEERING ON OFF-TRACKING AND DYNAMIC LATERAL RESPONSE OF ARTICULATED TRACTOR-TRAILER COMBINATIONS

1. INTRODUCTION.....	III-5
2. LINEAR YAW PLANE MODEL.....	III-6
3. PERFORMANCE CHARACTERISTICS.....	III-10
4. STABILITY ANALYSIS.....	III-11
5. CONCLUSION.....	III-12
REFERENCES.....	III-13
APPENDIX.....	III-14

PART IV: SIMULATION STUDY OF PRODUCTIVITY GAINS WITH SHORT TRAILER COMBINATION VEHILCE (STCV)

1 PHYSICAL SYSTEM.....	IV-4
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2 CONVENTIONAL SIMULATION MODEL.....	IV-7
3 EXPERIMENTATION AND RESULTS FOR THE CONVENTIONAL- MODE SIMULATION MODEL.....	IV-12
4 STCV SIMULATION MODEL.....	IV-20
5 EXPERIMENTATION AND RESULTS FOR THE STCV MODE SIMULATION MODEL.....	IV-24
5.1 Experimentation and Results for the One Hub Model Scenario.....	IV-25
5.2 Experimentation and Results for the Two Hub Model Scenario.....	IV-34
5.3 Experimentation and Results for the Three Hub Model Scenario.....	IV-42
6 STATISTICAL COMPARISON BETWEEN THE CONVENTIONAL SYSTEM AND THE STCV HUB SYSTEMS.....	IV-51
7 CONCLUSION.....	IV-69

Appendices on CD

APPENDIX A: PROGRAM LISTING FOR SIMULATION MODEL FOR CONVENTIONAL MODE OF VAN LINES OPERATIONS	IV-71
APPENDIX B: PROGRAM LISTING FOR SIMULATION MODEL FOR STCV MODE OF VAN LINES OPERATIONS.....	IV-151
APPENDIX C: CONVENTIONAL MODEL (NO HUB) 95% CONFIDENCE INTERVALS.....	IV-367
APPENDIX D: STCV 1 HUB MODEL 95% CONFIDENCE INTERVALS...IV-373	
APPENDIX E: STCV 2 HUB MODEL 95% CONFIDENCE INTERVALS...IV-377	
APPENDIX F: STCV 3 HUB MODEL 95% CONFIDENCE INTERVALS...IV-381	

**AUTOMATIC STEERING FOR CONVENTIONAL TRUCK TRAILERS:
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FINAL REPORT

PART I:

BACKGROUND AND PROJECT DESCRIPTION

1. BACKGROUND

1.1 Motivation for this Research

Faced with the rising fuel cost, labor shortage, cost of health care for its labor force, congestion on the nation's roadways, the trucking industry is in urgent need for a significant increase of productivity, and a major method for achieving such an increase is to transport freight with large trucks, particularly with a group of large trucks known as the longer combination vehicles (LCVs). The three major configurations of LCVs are Rocky Mountain Double (i.e., a tractor-semi-trailer plus a trailer up to 28 feet), Turnpike Double (i.e., a tractor hauling two trailers up to 48 feet each), and Triple Trailer Combination (i.e., a tractor hauling three trailers up to 28 feet each) (General Accounting Office, 1994; Federal Highway Administration, 1986). For ease of discussion, they will be abbreviated and referred to as RMD, TD and Triple, respectively.

Large trucks travel with automobiles on virtually all roads of the US and the world. To limit safety hazards and damage to roadway pavement, limits on weight, size and configuration have long been imposed on trucks (e.g., Transportation Research Board, 1982; Federal Highway Administration, 2000). Here, configuration refers to the number and sizes of trailers that are hauled by a tractor. The most common configurations in the State of California are straight truck (i.e., a single-unit truck), tractor-semitrailer combination (i.e., a tractor hauling a semi-trailer of length up to 53 feet), and a tractor hauling two trailers of 28 feet or shorter (i.e., a Double). For ease of discussion, they will be referred to as Straight, Single and Double, respectively. We will also use 48 feet as the typical upper limit for the length of a semi-trailer, following other authors before us [e.g., Lankard and Lehrer, 1999].

Larger trucks are more efficient because they use less fuel per unit weight than smaller trucks and because their drivers achieve higher productivity. Fuel consumption increases as gross vehicle weight increases, but an LCV can haul considerably more cargo with a relatively small reduction in fuel mileage [Lankard and Lehrer, 1999]. The productivity of a driver literally doubles if he or she drives a Turnpike Double rather than a tractor-semi-trailer combination. It increases literally by 50% if he or she drives a Triple rather than a Double.

Twenty states in the nation have been permitting operations of one or more of the three major configurations of LCV on selected highways and access roads [March, 2001]. Despite the need of the trucking industry to significantly increase the productivity of its equipment and driver and despite the repeated calls by the industry to achieve such an increase by allowing it to transport more goods with longer combination vehicles (LCVs), no LCVs have been allowed in California [California Legislative Counsel, 2001] and many other states. A primary issue is safety, and a primary concern is the safety hazards such trucks may impose on the surrounding traffic, particularly the automobiles and the LCV drivers themselves [e.g., Lankard and Lehrer, 1999]. In addition, LCV operations can also damage roadways and bridges not equipped to support the operations [Harkey, Council, and Zegeer, 1996; California Department of Transportation, 1984].

Size and weight limits on trucking operations have long been imposed and were motivated to limit the possible safety hazards and the possible damage to the roadway infrastructure. The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA; Public Law 102-240) imposed an “LCV freeze” prohibiting all 50 states from allowing any expansion of LCV operations either in terms of routes upon which LCVs may operate or the vehicle weights or dimensions that may be allowed [U.S. Congress, 1991]. The Transportation Equity Act for the 21st Century (TEA-21; Public Law 105-178) did not lift that LCV freeze [U.S. Congress, 1998]. 2003 Senate Joint Resolution No. 7 of the State of California “respectfully memorialize the President and the Congress of the United States to maintain the current federal truck size and weight limitations and to oppose proposals to experiment with longer and heavier trucks on public highways in the reauthorization of the federal Transportation Equity Act for the 21st Century (Public Law 105-178).” Note the objection to further experimentation aimed to gain understanding of the pros and cons of expansion of LCV operations in the U.S. The railroad industry also voiced their strong opposition to relaxing the size and weight limits for fear that such relaxation may lure business away from the railroad; it views trucking industry’s use of the national highway system as governmental subsidy of the trucking industry [McCormick, 1999].

Several citizen groups have, as one of their primary goals, opposed to relaxation of limitations on truck size and weight; they include Citizens for Reliable and Safe Highways (CRASH). Some alliances have been formed explicitly to limit the size and weight of large trucks; they include Coalition Against Bigger Trucks (CABT). Other associations are also against such relaxation. For example, General Federation of Women’s Clubs supports highway bills that maintain existing laws on truck size and weight limits [General Federation of Women’s Clubs, 2005]. Also, National Student Nurses’ Association (NSNA) supports Coalition Against Bigger Trucks as one of the Association’s 2005 resolutions [National Student Nurses’ Association, 2005]. With all these opposing forces, expansion of LCV operations for the purpose of a significant increase of productivity and efficiency appears to be very difficult, at a time when such an increase seems to be needed more so than ever.

All the discussion about truck size and weight limitations or about the pros and cons of LCV operations is predicated on the use of conventional tractors and trailers. The industry and the research community seem to have resigned to the status quo of the current LCV equipment and have not begun to explore the use of modern vehicle automation technology to improve the LCV operations. We however observed that a root cause of several major disadvantages of LCV operations is the problem of off-tracking, either during low-speed or high-speed travel. Moreover, we believe that this off-tracking problem can be drastically reduced with a new operational concept and the corresponding partial-automation technology of automated trailer steering. With respect to the “dumb” trailers being used today, the trailers equipped with such automated trailer steering may be called “intelligent trailers.” This project was motivated to study the potential of automated trailer steering for LCV and other large-truck operations via reduction of off-tracking, particularly from the perspectives of productivity, safety and roadway

geometry.

1.2 Problem Statement and Potential Contribution to Transportation Practices

Off-tracking refers to the phenomenon that the rear wheels of a truck do not follow the track of the front wheels and wander off the travel lane. Quantitatively, off-tracking is defined as “the distance between the path of the front inside wheel and the path of the rear inside wheel as a vehicle traverses a curve or turn” [Harkey, Council and Zegeer, 1996].

We believe that this off-tracking problem can be eliminated or alleviated drastically through automatic trailer steering, in the form of automated trailer track-following. With such an automation technology in place, new and more productive modes of truck operations may be feasible. For example, a truck can safely haul a larger number of shorter trailers, and this mode of operation may have high productivity potential for the Less-Than-Truck-Load (LTL) freight industry, particularly those segments of the LTL industry in which loading, packing, load balancing, and unloading account for a significant amount of the total time of truck operation. Moreover, smaller trailers can be dropped off for loading and unloading by the customer before and after transportation. All these will allow trucks to do what they are meant to do: traveling, not waiting. The lower per-axle load and the more uniform axle spacing within one trailer or across neighboring trailers may also significantly reduce pavement wear. Moreover, such a technology may also have applications on articulated buses and many other types of large vehicles.

Many states of Western U.S. allow Longer-Combination Vehicles (LCVs) to operate on designated highways and on nearby roads needed for access to service stations and freight transportation hubs. As indicated earlier, California does not allow such operations, and major reasons include the safety hazards and threat to the infrastructure associated with the off-tracking problem. This new technology may help realize safe LCV operations in California and will certainly help improve the safety of existing LCV operations. This technology has the potential for facilitating the deployment of a physically separated truck lane dedicated to only trucks and LCVs and that of a truck Automated Highway System (AHS) [Tsao and Botha, 2002].

The proposed technology of automated trailer steering can be used to create a new mode of operations in which a tractor can pull a larger number of short trailers. We refer to such combination vehicles as Shorter Trailer Combination Vehicles (STCVs) and the corresponding operations as STCV operations. Such operations can be used not only for trucking on the nation’s roadway systems but also for other operations involving towed vehicles, e.g., warehouse operations where a tractor pulls a number of vehicles carrying merchandise for storage or dispensing. For the purpose of this research, we focused on its potential benefit for the household-goods moving industry, i.e., the van lines. In this portion of the study, we do not explicitly address the LCV operations, but such operations can be a special case. The current van-lines operations involve packing goods of multiple households into one large truck and therefore incur much delay to the goods’ delivery due

to the necessity of loading/unloading and packing/unpacking for one household and, in the meantime, keeping the goods of other households and even the driver waiting.

2. PROJECT DESCRIPTION

This is a one-year \$58K project. Professors Jacob Tsao and Yasser Dessouky of the Department of Industrial and Systems Engineering of San Jose State University have been the investigators.

2.1 Scope of Research

In this research, we studied the pros and cons of current LCV operations. We focused on those aspects that may benefit from automated trailer steering and address in detail these aspects in this report, e.g., low-speed off-tracking on city streets and medium-speed off-tracking on interchange ramps (including freeway-to-freeway and city-street-to-freeway ramps). We developed operational concepts and selected one that, we believe, is the most promising. We then developed vehicle-dynamics models to show the potential of the operational concept in reducing significantly off-tracking for several critical scenarios. Our systems-analysis results are summarized in Part II of this report while the vehicle-dynamics models are summarized in Part III. We developed a simulation model and a simulator to analyze the efficiency potential of the STCV operations as applied to the household-goods moving industry, i.e., the van lines. The results are summarized in Part IV of this report.

2.2 Related Research

Off-tracking has long been recognized as a major problem for truck operations and has long been a major factor determining truck weight and size limits [e.g., Federal Highway Administration, 2000; J.W. March, 2001]. However, the trucking industry, the truck manufacturing industry and the academia seem to have regarded this as an innate problem of trucking and hence seem to have resigned to the consequences. Other than the development of the technology of passive “self-steering suspension” [LeBlanc and El-Gindy, 1992; Palkovics, et al., 1993; Palkovics, 1994; Grandbois and Richard, 1995], the principal investigators are not aware of any systematic effort to overcome this major problem. Due to the passive nature of self-steering suspension, the performance is questionable and some unintended consequences have become clear [Transportation Research Board, 1990]. There have been very few other studies about overcoming the off-tracking problem. Tilbury et al. [1993] studied feedback control for the control of a multi-steering trailer system. Altafini and his colleagues [Altafini and Gutman, 1998; Altafini, 2001; Altafini, 2003] have also studied the vehicle dynamics and control of such systems. However, all these studies center around mobile robotic systems and do not consider many factors that influence the trajectory of a truck-trailer combination. Nevertheless, they seem to point out the technical feasibility from the perspective of vehicle dynamics.

Vehicle dynamics and control of four-wheel steering on the two axles of a straight truck or on the two axles of a tractor has been studied [e.g., Vaughn and Miller, 1990; Watanabe et al., 1993; Keller and Kogel, 1996]. Few publications dealing with dynamics and control of combination vehicles with multi-axle steering exist [Palkovics, L., and Fries, 2001]. Wu and Lin [2003] deal with vehicle lateral response to multi-axle steering of a tractor pulling one full trailer. Chikamori, S., and Kawasawa [1996] deal with the vehicle stability of such a combination vehicle with all-wheel steering. O'Brien and Piper [2000] deal with the same issue but use the technology of differential braking [i.e., individual braking] instead to achieve the purpose of trailer steering control.

We extended these studies and investigated vehicle dynamics of a tractor pulling up to three trailers, with an explicit focus on off-tracking. The front axle of all the trailers is equipped with automated steering in order for the trailers to follow the track of the tractor and hence to reduce off-tracking.

More related research will be discussed in more detail in Part II, Part III and Part IV.

2.3 Related PATH Research

PATH has conducted extensive research into vehicle automation for trucks, buses and automobiles. Much of the research has been focused on automated vehicle lateral control. However, the focus seems to have been exclusively on automated steering of the front wheels of a vehicle for fully automated lane-keeping (in place of human steering control) and has not examined the potential for or the technology of automated (active) trailer steering. Also, although PATH has investigated extensively electronic linkage between a vehicle and its followers, it does not seem to have studied the control and cooperation between two or more mechanically linked units, e.g., between a truck tractor and mechanically linked trailers. However, expanding the current PATH research into this new direction can certainly capitalize on the large amount of expertise already accumulated by PATH research.

Given the recent advances in automated vehicle lateral control for trucks and automobiles made by PATH, we believe that this off-tracking problem can be eliminated or alleviated drastically by automated trailer steering, in the form of automated trailer track-following. Although the current PATH technology of front-wheel steering control is expected to be different from the required technology for automated trailer steering, much of the existing PATH technology and research can be very useful for developing the new technology.

In summary, this research complemented the completed and on-going research at PATH and other California transportation research programs in at least three ways. First, it expanded the research attention to a promising new but very related direction. Second, it can reuse much of the expertise accumulated by California researchers since the creation of the PATH Program. Third, it examined partial automation as a potential means of improving current transportation operations, as opposed to focusing on the long-term possibility of full automation.

2.4 Research Approach

As pointed out earlier, trailer off-tracking has been a major source of problems for decades, including safety hazards and infrastructure damage. These safety, damage-reduction and productivity potentials must be assessed and evaluated from many different perspectives, e.g., technological feasibility, increased safety, reduced infrastructure cost, increased vehicle cost, increased trucking efficiency, etc., and in the larger context of the transportation and logistics systems. This project developed promising operating concepts featuring automatic (active) trailer steering for the purpose of improving the safety, infrastructure impact and productivity of trucking and assessed these concepts at the systems level, including technological feasibility and potential benefits and costs to the trucking industry and the infrastructure provider.

2.5 Organization of Report

The background information and project description are summarized in this part (Part I) of this final report. The results of our systems analysis about the potential of automated trailer steering are summarized in Part II, with the technical details about two key aspects of this research discussed in the next two Parts. Details about the vehicle-dynamics models for automated trailer steering are summarized in Part III. The simulation model for the STCV operations, the simulator and our simulation results are all summarized in Part IV of this report.

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**AUTOMATIC STEERING FOR CONVENTIONAL TRUCK TRAILERS:
DEVELOPMENT AND ASSESSMENT OF OPERATING CONCEPTS FOR
IMPROVING SAFETY, PRODUCTIVITY AND PAVEMENT DURABILITY**

FINAL REPORT

PART II:

**SYSTEMS ANALYSIS FOR THE POTENTIAL OF AUTOMATIC TRAILER
STEERING FOR OPERATION OF LARGE TRUCKS: PRODUCTIVITY,
SAFETY AND ROADWAY GEOMETRY**

1. INTRODUCTION

In the United States, there exist virtually no physically separate roadways dedicated to large truck operations. Virtually all large trucks travel in midst of automobiles. Such sharing has caused several major concerns, particularly safety hazards for the surrounding traffic and the truck drivers themselves, negative impacts on traffic operations, damage to infrastructure, etc.

1.1 Scope of Study: All Large Trucks, Not Just Longer Combination Vehicles (LCVs)

The large trucks studied in this project include the ubiquitous tractor-semitrailer combination and tractor-double-trailer combination as well as the class of longer combination vehicles (LCVs). Automatic trailer steering can improve the operation of all these large trucks, not just that of the LCVs.

For ease of discussion, we refer to the ubiquitous tractor-semitrailer combination, tractor-double-trailer combination and other non-LCV large trucks as STAA trucks because all 50 states of the United States have been mandated by Surface Transportation Assistance Act (STAA) of 1982 [U.S. Congress, 1982] to allow large trucks to operate on the "National Network," which is comprised of the Interstate System plus the non-Interstate Federal-aid Primary System. As defined in the STAA of 1982 (Title 23, Part 658 (Section 13) of Code of Federal Regulations or Public Law No: 97-424), "larger trucks" include (1) doubles with 28.5-foot trailers, (2) singles with one 48-foot semitrailer and an unlimited kingpin-to-rear axle (KPR) distance, (3) unlimited length for both vehicle combinations, and (4) widths up to 102 inches. As discussed in Part I, we discuss explicitly three particular subclasses of LCVs in this report: Rocky Mountain Double, Turnpike Double and Triple. To distinguish the tractor-double-trailer combination whose operation is ensured by the STAA of 1982 from the Rocky Mountain Double and the Turnpike Double, we refer to it simply as the STAA double, as it is commonly referred to in the existing literature.

A major source of these concerns is the problem of off-tracking. We believe that automatic trailer steering (ATS) has the potential of eliminating or significantly reducing off-tracking and hence significantly improving the operations of large trucks. More specifically, automatic trailer steering is considered for installation on the front axle of full trailers. However, it is considered for installation on the rear axle of semitrailers.

1.2 Goals of Study: Improving Operations for All Large Trucks and Developing a New Model of Freight Transportation

This project has two primary goals:

- Improve the operations for all large trucks,
- Explore a new mode of trucking for freight transportation enabled by Short Trailer Combination Vehicles (STCVs) for higher productivity.

As indicated in Part I, the second goal is the focus of Part IV. We will motivate the concept of STCV in the next section but will focus on the first goal in the rest of this Part.

Given the scope of all large trucks, the objectives of this study associated with the first goal are to:

- improve the operations of the STAA trucks to reduce safety hazards and infrastructure damage,
- improve the current LCV operations on the limited roadway networks in which such operations are currently permitted by federal, state and local authorities to reduce safety hazards and infrastructure damage,
- increase the likelihood of such authorities to permit LCV operations on additional roadways, for achieving higher trucking productivity without undue increase of safety hazards and infrastructure damage,

with our proposed technology of automatic trailer steering (ATS).

1.3 Study Approach

The key technology proposed and studied by the investigators is automatic trailer steering (ATS). This technology is not a recognized Intelligent Transportation Systems (ITS) service and hence is not part of the ITS Systems Architecture. However, it could have been if it had been proposed prior to the development and adoption of the National ITS Architecture. It can facilitate the possible deployment of those ITS technologies related to vehicle automation and the possible deployment of truck lane and other innovations. Recently, Tsao [Tsao, 2001] developed a framework for recognizing and organizing Intelligent Transportation Systems (ITS) deployment issues and integrated the R&D process within that deployment framework. That framework was developed after he researched into the difficult deployment issues associated with the most technology-intensive and most forward-looking ITS user service of automated highway systems (AHS) [e.g., Tsao, 1995a; Tsao, 1995b; Tsao, 1995c; Tsao, 1998a; Tsao, 1998b; AlKadri, Benouar and Tsao, 1998; Hanson and Tsao, 1996]. We used this framework to guide this research project. Before we state our approach and the corresponding organization of this report, we briefly describe the framework below.

Because Intelligent Transportation Systems (ITS) R&D is performed for the ultimate deployment in the real world, deployment issues may limit design options for ITS operating concepts and technologies and, hence, can be viewed as constraints on ITS R&D. Therefore, ITS deployment issues must be studied at the outset of the R&D process. Faced with many transportation *needs*, *solutions* are sought; with the recent advances in information, communication, sensor, control, computer and other technologies, many *opportunities* for improving current surface transportation systems exist. The fact that a multitude of decisions are required for selecting, developing and implementing proper ITS user services as solutions to serve properly selected transportation needs necessitates a focus on relevant decisions and *decision makers*.

Under the assumption that no single organization has the full authority over and the full capability of taking all the actions required for the successful deployment of an ITS user service, he postulated that only the role of a champion can be expected from any organization promoting ITS deployment. Based on the understanding of the *decision-making* processes of relevant decision makers (i.e., stakeholders), the champion seeks to maximize the probability of successful deployment, in the presence of possible exogenous variables/events, by *influencing* stakeholders' decisions through, e.g., good designs and deployment "roadmaps," incentives, pressure, etc.

Gradual interaction among the decision makers and cautious introduction of changes by the decision makers necessitate incremental deployment through *time*. The champion faces many uncertainties, e.g., in influencing the stakeholders, and this makes *risk management* a must. The presence of multiple user services and multiple implementation locations necessitates search for *synergy* in deployment of different user services in different locations, for efficiency, risk mitigation and other purposes. The resulting eight dimensions of ITS deployment issues are: need, solution/opportunity, decision maker, decision making, decision influencing, time, risk management, and synergy.

To study the technology of automatic trailer steering, we adopted the following steps:

- Analysis:
 - Consistent and conflicting stakeholder needs, solutions for the consistent needs, and opportunities offered by the new technology for satisfying the conflicting needs (Section 2)
 - Vehicle operating requirements, design options, technology selection, and comparisons (Section 3)
- Synthesis:
 - Development of promising operating concepts (Section 4)
 - Demonstration of technological feasibility: vehicle dynamics and control and physical implementation (Section 5 and Part III)
 - Early adopters to ensure successful incremental deployment (Section 6)
- Evaluation:
 - Analysis of effects of the technology on non-safety cost and benefit, particularly trucking productivity, traffic operations, roadway infrastructure (Section 7)
 - Analysis of effects of the technology on safety (Section 8)

1.4 Organization of This Part (Part II)

The organization of this Part is organized in nine sections. The purposes of Sections 2 through 8 have been shown in the list above. Concluding remarks are provided in Section 9.

Details about the dynamics and control of large trucks as a critical component of the study of technical feasibility are summarized in Part III. Also, details about short trailer combination vehicles (STCVs) as a new mode of trucking operations are provided in Part IV.

2. ANALYSIS: NEEDS AND OPPORTUNITIES FOR STAKEHOLDERS

2.1 Needs

PERSPECTIVE OF THE INFRASTRUCTURE PROVIDER

Operations of STAA Trucks:

A major need is to improve the safety of trucks' turning movements, particularly those made by long trucks: The "wide turns" made by trucks, particularly long ones, pose significant safety hazards for surrounding vehicles, most notably automobiles, bicyclists and pedestrians. Off-tracking is a primary reason for such wide turns, and elimination or reduction of off-tracking can help alleviate the need for such wide turns. Another need is to reduce infrastructure damage done by large trucks, including the damage to existing infrastructure at curves, freeway access/egress ramps, and curbs and roadside traffic signs on city streets. Elimination or reduction of off-tracking can help reduce such damage.

We briefly discuss the length restrictions imposed on the tractor-semitrailer combination by STAA and those imposed by the State of California:

The STAA regulations [U.S. Congress, 1982] stipulate about the semitrailer (a) a maximum length of 48 feet (for the semitrailer) with no limitations on the Kingpin-To-Rear Axle Length (KPRAL) and with no limitation on the length of the combination or (b) a maximum length of no longer than 53 feet (but over 48 feet) but with a KPRAL restriction of 40 feet max and with no limitation on the combination length.

California's restrictions on the length of a semitrailer [Caltrans, 2005], which are somewhat different, stipulate no explicit restriction about the length of the semitrailer but stipulate a maximum KPRAL of 40 feet for semitrailers with 2 axles in rear, a maximum KPRAL of 38 feet for semitrailers with one axle in rear, and a maximum combination length of 65 feet.

California has a large network of rural two-lane road (one lane in each direction), and a significant portion of it is considered unsafe for operations by large trucks due to off-tracking. According to a 1989 Caltrans study [Caltrans, 1989; Caltrans, 2005], of the 15,166 miles comprising the State Highway System, 3,364 miles (over 20%) cannot accommodate large trucks with a 40-foot Kingpin-To-Rear Axle Length (KPRAL) length or longer, and 3,185 miles (about 20%) cannot accommodate large trucks with a 38-foot KPRAL length or longer. Such large trucks include the trailer-semitrailer combination allowed ubiquitously in the state of California. Those route segments that cannot safely accommodate a 40-foot KPRAL were designated "Advisory." However, such large trucks are not prohibited by law from using these route segments. Grassroots organizations like Citizens for Reliable And Safe Highways (CRASH) have tried impose further restrictions on large truck operations and to combat possible relaxation of truck size and weight limits through state and federal legislatures. In fact, one of the goals of CRASH is to

freeze truck size and weight limits at current levels. See the PERSPECTIVE OF THE DRIVING PUBLIC below for more details about CRASH.

Providers of roadway infrastructure obviously are concerned about the safety hazards and traffic-operation impacts caused by off-tracking of STAA trucks to the rest of the traffic in such route segments, among others. We will demonstrate in Part III and discuss later in this Part (Part II) that the technology of automated trailer steering (ATS) can drastically reduce the phenomenon of off-tracking for large trucks.

Current Operations of Longer-Combination Vehicles (LCVs):

An FHWA study [Federal Highway Administration, 1986] requested in 1985 by the Senate Appropriations Committee to study LCV operations in the Western States concluded that the productivity benefits of allowing LCVs to operate more widely and at higher weights are unquestioned. It also noted USDOT's commitment to work with the States and trucking groups to explore ways to improve the efficiency and safety of trucking. There are clear needs for those states already allowing LCV operations to (a) improve safety when LCVs travel on designated highways or access service stations off the designated highways and (b) reduce damage to infrastructure induced by LCVs on designated highways and on other designated roads connecting such highways to truck service stations.

We will address in Section 2.2 the opportunities for possible expansion of LCV operations to states in which LCV operations are not allowed currently, among other potential opportunities.

PERSPECTIVE OF THE TRUCKING INDUSTRY

Inter-City Trucking

The productivity of a driver literally doubles if he or she drives a Turnpike Double rather than a tractor-semi-trailer combination. It increases literally by 50% if he or she drives a Triple rather than a Double. Twenty states in the nation have been permitting operations of one or more of the three major configurations of LCV on selected highways and access roads [March, 2001].

Larger trucks are more efficient because they use less fuel per unit weight than smaller trucks and because driver productivity increases. Fuel consumption increases as gross vehicle weight increases, but an LCV can haul considerably more cargo with a relatively small reduction in fuel mileage. U.S. DOT's Highway Revenue Forecasting Model provided fuel economy estimates in terms of miles per gallon for various large trucks. The estimates are given in Table 1. As evidenced by the estimates, the fuel economy is rather insensitive to the gross vehicle weight. Based on these estimates, fuel efficiency associated with LCVs is apparent.

Table 1: Miles Per Gallon for Large Trucks

Configuration	Gross Vehicle Weight (pounds)					
	40,000	60,000	80,000	100,000	120,000	140,000
3-axle Single	5.11	4.42				
4-axle Single	4.80	4.15				
5-axle Semi		5.44	4.81	4.31		
6-axle Semi		5.39	4.76	4.27		
5-axle Double		5.95	5.29	4.76		
7-axle RMD			5.08	4.58	4.36	4.16
8-axle TD			5.08	4.82	4.58	4.36
Triple			5.29	5.01	4.76	4.54

Given the labor and fuel savings achievable with LCVs, it is not surprising at all that the trucking industry has been seeking to have truck size and weight limitations relaxed.

In a 1999 interview with Transport Topics [Barnes, 1999], American Trucking Association (ATA) President Walter B. McCormick Jr. pointed out that the trucking industry must fight efforts in Congress to strangle its productivity. In addition, he said trucking productivity will be among ATA's top goals in Congress for 1999. He emphasized that the trucking industry was not looking for wholesale increases in truck sizes and weights but the industry supported eliminating gaps in the national highway network for triple-trailers, turnpike doubles and Rocky Mountain doubles. The network had remained basically unchanged since 1991, when Congress decided that no new routes could be added and imposed the so-called "LCV freeze." States without pre-existing rights could not allow trucks exceeding the 80,000-pound weight limit on federal roads without specific congressional approval.

PERSPECTIVE OF THE DRIVING PUBLIC

A legislative bill commonly referred to as "The Kim's Law" has been repeatedly proposed by CRASH in California legislature. The grassroots effort started after an accident in which a truck-and-semitrailer combination took up most of a two-lane rural road as it negotiated the curve and dragged the Ford Bronco carrying the 33-year-old pregnant woman Kim Mosqueda 35 feet before flipping it over. Since then, Kim Mosqueda's sister-in-law Darlene Studdard, who survived the 1991 Thanksgiving Day accident, and the Mosqueda family have joined other truck safety advocates in pushing for legislation that would restrict the length of trucks on certain state highways, particularly rural and mountain roadways judged by California Department of Transportation as unable to safely accommodate large trucks [Caltrans, 1989].

Although this bill has not become law in California and tractor-semitrailer combinations are not barred from using the unsafe route segments identified in the 1989 Caltrans study [Caltrans, 1989], CRASH assisted in passing The Intermodal Surface Transportation Efficiency Act of 1991 (commonly known as ISTEA; P.L. 102-240) in 1991 through Congress to freeze the use of Longer Combination Vehicles (LCVs) and to prevent the spread in their use through the 48 contiguous states [U.S. Congress, 1991]. Some

alliances have been formed explicitly to limit the size and weight of large trucks; they include Coalition Against Bigger Trucks [2005]. Other associations are also against such relaxation, and they include. For example, General Federation of Women's Clubs supports highway bills that maintain existing laws on truck size and weight limits [General Federation of Women's Clubs, 2005]. Also, National Student Nurses' Association (NSNA) supports Coalition Against Bigger Trucks as one of the Association's 2005 resolutions [National Student Nurses' Association, 2005].

2.2 Opportunities

Expansion of LCV Operations to More Roads and More States

The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) (Public Law 102-240) imposed an "LCV freeze" prohibiting all 50 states from allowing any expansion of LCV operations either in terms of routes upon which LCVs may operate or the vehicle weights or dimensions that may be allowed [U.S. Congress, 1991]. The Transportation Equity Act for the 21st Century (TEA-21) (Public Law 105-178) did not lift that LCV freeze [U.S. Congress, 1998]. 2003 Senate Joint Resolution No. 7 of the State of California "respectfully memorialize the President and the Congress of the United States to maintain the current federal truck size and weight limitations and to oppose proposals to experiment with longer and heavier trucks on public highways in the reauthorization of the federal Transportation Equity Act for the 21st Century (Public Law 105-178)."

All these restrictions have been imposed on conventional large trucks. The technology of automated trailer steering has the potential of overcoming one of the major problems of LCV operations – off-tracking. When this potential is proven, these restrictions may be re-evaluated.

New Mode of Truck Operation: shorter-trailer combination vehicle (STCV)

The conventional combination trucks have been in use for decades. They are most efficient for full truck loads, but not for less-than-truck-loads (LTL). For example, a 18-wheeler used to move house-hold personal belongings typically hauls belongings of multiple households and parks at a destination for either loading or unloading while the rest of the load or at least the tractor waits for hours or even a day. A possible solution to this problem is to use short trailers (that can be easily coupled and decoupled from the tractor or the other short trailers) but more of them than their conventional counterparts. This is a special form of a new mode of operations: Short Trailer Combination Vehicles (STCVs). However, a possible major technology issue is off-tracking.

The opportunity for using shorter trailers with a lighter load on each trailer so that the current total weight limit can be distributed across the larger number of trailers and hence the per-axle weight and hence road damage are reduced. The potential of this opportunity and the importance of lower per-axle (or per-trailer in our context) are illustrated in a frequently-cited TRB study [Transportation Research Board, 1990]. That study also emphasized the importance of solving the off-tracking problem and the need to

prohibit the self-steering suspension, which, as discussed earlier, is a passive device with no active control by the vehicle.

The need for the infrastructure provider to reduce road damage and the desire of the trucking industry to increase productivity are the subjects of that study. The TRB evaluated an approach to truck size and weight (TS&W) regulation wherein motor carriers could voluntarily choose between using existing equipment or adopting new "Turner trucks" with lower axle weights (to reduce pavement damage); higher GVW (to increase productivity); and superior stability, control and operational properties (to enhance safety). It identified a series of Turner trucks and detailed, innovative regulations for them. These proposed regulations addressed: (1) tire and axle limits, (2) a new bridge formula, (3) performance-related provisions concerning off-tracking, (4) configuration-specific regulation differences, (5) prohibition of C-trains and self-steering axles, (6) prohibition of lift axles, (7) a requirement for anti-lock braking on tractor axles, (8) a performance-related gradeability standard, (9) operating routes, and (10) special driver qualification requirements. However, Congress took no action on these recommendations. Note that these recommendations and the Congress decision were made without the possible benefits of automatic trailer steering and the possible new modes of truck operations.

Another possible opportunity would be a reduction in the collision impact between another vehicle with an STCV trailer because of the (shorter and) lighter weight of such a trailer, even if the total weight of the truck is kept unchanged. This possibility needs to be carefully studied and verified, but is beyond the scope of this study.

Urban Trucking:

Like its inter-city counterpart, Shorter-Trailer Combination Vehicle (STCV) configurations may increase the productivity of urban LTL trucking. An example would be trucking for delivering grocery orders to supermarkets.

If smaller trailers can be standardized, they can be dropped off for loading and unloading by the customer before and after transportation. Note that the freight contained in the different trailers hauled by a tractor may not be of the same type and may belong to different owners. This will be another new mode of operation.

A common theme of these opportunities is that the STCV configurations will allow trucks to do what they are meant to do: traveling, not waiting.

Also note that even for truck loads, the alternative STCV configurations may also offer significant benefit because loading and unloading can be performed in parallel, cutting down the idle time for the tractor, the driver and the freight. Implementation of the modern concept of just-in-time logistics may benefit from such new configurations and the new mode of freight transportation. This is the subject of Part III of this report.

Tsao and Rizwan [2000], in studying the air-express freight forwarding business recently, pointed out a “vicious cycle” regarding urban traffic congestion and freight movement. Given a fixed amount of freight to be delivered to customers, a typical reaction to traffic congestion on the part of freight carriers is to send more trucks. However, this leads to more congestion. Unlike passengers, who can benefit from using public transit or HOV lanes, freight transportation has nothing similar to resort to. New and more efficient modes of operations enabled by partial automation may provide options for increased productivity of urban trucking.

Truck Lanes Accommodating LCVs

Other needs and opportunities include the need to drastically increase the productivity gain for trucks using a truck lane and the opportunity to optimize the geometry at curves the mainline and the geometry of access/egress ramps of truck lanes that accommodate longer-combination vehicles.

Dedication of truck lanes has the potential of drastically increasing the productivity of trucking. However, the concept of conventional truck lanes have been proven repeatedly to be not self-sustainable in terms of using user fees to defray capital and operating costs. For example, in the California SR 60 truck-lane study [KAKU Associates, 2001], only 25% of the costs are considered collectable from the truck user fees. (Many failed attempts to justify truck lanes are cited in that report.) Allowing LCVs on dedicated truck lanes offers a good opportunity for higher user fees as well as higher usage.

Tsao and Botha [Tsao and Botha, 2002a; Tsao and Botha, 2002b] also observed that productivity gain has been a major need of the inter-city trucking industry, and a major means to significantly increase the productivity is to operate LCVs. The Reason Public Policy Institute [Samuel et al., 2002] published a report championing the concept of dedicated truck lane and cited [Tsao and Botha, 2002a] about their proposed concept of allowing LCVs on dedicated truck lanes, as a way to increase user fee and justify the dedication and also as a step toward a truck-AHS.

Automated Highway Systems (AHS)

Traffic congestion on the nation’s highways has a significant impact not only on the movement of passengers or passenger vehicles, but also on the nation’s freight movement and economic well-being. Consequently, the efficiency of goods movement has received much attention, and some state and the federal governments have begun to pay attention to the issues faced by the freight industry. For example, one of the two focal areas of the 1998 California Transportation Plan (Update) is goods movement [California Department of Transportation, 1998a; California Department of Transportation, 1998b]. Other states have also realized the importance and the urgency of this issue. For example, the states along the freight corridor of I-10 have recently begun to work together to try to relieve the impact of traffic congestion on I-10 on goods movement. These states formed a consortium known as National Automated Truck Facility (NATF), which is a multi-state pooled fund project.

Tsao and Botha [Tsao and Botha, 2002a; Tsao and Botha, 2002b] proposed a sequence of deployment steps toward a truck-AHS. A truck-AHS requires a dedicated lane for each direction, but few dedicated truck lanes exist now in the U.S., except at locations with steep grades. We believe that a possible major roadblock (or “show-stopper”) for implementing the truck-AHS is the prerequisite of a dedicated truck lane. Conventional dedicated truck lanes will not be dedicated or built unless they truly satisfy some near-term needs of the long-haul trucking industry in a cost-effective way and the stakeholders welcome them or at least can accept them. Productivity seems to be the number-one concern of the long-haul trucking industry, which has been campaigning for wider acceptance of LCVs by major stakeholder groups. We observed that most stakeholder concerns about the operations of such LCVs, e.g., safety, can be alleviated by physically separating LCVs (as well as many other smaller trucks) from the automobile traffic and limiting their operations to truck lanes and the staging areas. Only when such dedicated truck lanes have been accepted by the public and have been heavily used by the trucking industry could truck automation be considered a real possibility. As discussed earlier, the proposed technology has the potential of facilitating the permission of LCV operations in California. This prerequisite of a dedicated truck lane for a truck-AHS and the potential of allowing LCV operations in California for better justifying such dedicated truck lanes point to the potential of the proposed technology in the deployment of a truck-AHS.

It is widely held that heavy trucks inflict a disproportionate amount of damage to pavement compared to the rest of vehicle population. Lankard and Lehrer [1999] reported that Frank McCullough of the University of Texas at Austin estimated that the damage by one pass of a tractor-trailer rig is equivalent to the damage by the passing of 2,000 to 3,000 automobiles [Lankard and Lehrer, 1999]. The truck-AHS concepts to be proposed will concentrate most of the trucks in one lane and also narrow their driving path in that lane, because the automated guidance will decrease the amount of “wander” in the lane. Both of these AHS characteristics will allow more efficient design and construction of the pavement, because the strengthening can be applied where required.

Mixing of small and heavy vehicles on the highway has been a significant safety concern. The truck-AHS operating concepts to be proposed require a dedicated truck-lane that is physically separated from all manual traffic. Not only the driving public but also the trucking industry will likely welcome this separation of truck traffic from the rest of the freeway traffic.

TRAILER PARKING LOT

Some fleet operators, e.g., UPS, have a large number of distribution centers and a distribution center may have a large number of trailers. When the trailers are off-duty, they must be parked in a parking lot. Parking these trailers and hauling them out of the parking area are often done in crowded conditions. Automated trailer steering has the potential of facilitating such activities.

OTHER OPPORTUNITIES

Other opportunities include application of the automated trailer steering technology to tractor-trailer systems used for warehouse operations. A more abstract description of the potential applications of this technology would be to apply it to any situation where a tractor hauling a sequence of trailers need to navigate through narrow paths amid dense infrastructure. This technology may also have high potential in densely populated areas or nations.

3. ANALYSIS: VEHICLE OPERATING REQUIREMENTS AND DESIGN OPTIONS, TECHNOLOGY SELECTION, COMPARISONS

Our goal is not to develop detailed specifications of technology or vehicle-control algorithms. Rather, the goal is to develop operating concepts that are sufficiently detailed as a guide to develop detailed requirements for the technology and for vehicle and systems operations.

During the preliminary study conducted as part of our proposal preparation, we found several papers that address the issue of controlling a multi-axle-steering n -trailer system for following a given path, i.e., controlling a tractor and n steered trailers in such a way that the system follows a pre-defined trajectory, or for advancing from an initial position to a final position [e.g., Nakamura et al., 2001]. During that preliminary study, we also found one paper addressing multi-axle-steering of a large tractor-full-trailer truck, with full consideration of tire-pavement interaction [Wu and Lin, 2003].

A tentative assumption made then was that off-tracking for a tractor-trailer system with up to three trailers could be drastically reduced and furthermore that more extensive literature search would turn up papers demonstrating the drastic reduction for a tractor-trailer system with up to three full trailers through advanced vehicle control. However, after careful and extensive literature search, it became clear that all the studies on “ n -trailer systems” were conducted for mobile robotic vehicles in laboratory environment and hence could not serve as evidence for the potential of drastic reduction in off-tracking for large trucks. A small number of papers about off-tracking elimination have been found, e.g., [Manesis et al., 2002]. However, they considered innovative mechanical control, e.g., sliding kingpin, instead of automated trailer steering. No literature about modeling of tractor with two or more steered trailers was found in the extensive search. Because the potential of automated trailer steering for drastic reduction of off-tracking for large trucks, including longer combination vehicles, is at the core of this project, we developed dynamics models for tractor-trailer systems with up to three full trailers and demonstrated the potential via simulation. This work on developing dynamic vehicle models and the companion simulation is out of the scope proposed for this project. We performed this additional study anyway because of its importance. The details are provided in Part III.

We briefly discuss several dimensions of operational requirements and design options below and select those that are promising as part of an operating concept. We focus on the systems analysis in this Part based on the details reported in Part III.

3.1 Options Regarding the Basic Needs for Automated Trailer Steering

We considered the following categories of design options for key operational requirements:

- Active Axle Steering: At least two options exist:
 - Automated steering on one axle per trailer: This option is preferred. Our study shows that automated steering on one axle suffices for drastic reduction of off-tracking
 - Rear axle: This is required for a tractor-semitrailer combination because the rear axle is only axle present on a semi-trailer.
 - Front axle: Automating the front axle of a full trailer suffices for a drastic reduction of off-tracking. Our study reveals that automating the rear axle of a full trailer, instead of the front axle, does not provide any advantage over automating the front axle.
 - multiple or all axles of a trailer: Automating the front axle of a full trailer alone suffices for a drastic reduction in off-tracking. There is no additional advantage in automating all axles of a full trailer.
- Power for Steering: Commercial products for automatic trailer steering already exist, already they have been designed for purposes other than off-tracking elimination or reduction. They were developed for reduction of turning radius and other special purposes.
 - Electronic control of the actuators
 - Hydraulic or pneumatic power for actuation: The oil and hence the hydraulic power may come from the engine directly, if the tractor and the trailers are meant to be used together on a permanent basis, or may come from the trailer itself with the assistance of an electrically powered pump.
- Variable Number of Trailers behind the Tractor: We studied in detail the behavior of up to three trailers.
- Variable Distance behind the Tractor: This distance is a parameter in our study. However, it is not an important one.
- Maneuvers Other Than Moving Forward in the Travel Lane
 - Lane changing: This occurs frequently. The driver should not be required to inform the vehicle of his or her intent to make a lane change. (This makes lane-following, with or without the aid of lane markers, impractical.)
 - Turning on interchange ramps: Off-tracking of a large truck, particularly the Turnpike Double, while traveling on an interchange ramp may be significant, as will be seen later. But, the degree of off-tracking for the three major categories of LCVs varies significantly. (This also makes following a set of lane markers by large trucks of different configuration and sizes impractical.)

- Turning at intersections: Off-tracking of a large truck, particularly the Rocky Mountain Double and the Turnpike Double, is significant, as will be seen later. As in the case of turning on intersection ramps, the degree of off-tracking for the three major categories of LCVs varies significantly. (This also makes following a set of lane markers by large trucks of different configuration and sizes impractical.)
- Moving in parking lot and at loading docks: Movements in such areas are not restricted to lane or other designation. (This also makes following a set of lane markers by large trucks of different configuration and sizes impractical.)
- Backing-up (reverse motion): The existing literature contains several reports about controlled backing-up of a system of n -trailer, e.g., [Tilbury et al., 1993; Altafini and Gutman, 1998; Altafini, 1999; Altafini, 2001; Altafini, 2003]. However, the n -trailer systems are a system of mobile robotic vehicles, and they do not inform us about how best to control large trucks for backing up. After we have developed dynamics models for tractor-and-three-trailer systems and simulated the behaviors during forward movements, we believe that successful extensions of the models and control laws found in the literature to those for large trucks are highly likely. As a result, we did not study this particular issue. Backing-up movements are not restricted to lane or other designation. (This also makes following a set of lane markers by large trucks of different configuration and sizes impractical.)
- Track-Following vs. Lane-Following: Track-following is definitely preferred for many reasons:
 - Those reasons just mentioned above
 - Off-tracking is with respect to the track of the front wheels after all.
 - This is also preferred because it requires no infrastructure modification.
 - Our study demonstrates that off-tracking can be drastically reduced without the use of any lane markers.

3.2 Design Options Regarding Opportunities for Capitalization on Automated Trailer Steering

- Trailer dimensions:
 - Length: We keep this as a parameter.
 - Height (center of mass): This is ignored in our study because the focus is on off-tracking.
 - Axle spacing within a trailer for reducing and minimizing impact on pavement: This is ignored because the focus is on off-tracking.
 - Distance between the hitch and the front axle of a trailer: This is a parameter. It does play a significant role, as will be seen in Part III.
- Configurations:
 - Number of trailers: We study tractor-trailer combinations with up to three full trailers.

- Variable sizes: Size is treated as a parameter in our study. It does not play a significant role about the ability of automated trailer steering in reducing off-tracking.
- New Hierarchy of Delivery for Less-Than-Truckload (LTL) Transportation: This is studied in Part IV. A new hierarchy involves the creation of a regional hub. The hub is equipped with trucks handling regional freight movement by hauling loaded or empty trailers between the customer locations and the regional hub; inter-regional freight is moved by the a different set of trucks. We focus on the effect of the new hierarchy on the van lines – the freight forwarders moving household goods. Range of parameters for which this new hierarchy benefits the van lines are identified in Part IV.
- Possible New Hierarchy of Delivery for Truckload Transportation: This is a special case of the new hierarchy for the LTL case in which all loads are full.
- Off-the-road Track Following: This poses no additional complexity if the track-following technology is implemented. (However, if the lane-following technology is implemented, this will not be possible.)
- Automated Track-following for Unmanned Trailing Vehicles without Mechanical Linkage but with electronic linkage: This will be enabled by combining the technology of (track-following) automated trailer steering with the Advanced Vehicle Control System (AVCS) technology of (via wireless communication and automatic lateral and longitudinal vehicle control already developed at PATH.

4. SYNTHESIS: PROMISING OPERATING CONCEPT

We focus on the specification of basic tractor-trailer operations involving up to three trailers. A new hierarchy for Less-Than-Truckload (LTL) freight transportation is the sole focus of Part IV, and the many details about the companion operating concepts and many operating scenarios are defined there.

Based on the operational requirements, design options and design comparison discussed above, we summarize a promising operating concept below.

- Track following, instead of lane following,
- Trailer steering for forward movements, including lane-keeping, lane-changing, turning on an interchange ramps, turning at an intersection, turning at unmarked areas (parking lots or loading docks), for backward movement, and for all other maneuvers.
- Automated steering for the front axle of a full trailer and for the rear axle for a semi-trailer.
- Electronic control integrating sensor signals, command computation and actuation
- Automated trailer steering activated with a switch
- Speed-dependent trailer steering, with speed-independent trailer steering as a supported extreme case
- Steer-by-wire; no mechanical connections between the tractor and the trailer(s) for steering other than the hydraulic links

- Hydraulic steering actuation (exclusive electrical-power actuation also a possibility.)
- Automatic centering of trailer wheels or axle in case of failure to ensure safety

5. SYNTHESIS: DEMONSTRATION OF TECHNOLOGICAL FEASIBILITY - VEHICLE DYNAMICS AND PHYSICAL IMPLEMENTATION

5.1 The Scope of Our Study and the Existing Literature

This section addresses the technical feasibility of the concept of automatic trailer steering for the purpose of eliminating or significantly reducing off-tracking for large trucks. Recall that our scope includes all large trucks.

Although automated steering for a sequence of mechanically-linked wheeled-vehicles has received some attention in recent literature, all of the reported efforts center around robotics and deal with car-like mobile robots vehicles [e.g., Tilbury et al., 1993; Tibury, et al., 1995; Altafini, C. and P. Gutman, 1998; Tanaka et al. 2002], not road vehicles. These efforts do not consider the important factors about wheel-pavement interaction, e.g., wheel cornering stiffness.

A small number of papers have been published on the performance of semi-trailer steering systems [e.g., LeBlanc et al., 1989; Sankar et al., 1991; LeBlanc et al., 1992; Prem, 2002; Jujnovich and Cebon, 2002]. Wu and Lin [2003] deal with the tractor-full-trailer combination. and Woodrooffe et al. [1983] deal with both single-unit trucks and the tractor-full-trailer combination. Our scope includes all large trucks, including STAA doubles (i.e., tractor-double-trailer combinations) and LCVs, and hence extends much beyond tractor-semi-trailer and tractor-full-trailer combinations.

Four-wheel drive of a straight truck as an extension to four-wheel drive of an automobile has also been studied [e.g., Vaughn and Miller, 1990]. Chikamori, S., and Kawasaki [1996] dealt with articulated trucks with multi-axle steering but studied the stability of such vehicles.

Chen and Tomizuka [2000], in their study on lateral control of tractor-semitrailer type commercial vehicles, showed that by applying coordinated steering (of the front-axle of the tractor) and independent braking-force control, trailer yaw velocities could be reduced. Tai and Tomizuka [2004] modeled the dynamics of multi-unit trucks for simulation of vehicle behavior and for controller design. However, they did not consider the possibility of trailer steering.

We are unaware of any published literature or any research on dynamics or control of road vehicles having two or more trailers that addresses wheel-pavement interaction, e.g., wheel cornering stiffness.

5.2 Our Study Approach

Due to the large number of possible configurations and their possible design dimensions, e.g., the actual length of a full-trailer, semi-trailer or a tractor, we focus our study on three main configurations and treat the actual lengths of the trailers as parameters. The

three configurations are a tractor hauling one, two or three trailers. To capitalize on the opportunity to compare our results with those reported in the small number of papers recently published in the existing literature, we extend the work of Wu and Lin [2003].

We anticipated the possible performance difference between front-axle automated trailer steering and rear-axle automated trailer steering with respect to reduction of off-tracking. However, we did not observe a major difference after a preliminary study. Therefore, we focus on front-axle steering.

5.3 Major Problem with Operations of Large Trucks

Several studies have revealed the true nature and extent of the off-tracking problem associated with the operations of large trucks. Most notably, California Department of Transportation [Caltrans, 1984] conducted an operational test of longer combination vehicles in 1983, and Harkey et al. [1996] reported on the operational characteristics of large trucks, with a focus on longer combination vehicles and related geometric design issues and with a comparison to those associated with tractor-semi-trailer combination.

The 1983 Caltrans LCV operational test focused on the same three types of LCVs studied in this project: Rocky Mountain Double, Turnpike Double and Triple. Each of the three combinations was operated over an essentially identical 1,200-mile route, allowing a direct comparison between the combinations. That study covered observations in the areas of: freeway interchanges, open-road travel, urban traffic (including arterials and intersections), narrow lanes, two-lane roads, other freeway facilities like rest areas and scales, off-tracking, speed on grades, braking, acceleration, travel during rain and wind, noise generation, and fuel economy. Due to our focus on off-tracking, we briefly discuss below the conclusion reached in that study about off-tracking. Note that, in the 1983 Caltrans LCV operational test, off-tracking refers to the additional width (over and above the truck width) required by a vehicle when the tractor follows a predefined circular course. Therefore, we are interested in the conclusions made about off-tracking in the operational categories of freeway interchanges, open-road travel, urban traffic (including arterials and intersections), and off-tracking.

Caltrans [1984] stated, “The Triple Trailer combination was the most maneuverable of the three combinations as witnessed by the off-tracking tests and travel through numerous interchanges and intersections. Generally, this combination could maneuver almost as well as other observed long tractor-semitrailer combinations mandated by the 1982 Surface Transportation Assistance Act (STAA) to operate over the Designated system.” It also stated, “During the fast stops the trailers did not always stop in a straight line and would not always remain in its own lane.”

About the Rocky Mountain Double, Caltrans [1984] stated, “The Rocky Mountain combination was the intermediate of the three tested combinations for maneuverability. ... Again, however, the Rocky Mountain Doubles did not always stop in a straight line.”

“The Turnpike Doubles were the least maneuverable of the three combinations tested. This was shown by the movements through interchanges and intersections and by the off-tracking tests. In fact, this combination had problems maneuvering through interchanges of the latest design in rural areas. On occasion, the Turnpike’s inside rear tandems mounted the asphalt beam delineating the shoulder edge and ran off of the pavement while using all the space available on the ramp.” Note that Turnpike Doubles even had trouble maneuvering through interchanges of the latest design in rural areas, where real estate is abundant. They had particular troubles maneuvering through interchanges and intersection in urban areas.

The major specific operational problems identified by the 1983 Caltrans LCV operational test about off-tracking include:

- Freeway Interchanges: “Both the RM and 2x48 consistently crossed over and climbed this rolled curb. Where this occurred, it was not unusual for only one tire of each rear dual to be riding on top of the curb (a 1-2 inch width) with the other dual tire being suspended in the air. This situation would create significant pressure (essentially $\frac{1}{4}$ of the trailer weight over a few square inches) on both the tires and the curbs. This would create the potential for very rapid curb deterioration and/or tire blowout.”
- Urban Arterials: The 2x48, and to some extent the RM, also had some difficulty in entering/exiting Viking yards on arterials. In Modesto, the Viking facility is one Crows Landing Road, a 4-lane arterial with a striped dual left-turn lane, and has a curbed 30-foot wide entrance and exit. On a right-turn exit from this yard, the 2x48 actually encroached about 4 feet into the dual left-turn lane. This move required stopping the traffic on Crows Landing Road at 11:00 AM so that truck could make the move.
- Urban Intersections: “In each case, there was some encroachment into adjacent lanes, both into and out of the turn, for each combination. This ranged from about 2-feet each (into and out of the intersection) for the Triples, to approximately 4-feet each for the RM, to the full lane each for the 2x48. If encroachment room was not available for either the entrance or exit, that much additional room was needed for the other half of the movement. This encroachment could result in delay to either the truck or other traffic until sufficient room to make the move became available.”
- Off-tracking: The off-tracking tests were conducted in Viking’s Santa Clara yard. A Caltrans survey crew laid out 60-, 80- and 100-foot radius curves over a 180-degree central angle on the parking lot surface. Central angle increments of 30 degrees were marked on the curves. Each test combination entered each curve on the tangent, placed the outside edge of his left front tire on the curve, proceeded to drive around the curve to the right, and exited the curve on the tangent. The off-tracking was generally at a maximum at around 120 degrees of central angle. The off-tracking did increase as the combinations went from 48-ft semi, to COE Triple, to conventional Triple, to RM, to 2x48.” The maximum swept width distances (including the 8.5-foot width of rear axle) for the Turnpike Double is 40.3 feet, 30.4 feet and 25.4 feet for the radii of 60 feet, 80 feet and 100 feet,

respectively. They are also the maximum swept width distance for all large trucks tested, including the tractor-semi-trailer combination and the three LCVs.

In short, the major problems identified in the 1983 Caltrans Operational Test seem to be the off-tracking problem associated with the Rocky Mountain Double and Turnpike Double on free interchanges and on urban intersections and the constant-sway problem with the Triple Trailer combination.

Although no problems were reported for the test on two-lane roads, a tragedy occurring on a rural two-lane road led to a proposed bill in California legislature nicknamed “Kim’s Law,” as discussed in Section 2.1.

5.4 Quantitative Characterization of Off-Tracking: High-Speed and Low-Speed

As mentioned earlier, off-tracking can be measured as the distance between the path of the front inside wheel and the path of the rear inside wheel of a truck as a vehicle traverses a curve or turn [Harkey et al., 1996]. The maximum swept path is another way of measuring the amount of off-tracking and is defined as the width of the vehicle plus the off-tracking distance [Harkey et al., 1996]. This measure is good when judging whether the width of a lane, on the freeway or on an interchange ramp, is wide enough for large-truck operations. If this maximum swept path exceeds the width of the travel lane, the vehicle will encroach into adjacent lanes or the shoulder during the turning maneuver.

High-speed off-tracking and low-speed off-tracking differ in the relative position of the track of the front wheels and that of the rear wheels. In high-speed tracking, the rear wheels track outside the front wheels (i.e., outside of the circle that could be generated by the tractor’s turning movement) while in low-speed off-tracking, the rear wheels track inside the path of the front wheels.

Ervin et al. [1984] reported measurements of high-speed and low-speed off-tracking for tractor-semi-trailer combination and LCVs. They can also be found in Harkey et al. [1996]. Table 2 summarizes the two off-tracking measures for high-speed off-tracking at the high speed of 55 miles per hour on a curve of 600-ft radius. The measures of maximum swept path show that these large trucks do not encroach into adjacent lanes or the shoulder if the lane width is 11 ft and the driver positions the truck appropriately while entering the lane. (ASSHTO recommends 12-ft or wider lanes where high truck traffic is expected, particularly on high-speed roadways on which off-tracking may be a problem.)

Although high-speed off-tracking does not seem to be a serious issue, low-speed off-tracking is a very serious problem.

Table 3 summarizes the two measures for low-speed off-tracking on a curve with a radius of 200 feet as well as the two measures on a curve with a radius of 300 ft. These two radii are typical for interchange ramps. AASHTO recommends a lane width of 16 ft for ramps of these radii when large trucks will be present. Under the assumption that the

driver positions the truck appropriately while entering a lane of this recommended width of 16 ft, the only large truck that cannot remain in the lane is the turnpike double with two 48-ft trailers. However, not all interchanges are equipped with ramps of this recommended width, and not all drivers position their trucks appropriately when entering such a ramp lane. AASHTO [1984] surveyed the states' Department of Transportation, and Table 4 summarizes the percentage of interchanges, including urban and rural interchanges, that can accommodate these large trucks. Note that less than 50% of the interchanges are adequate for accommodating tractor-semi-trailers and less than 25% are adequate for accommodating turnpike doubles (with two 48-ft trailers).

Table 2: High-Speed Off-tracking and Maximum Swept Path: 600-ft Radius

Truck Configuration	Off-tracking	Maximum Swept Path
Double - 28/28	0.52	9.02
Triple - 28/28/28	1.12	9.61
Tractor Semi - 48	1.25	9.74
Rocky Mountain Double - 45/28	1.34	9.84
Rocky Mountain Double - 48/28	1.44	9.84
Turnpike Double - 45/45	1.44	9.94
Turnpike Double - 48/48	2.13	10.63

Recall the result of the 1983 Caltrans operational test of LCVs. : “Both the RM and 2x48 consistently crossed over and climbed this rolled curb. Where this occurred, it was not unusual for only one tire of each rear dual to be riding on top of the curb (a 1-2 inch width) with the other dual tire being suspended in the air. This situation would create significant pressure (essentially ¼ of the trailer weight over a few square inches) on both the tires and the curbs. This would create the potential for very rapid curb deterioration and/or tire blowout.”

Table 3: Low-Speed Off-tracking and Maximum Swept Path: 200-ft and 300-ft Radii

Truck Configuration	200-ft Radius Off-tracking	200-ft Radius Maximum Swept Path	300-ft Radius Off-tracking	300-ft Radius Maximum Swept Path
Double - 28/28	3.02	11.51	2.00	10.50
Triple - 28/28/28	4.40	12.89	2.89	11.41
Tractor Semi - 48	4.79	13.32	3.21	11.71
Rocky Mountain D. - 45/28	5.12	13.61	3.41	11.91
Rocky Mountain D. - 48/28	5.71	14.20	3.80	12.30
Turnpike Double - 45/45	7.41	15.91	4.89	13.42
Turnpike Double - 48/48	8.50	17.02	5.61	14.10

Table 4: Percentage of Interchanges Determined As Adequate for Truck Configurations by State DOTs (AASHTO Survey)

Location	Truck Configuration			
	Tractor 48-ft Semitrailer	Rocky Mountain Double	Turnpike Double	Triple
Rural	46%	27%	23%	36%
Urban	50%	29%	24%	39%

Although low-speed off-tracking is a serious problem for large-truck operations, the most serious problem with large-truck operations is the off-tracking at at-grade 90-degree intersection. Table 5 summarizes the two off-tracking measures for at-grade intersections with a turn radius of 45 ft. AASHTO recommends a curb radius of 40 ft or longer to accommodate large trucks (AASHTO, 1990). Although AASHTO also recommends longer turning radii of 45 ft, 48 ft and 60 ft for doubles, tractor-semi-trailer combinations and turnpike double, respectively. However, such recommendations are not always heeded, often because of lack of right-of-way. The maximum swept paths revealed in Table 5 often require large trucks to encroach into adjacent lanes on the exiting or the receiving leg of the intersection (or both). Recall the result of the 1983 Caltrans operational test of LCVs, “In each case, there was some encroachment into adjacent lanes, both into and out of the turn, for each combination. This ranged from about 2-feet each (into and out of the intersection) for the Triples, to approximately 4-feet each for the RM, to the full lane each for the 2x48. If encroachment room was not available for either the entrance or exit, that much additional room was needed for the other half of the movement. This encroachment could result in delay to either the truck or other traffic until sufficient room to make the move became available.”

Table 5: 90° Intersection Off-tracking and Maximum Swept Path: 45-ft Radius

Truck Configuration	Off-tracking	Maximum Swept Path
Double - 28/28	12.50	21.02
Triple - 28/28/28	16.89	25.42
Tractor Semi - 48	17.52	26.01
Rocky Mountain Double - 45/28	18.50	27.03
Rocky Mountain Double - 48/28	20.11	28.60
Turnpike Double - 45/45	24.40	32.90
Turnpike Double - 48/48	27.13	35.62

5.5 Other Studies

FHWA (1985) stated, “Rocky Mountain doubles and turnpike doubles would have to encroach on opposing traffic lanes much more than tractor semitrailers to make right turns at intersections without running over curbs and possibly knocking over signs, poles, or other roadside features”. Respondents to the AASHTO survey cited the inability of large trucks to negotiate turns at intersections as one of the reasons why LCVs should be severely restricted on the Interstate system [AASHTO, 1984].

5.6 Our Study of the Dynamics and Control of Multi-Trailer Large Trucks

Note that all these studies are about the conventional trailers, without being equipped with any steering capability. Part III summarizes the results of our study of the dynamics and control of multi-trailer truck combinations. They clearly show the potential of automatic steering control to eliminate or drastically reduce off-tracking of large trucks.

Off-tracking occurs when rear wheels of the trailer(s) do not follow the path traversed by the front wheels of the tractor during a turn. Low-speed off-tracking occurs when the wheels of the rearmost trailer axle traverse a path inside the path of the tractor's front steering axle. We examine low-speed off-tracking for articulated systems with 1, 2 and 3 trailers. Figure 2 of Part III demonstrates the effect of trailer (front-wheel) steering on off-tracking at a low speed of $V_x = 5$ ft/sec (or 3.4 miles/hour) during a 90-degree turn. Tractor's steering angle is 18 degrees for all the three systems. Trajectories of rearmost axles of the three systems and of the front axle of the tractor, with and without trailer steering, are shown. Figure 2(a) of Part III focuses on the case of one trailer where the trailer's front axle is steered with 36 degrees in the opposite direction (steering ratio = -2). Off tracking is reduced from 1.7 ft to 0.6 ft. In Figure 2(b) of Part III, the first and second trailer's front axles are steered at 18 degrees in the opposite direction as that of the tractor (steering ratio = -1). Off tracking in this case is reduced from 2.2 ft to 0.7 ft. In Figure 2(c) of Part III all three trailers' front axles are steered at 23 degrees (steering ratio = -1.3). Off tracking in this case is reduced from 3.7 ft to 0.6 ft. For all the three cases, in comparison to the base cases of no trailer steering (steering ratio = 0), trailer steering has the benefits of (1) a smaller radius of turn for the same tractor front-wheel steering angle and (2) less off-tracking, i.e., a reduced distance between the paths of the tractor's front axle and the trailers' rear axle. With trailer steering, all the vehicles are able to successfully complete the sharp 90-degree turn within the lower bound of AASHTO-recommended curb radii of 40 ft for LCVs [AASHTO, 1990].

In high-speed off-tracking, the trailer units move outward due to lateral accelerations. We examine high-speed off-tracking for 1-, 2-, and 3-trailer systems with a forward speed of $V_x = 50$ ft/sec (or 34.2 miles/hour) and tractor steering angle of 3.6 degrees during a 90-degree turn. Figure 3(a) of Part III corresponds to the case of a tractor with one trailer. The trailer unit is steered at 6.3 degrees (steering ratio = 1.75). As in the case of low-speed turning, off-tracking, as measured by the maximum distance between the trajectory of the rear wheel of the trailer and that of the tractor's front wheel, is reduced from 7ft to 2.0 ft, and the whole combination negotiates a wider turn radius than for the case without trailer steering.

As shown in Figure 3(b) of Part III for the case of two trailers, we see a similar performance as the case of one trailer. Off-tracking is reduced from 18 ft to 3 ft, and the whole combination negotiates a wider turn radius. Trailer-1's front wheels are steered at 2.7 degrees (steering ratio = 0.75) in the same direction as the tractor's while trailer-2's front axle is steered at 4.5 degrees opposite of the tractor's steering direction (steering ratio = -1.25). In the case of three trailers as shown in Figure 3(c) of Part III, trailer 1 front axle is steered at 4.3 degrees in the same direction as the front axle of the tractor

(steering ratio = 1.2), trailer 2 is steered at 3.6 degrees opposite to tractor steering (steering ratio = -1.0), and trailer 3 is not steered.. We observe a result similar to those in the cases of one- and two-trailer systems. The severe off-tracking of 22 ft experienced by a three-trailer system without trailer steering is reduced significantly to 4 ft when the trailers' front wheels are also steered.

We note that implementation of automatic control should enable the appropriate levels of trailer steering and in turn reduce LCV off-tracking significantly. Developing such control algorithms and mechanisms is a worthy research subject for reducing the safety and infrastructure hazards associated with large-truck operations.

5.7 Physical Implementation

Automated trailer steering has been implemented on high-end combination trucks for purposes other than reduction of off-tracking on such trucks. Its implementation typically involves electronic control of hydraulic axle- or wheel-steering subsystems.

We use the Electronic Trailer Steering (ETS) developed and marketed by Vehicle System Engineering of The Netherlands as an example.

- Electronic control integrating sensor signals, command computation and actuation
- Developed for several different tractor-trailer configurations; one-axle or multi-axle trailer steering
- Capable of speed-dependent trailer steering and speed-independent trailer steering
- Trailer steering for both forward and backward movement
- An LCD display serving as user interface for selecting and displaying mode of operation: off, automatic and manual. (Trailer steering can be manually controlled via the display panel.)
- Non-contact sensing of angle between tractor and trailer and angle between trailers; non-contact sensing of steering angle of trailer wheels or axle
- Steer-by-wire; no mechanical connections between the tractor and the trailer(s) for steering other than the optional hydraulic links
- Hydraulic steering actuation: power pack unit units installed on trailer(s), with hydraulic power supplied by an electronically controlled steering pump; when the combination involves the tractor and one dedicated trailer or when more than one trailer needs to be steered, the oil supply can come from an engine driven steering pump installed on the tractor and hence no extra power pack unit is required for the trailer(s).
- Automatic centering of trailer wheels or axle in case of failure to ensure safety
- Tractor independence possible, thus facilitating retrofitting

The Electronic Trailer Steering (ETS) for trailers is currently designed for high-end trucks. However, when demand for trailer steering increases and after the experience in deploying the technology accumulates, the cost should reduce. However, the mass production cost is unclear at this point. ETS declined to provide cost estimates for

retrofitting a conventional trailer with trailer steering or mass-producing new trailers with trailer steering due to the fact that the cost hinges upon detailed specifications.

Palkovics and Fries [2001] commented, “In case of combination vehicles the trailer’s axle(s) can also be steered to minimize the turning radius, decrease the tire wear and improve high-speed stability. The so-called forced steering is already state-of-the-art in some type of trailers (especially the long ones). The active steering of the trailer wheels is also an option (TWS) and can bring quite a good improvement especially in trailer handling, however the energy supply problems on the trailer and also the complexity does not justify for that.” They do not think that the cost would justify the technology. Note that they never considered reduction or elimination of off-tracking as a benefit for this technology. The safety gain, the potential for expansion of LCV operations and the resulting productivity gain may entice the trucking industry to adopt the technology of trailer steering and the infrastructure provider to mandate it for current or expanded LCV operations.

The proposed project called for the study of the technology of automated trailer steering, and therefore this technology has been the focus of all our research. To avoid the additional cost associated with the additional functionality and equipment required by this technology, some researchers considered the concept of “individual braking” to achieve better lateral control of heavy vehicles [e.g., Chen and Tomizuka, 2000]. In individual braking, braking forces are independently controlled on the inner and outer wheels of a trailer. This concept is appealing in its potential lower cost because its implementation does not require extra equipment to be installed on a trailer and can actually be based on the braking function already implemented on trailer wheels. This possibility is a worthy subject for future study.

To minimize implementation costs associated with automated trailer steering, reducing the number of steered trailer axles can be considered. Achieving the same amount of off-tracking with a reduced number of automatically steered trailers is a worthy research subject.

Implementing the new technology of automated trailer steering will incur additional cost, and the additional cost will be high initially when the deployment is not wide spread. The real issue becomes one of willingness to pay and hence one of identifying “killer application.” A good target category of customers is Less-than-truckload (LTL) freight forwarders, e.g., UPS and FedEx. U.S. General Accounting Office [1994] reported that “...One sector, the large companies that consolidate packages or shipments under 10,000 pounds, could benefit immediately from even a partial expansion of LCV routes. These less-than-truckload companies have extensive terminal networks for collecting and distributing shipments, and they can use triple 28-foot trailers for trips between terminals.” Of course, safety is a major concern for those states what do not currently allow LCV operations. However, if such expansion comes with the condition that automated trailer steering be implemented for improved safety and reduced infrastructure impact, such fleet operators may be willing to pay for the new technology. The investigators also explored with UPS operations managers at the corporate level and the

regional level. They all expressed enthusiasm for this new technology, despite that the mass-production cost or mass-retrofitting cost is difficult to predict at this point.

Part III of this report is devoted to the study of vehicle dynamics of a tractor-trailer combination with up to three full trailers. Our modeling and simulation results demonstrate that, with steering angles for steered trailer axles selected in an *ad hoc* manner, off-tracking can be drastically reduced.

Control algorithms for systematically minimizing off-tracking are being developed, and preliminary results show that off-tracking can virtually be eliminated. These preliminary results will be reported in the future when a systematic study is completed.

6. SYNTHESIS: EARLY ADOPTERS FOR INCREMENTAL DEPLOYMENT

We address possible early adopters of the technology of automated trailer steering in two categories of operations: STAA trucks and LCVs.

Recall that, according to a 1989 Caltrans study [Caltrans, 1989; Caltrans, 2005], of the 15,166 miles comprising the State Highway System, 3,364 miles (over 20%) cannot accommodate large trucks with a 40-foot Kingpin-To-Rear Axle Length (KPRA length) or longer, and 3,185 miles (about 20%) cannot accommodate large trucks with a 38-foot KPRA length or longer. Currently, those route segments that cannot safely accommodate a 40-foot KPRA were designated “Advisory,” but such large trucks are not prohibited by law from using these route segments. One way to improve the safety of using large STAA trucks on such rural roads in California and other states of the U.S. is through drastic reduction of off-tracking enabled by the use of automated trailer steering. This technology will also improve STAA truck operations in urban areas, particularly intersections on city streets.

This technology will also provide immediate benefit for current LCV operations. Recall the serious off-tracking problems associated with operations of Rocky Mountain doubles and Turnpike doubles on interchange ramps and intersections.

As for expansion of LCV operations, U.S. General Accounting Office concluded, “Expanding routes open to LCVs would benefit some sectors of the trucking industry more than others. For example, if expansion of LCV routes were limited to highway with low traffic density, the potential benefits would be lower and would apply mostly to companies that use triple 28-foot trailers to transport consolidated small shipments between terminals. These less-than-truckload and package companies make extensive use of double 28-foot combinations nationwide and add a third trailer wherever triples are legal.” This points to the flexibility of operations of triples by such companies and to the fact that these companies can expand such operations incrementally as the possible expansion takes place incrementally. Note that the most realistic scenarios for LCV routes would involve incremental expansion. If such limited expansion is implemented with the requirement for automated trailer steering on all trailers or on a subset, the LTL sector of the trucking industry will be a good candidate for early adoption of this new technology.

7. EVALUATION: NON-SAFETY COSTS AND BENEFITS

Non-safety benefits of automated trailer steering result from LCV operations. Therefore, this section focuses on the costs and benefits of expanding LCV operations.

Among the many sources of information we used in cost-and-benefit evaluation is the Comprehensive Truck Size and Weight Study initiated in 1994 by the Federal Highway Administration (FHWA) of the U.S. Department of Transportation, which transmitted the final report to the U.S. Congress in 2000.

We partition our discussion about the potential impact of expansion of current LCV operations into two sections. In this section, we focus on non-safety impact and leave the discussion of safety impact in the next section.

Among the non-safety impacts of LCV expansion are:

- Pavement Cost: recurrent cost
- Bridge Cost – Construction Cost: one time cost
- Bridge Cost - User Cost (Construction Delay): one-time cost
- Geometric Cost – Interchanges and Intersections: one-time cost
- Geometric Cost - Staging Area: one-time cost
- Congestion Costs: recurrent cost
- Energy Costs: recurrent cost
- Shipper Costs: recurrent cost
- Diversion of Rail Freight to Trucking: recurrent

Among the nine categories of non-safety impact, Geometric Cost – Interchanges and Intersections is the category that can directly benefit from the technology of automated trailer steering. Given the fact that current LCV operations are not supported by staging areas and given the potential of automated trailer steering for drastically reducing or eliminating off-tracking, Geometric Cost - Staging Area may also benefit from the ATS technology.

The issue of diversion of freight from rail to trucking is a political issue, and is beyond the scope of this project. We will not discuss it further.

7.1 Roadway Geometry As The Primary Source of Cost Savings for LCV Expansion

U.S. General Accounting Office requested an FHWA analysis about the cost and benefit associated with expanding the current LCV operations to the entire Interstate System and some primary highways, and, based on that analysis and other information, concluded [U.S. General Accounting Office, 1994]:

“Analyses of benefits and costs attributable to LCVs have been somewhat theoretical because of the various assumptions used to analyze data. LCVs would probably not increase pavement wear, but according to recent Federal Highway Administration’s

(FHWA) analyses, nationwide use of LCVs on the interstate highway system could require additional investments of \$2.1 billion to \$3.5 billion to replace bridges, improve interchanges, and provide staging areas for the breakdown and assembly of LCVs. Much of the projected infrastructure costs would be incurred in the more densely populated areas of the country. If LCV expansion were limited to carefully selected routes away from major population areas, the cost impact would be limited, but the benefits would also be reduced.”

“A 1990 analysis for the trucking industry projected that nationwide use of LCVs on interstate and some primary highways would reduce annual trucking costs by about 3%, or 3.4 billion. As annually recurring benefits, these savings would exceed the one-time infrastructure investment costs estimated FHWA.”

Note that this estimate of \$2.1 billion to \$3.5 billion is a one-time cost while the \$3.4 billion estimated productivity gain for the US trucking industry is an annual estimate.

This range was derived as follows. At the request of GAO, FHWA provided two different estimates of the number of bridges considered inadequate for LCV use and the cost to replace them. Using a capacity rating of the bridges that is closer to that used in most states (instead of a more conservative capacity rating favored by the American Association of Railroads), FHWA projected \$248 million for rural interstates and \$1.1 billion for urban interstates. FHWA provided the range of \$750 million to \$2.2 billion for access improvement (including interchange improvement and staging area construction), thus the range of \$2.1 billion to \$3.5 billion as the estimated total cost of the infrastructure modifications required for nationwide use of LCVs. We believe that, with the technology of automated trailer steering, access improvement will not be needed and hence only \$1.3 billion is required. The range of savings will be from \$750 million to \$2.2 billion, i.e., from 36% to over 60%. This potential saving is drastic.

These cost estimates are much too low when compared to a set of new estimates produced by FHWA and reported in the 2000 Comprehensive Truck Size and Weight Study [Federal Highway Administration, 2000], which considered, among other things, the delay costs resulting from the replacement of bridges and deliberately used a larger network to arrive at an upper bound for the costs and benefits.

Before we begin discussing the new FHWA estimates, we point out that the technology of automated trailer steering (ATS) has the potential of eliminating all the concerns raised by Harkey et al. [1996] about LCV off-tracking. Harkey et al. organized all geometric-design issues about LCV operations in four categories: off-tracking, stability, braking and stopping distance, and speed and acceleration. Braking and stopping distance tends not to be a serious issue because LCVs typically have more axles than the tractor-semitrailer combination and hence can have higher braking force. Automated trailer steering has the potential of eliminating the off-tracking issue. In addition, it may increase the stability of LCVs. This is a worthy subject for future research. However, this technology does not require any change in the current weight limitations and hence cannot help alleviate the issue about speed and acceleration.

7.2 Impact of Automated Trailer Steering on the “Nationwide LCV Scenario” of The 2000 Comprehensive Truck Size And Weight Study

Regarding the micro-economic view of the productivity gain achievable by LCV operations, Caltrans concluded [Caltrans, 2005] that LCVs improve productivity due to an increase of cargo-carrying capacity of 30% to 100% per driver and due to more efficient use of fuel. In addition to this micro-economic assessment, several macro-economic assessments are also available. As discussed earlier, U.S. General Accounting Office concluded, “According to a study done for the trucking industry, opening the interstate system and some primary highways to LCVs would lower annual trucking costs by 3.4 billion (about 3 percent).”

In the 2000 Comprehensive Truck Size and Weight Study [Federal Highway Administration, 2000], FHWA defined five different sets of truck size and weight limits. They, together with five corresponding deployment networks, constitute five operating scenarios. FHWA also defined a base scenario. Based on these scenarios, FHWA evaluated and compared the costs and benefits of the five different sets of size-weight limits. In this report, we focus on the comparison between the LCV Nationwide Scenario and the Base Scenario. The comparison results are summarized in Table 6. We assume that the technology of automated trailer steering can eliminate the need for modifying interchanges and intersections within the deployment network. This, based on Part III of this report, is a safe assumption. We also assume that this ATS technology can eliminate the need for staging areas.

In this study, if we assume that the access cost, including the geometric cost for interchanges and intersections and the geometric cost for staging areas, can be eliminated, the saving will be \$7.9 billion. But, this saving is only a little over 1% of the total public cost. In addition, the advantage of the LCV Nationwide Scenario over the Base Scenario in terms of the total public cost is actually less than 1%. On the other hand, the shipper cost is reduced by \$568 billion in 20 years, and the cost reduction is over 11%. This cost reduction is rather significant.

8. EVALUATION: SAFETY

Discussion about the safety of large-truck operations usually involves two different approaches: statistical accident rate and safety-related characteristics of vehicle behavior. Major safety-related problematic characteristics of large-truck behavior, particularly those related to off-tracking, have been discussed in Section 5. This section focuses on the statistical accident rate.

Table 6: Comparisons between the LCV Nationwide Scenario and the Base Scenario

Cost Category	LCV Nationwide Percent Change	Base Case Estimate - 20 years	Additional costs – 20 years	LCV Nationwide Estimate – 20 years	LCV Nationwide with ATS
Pavement Costs	-0.2%	196,539	-398	196,141	196,141
Bridge Costs (one time)	+34.4%	154,000	53,000	207,000	207,000
User Costs (Construction Delay; one-time)	N/A	0	266,000	266,000	266,000
Geometric Costs – one-time (interchanges, intersections)	+965.0%	754	2,987	3,742	0
Geometric Costs – one-time (staging area)	N/A	0	4,153	4,153	0
Congestion Costs	-2.9%	5,858,000	-172,000	5,686,000	5,686,000**
Energy Costs*	-13.8%	1,496,014	-206,450	1,289,564	1,289,564
Total Public Costs	-0.68%	7,705,307	-52,707	7,652,600	7,644,705**
Shipper Costs	-11.4%	4,980,000	-567,720	4,412,280	4,412,280

*\$2.50 per gallon assumed; emission reduction not considered

**Delay reduction due to off-tracking reduction/elimination is significant but could not be estimated based on published reports about 2000 Comprehensive Truck Size and Weight Study.

8.1 Current Status and Trend of Large-Truck Accident Rates

The Federal Motor Carrier Safety Administration [2003] of the US Department of Transportation published “Large Truck Crash Facts 2001” summarizing the status and the trends of fatal crashes and fatal-crash rates by vehicle types that occurred in the U.S. up to the year of 2001. Table 7 summarizes the statistics of fatal crashes and crash rates that occurred in 2001.

Large Truck Crash Facts 2001 reports that over the last 20 years (1981 to 2001), the fatal crash rate for large trucks (including both single-unit trucks and combination trucks) has declined from 4.5 fatal crashes per 100 million miles traveled to 2.1 fatal crashes per 100 million miles traveled, a 53 percent decrease. In the same time period, the fatal crash rate

for passenger vehicles has declined from 3.0 fatal crashes per 100 million miles traveled to 1.5 fatal crashes per 100 million miles traveled, a 50 percent decrease. While the two percentages of decreases are comparable, the crash rates for both single-unit and combination trucks are significantly higher than that of passenger vehicles, as shown in Table 7.

Table 7: 2001 Fatal Crashes and Crash Rates by Vehicle Type

Vehicle Type	Fatal Crashes	Vehicles Involved	Occupant Fatalities	Total Fatalities	Million VMT	Fatal Crashes per 100 Million VMT	Vehicles Involved in Fatal Crashes per 100 Million VMT	Fatalities per 100 Million VMT	Total Number of Registered Vehicles
Passenger vehicle	34,342	48,151	31,910	38,542	2,557,261	1.3	1.9	1.5	207,719,870
Single-Unit Truck	1,238	1,261	204	1,371	72,286	1.7	1.7	1.9	5,703,500
Combi. Truck	3,286	3,532	500	3,818	135,400	2.4	2.6	2.8	2,154,174

Large Truck Crash Facts 2001 also reports that the large truck injury and property damage crash rates are also on the decline. From 1988 to 2000 (1988 was the first year in which FMCSA began collecting and analyzing injury and property damage crash data), the large truck injury crash rate has declined from 67.9 injury crashes per 100 million miles to 41.2 injury crashes per 100 million miles, a 39 percent decline. Similarly, the property damage only crash rate declined between 1988 and 2000 from 210.7 crashes per 100 million miles to 153.7 crashes per 100 million miles, a 27 percent decline.

Large Truck Crash Facts 2001 also reports that alcohol involvement for large truck drivers involved in fatal crashes has declined 75 percent since 1982, the first year that the Fatality Analysis Reporting System (FARS) included data for alcohol involvement in

National Highway Traffic Safety Administration [Moonesinghe, 2003] published An Analysis of Fatal Large Truck Crashes, which focuses on 1996 – 2000 and provides a detailed analysis about the characteristics of large truck fatal crashes.

8.2 Safety Comparison Among Truck Configurations

U.S. General Accounting Office [1994] concluded that the safety of longer combination vehicles is unknown and recommended that US Department of Transportation improve truck accident data, especially as they relate to the reporting of nonfatal accidents, the estimates of truck travel, and the identification of truck configuration. As a result, Federal Highway Administration (FHWA) provided grants under the Intermodal Surface Transportation Efficiency Act of 1991 to states to adopt the uniform accident reporting form and data elements recommended by the National Governors' Association (NGA), including data on truck configurations. NGA categorizes vehicle configurations as follows:

- Bus (>15 seats including driver)
- Single unit truck (2 axle, 6 tire)
- Single unit truck (3 or more axles)
- Truck/trailer
- Truck tractor (bobtail)
- Tractor/semi-trailer
- Tractor/doubles
- Tractor/triples
- Heavy truck, unclassified

However, even with this new classification, determining the relative safety hazards of LCVs with respect to other large trucks is still difficult, if not impossible. For example, the category of Tractor/doubles includes the tractor-trailer combination containing two 28-foot trailers, Rocky Mountain double and turnpike double.

FHWA improved Fatality Analysis and Reporting System (FARS) and started reporting in 2001 the truck configuration data according to NGA's specifications [Transportation Research Board, 1990].

FARS is the repository of data about traffic accidents involving fatalities. Based on FARS, Large Truck Crash Facts 2001 reports large trucks in crashes by truck configuration; see Table 8.

Table 8: 2001 Large Trucks in Crashes by Truck Configuration

Truck Configuration	Fatal	Fatal Percentage	Injury	Injury Percentage
Single Unit Truck (two axles, 6 tires)	613	12.8%	5,409	14.2%
Single Unit Truck (three or more axles)	535	11.2%	4,122	10.8%
Single Unit Truck (unknown # of axles)	183	3.8%	0	0%
Truck/Trailer(s)	53	1.1%	4,220	11.1%
Truck Tractor (Bobtail)	113	2.4%	1,203	3.2%
Tractor/Semi-Trailer(one trailer)	2,977	62.1%	18,053	47.4%
Tractor/Doubles (two trailers)	166	3.5%	713	1.9%
Tractor/Triples (three trailers)	16	0.2%	47	0.1%
Unknown	143	3.0%	1,039	2.7%
Missing			3,255	8.6%
Total	4,793	100.0%	38,061	100.0%

Since no data about vehicle miles travel are available at this detail level, no crash rates can be calculated. FARS still does not provide sufficient detail for comparing safety. Other ways of comparing safety between LCVs and Non-LCVs must be found.

8.3 Safety Comparison Between LCVs and Non-LCVs

U.S. General Accounting Office [1994] stated, "Many traffic data bases fail to identify LCV configurations, making it difficult to determine their safety record. The limited data

available from a few states and several large companies indicate that LCVs have not been a safety problem on the turnpikes and western highways where they have operated. Whether this record could be maintained in heavier traffic is open to question.”

“Effort to study the accident rates of multiple-trailer trucks have reached differing conclusions concerning the safety of LCVs. Weaknesses in the data at both the national and state levels as well as differing study approaches contributed to the differences. For example, the lengths of trailers are rarely recorded on accident forms, making it impossible to separate accidents involving turnpike or Rocky Mountain doubles from those involving the double 28-foot trailers operated nationwide. Also, very little mileage data on LCVs are available, this making it difficult to compare accident rates of LCVs with those of single-trailer trucks.”

American Automobile Association (AAA) Foundation for Traffic Safety is concerned about trucking safety for obvious reasons and published a report entitled Longer Combination Vehicles Safety Data Collection. The report states, “In 1999 and 2000, the AAA Foundation for Traffic Safety conducted a research program to identify barriers to analysis of large truck safety experience in the United States. The primary focus was on so-called Longer Combination Vehicles (LCVs) - the "doubles" and "triples" running on major highways throughout the country. Five states (Florida, Idaho, Nevada, Oregon, and Utah) participated in a review and evaluation of their data collection and analysis practices. Two of the states (Oregon and Utah) also participated in an audit of completed crash reports for crashes involving large trucks and specifically doubles and triples.”

It also states, “The results show that none of the five states has a crash reporting system that adequately supports the analysis of LCV safety. In general, there is a lack of reliable data on the exact configuration of vehicles involved in crashes, as well as a lack of specific measures of exposure for LCVs. Without good data on configuration and good measures of exposure, the main question about LCV safety (i.e., are they more or less safe than other large commercial motor vehicles?) cannot be answered empirically. The report concludes with a series of recommendations for improving the quality of data on crashes involving large trucks and for improving the states' ability to analyze LCV crashes specifically.”

Now, we focus on the accident rate of LCVs, when compared to the other large trucks. Although we will not be able to pinpoint the benefit of off-tracking reduction on LCV safety improvement, we like to point out some recent conclusions about the safety of LCV operations. The consensus seems to be that LCV operations are not more unsafe than the operations of the other large trucks. We focus on four recent studies: the 2000 Comprehensive Truck Size and Weigh Study, two studies using proprietary databases, and a Canadian study focused on Canadian LCV operations.

8.4 The 2000 Comprehensive Truck Size and Weigh Study

Due to the data inadequacy just mentioned, the 2000 Comprehensive Truck Size and Weight Study [Federal Highway Administration, 2000] compared the safety record of

tractor-semitrailers to that of the STAA doubles (plus a small percentage of the other doubles that are Longer Combination Vehicles) as a way to compare the safety hazards between tractor-semitrailer combinations and multi-trailer combinations. The rationale is that all LCVs are multi-trailer combinations and the behavior and hence safety hazards of LCVs can be approximated by those of the STAA doubles, which are also multi-trailer combinations.

After normalized to the vehicle miles travel for single trailer combinations, which is set to 100, the relative fatal crash rates of personal vehicles (including automobiles, light trucks, and sport utility vehicles), single-unit trucks, single-trailer combinations and multi-trailer combinations are: 57:51:100:97.

Although this analysis points out similar fatal crash rates for single-trailer and multi-trailer combinations, 2000 Comprehensive Truck Size and Weight Study warned about the extrapolation of this result. First, it is well known that crash rates are lower for better-equipped roads, e.g., the Interstate System. Second, it is also well known that fatal crash rates are higher in areas of higher traffic density. The Study suggested adjustments to the relative crash rates.

Since 53% of vehicle miles traveled (VMT) by single-trailer combinations are on the Interstate System and 62% of the VMT by multi-trailer combinations are on the Interstate System, the relative crash rates for the single-trailer and multi-trailer combinations were revised to 100:111. In other words, the fatal crash rate for LCVs is about 10% higher than that for the tractor-semitrailer combinations.

The Study noted that 72% truck accidents occurred on essentially the eastern half of the US, where higher traffic density is significantly higher than that of the western half. It suggested that if LCV operation is expanded to the whole nation, the relative crash rate of LCVs will be higher than 111 because of higher exposure to traffic conflict. However, the Study did not propose a numerical measure of the additional risk.

The 2000 Comprehensive Truck Size and Weight Study [Federal Highway Administration, 2000] did not reach a definite conclusion about the relative or absolute fatal crash rate for LCVs. In fact, it stated, "Using data from Utah, which collects the LCV crash data in the needed detail, the FHWA effort determined that, (1) over 20 years of data collection would be required in order to compute statistically reliable crash rates for long double- and triple-trailer combinations, and (2) these rates would be for Interstate highways only. If data were also available from four other states in which LCVs now operate, this time would be reduced to 6 to 8 years; but still the rate could only be applied to Interstate highways. Although not typically, LCVs do operate on non-Interstate highways to a small extent, which means that even more time would be needed to estimate their crash experience on these highways."

There are alternative data sources, and a small number of research projects have been completed and reported in the literature. However, they do not provide a definitive answer either.

8.5 An FHWA Study Entitled “Longer Combination Vehicles Involved In Fatal Crashes, 1991 – 1996”

The Office of Motor Carrier and Highway Safety of The Federal Highway Administration published a report entitled “Longer Combination Vehicles Involved in Fatal Crashes, 1991 – 1996 in September 1999, based on data from the University of Michigan’s Trucks Involved in Fatal Accidents (TIFA) file. Table 9 provides the number of combination trucks involved in fatal crashes.

Table 9: The number of combination trucks involved in fatal crashes.

LCVs	1991	1992	1993	1994	1995	1996	Total	Percent
Overlength	15	16	13	10	19	14	87	39%
Overweight	2	12	6	17	10	9	56	25%
Both	7	14	9	13	20	5	68	31%
Triple Trailers	0	3	1	2	1	3	10	5%
LCV Total	24	45	29	42	50	31	221	100%
STAA Doubles	135	132	139	116	122	145	789	
Tractor-Semitrailers	2,659	2,478	2,635	2,799	2,667	2,943	16,181	

Regarding the geographical distribution of fatal crashes involving LCVs, the report states, “There were 33 LCVs involved in fatal crashes in Michigan during 1991 – 1996; this was 15 percent of the national total. Only eight other states averaged more than one LCV involvement in a fatal crash per year, and all are in the far West.” The LCVs involved in fatal crashes has fluctuated between 24 and 50 per year over the 6 years, with an average of 37 per year. 132 STAA doubles and 2,865 non-LCV tractor-semitrailers per year were involved in fatal crashes in the six years.”

Regarding the percentage of fatal crashes that involved LCVs, the report states, “Of the 17,191 truck combinations involved in fatal crashes examined here [in 1991-1996], 221 (1.3 percent) were LCVs. Of these, 10 were triple-trailer combinations. The operation of LCVs is limited to very few roads. The limitations under which LCVs operate are reflected in the miles they travel. According to the 1997 highway cost allocation study conducted by the FHWA, LCVs accounted for 2 percent of all miles driven by the combination trucks in 1994.”

We briefly discuss the US truck fleet and the vehicle miles traveled to put the LCVs’ share in a proper context. Table 10 summarizes what the 2000 Comprehensive Truck Size and Weight Study reports about the composition of the US truck fleet and the VMT for various categories. In 1994, the total truck VMT was approximately 168 billion; California accounts for 10% of this total (16.8 billion).

Table 10: US Truck Fleet and Vehicle Miles Traveled*

Trucks	% of All Trucks	% of All Combination Trucks	% of All Trucks VMT	% of Combinations VMT
Single Unit	68%	N/A	42%	N/A
(Single Unit) Truck-Plus-Trailer Combinations	4%	14%	<2%	<3.5%
Tractor-Semitrailer Combinations (primarily 5 axles)	26%	82%	53%	91.4%
Double Trailer Combinations, including STAAs, RMDs and TDs	2%	STAA D: 4.5%	STAA: 2.6% RMD+TD: 1%	STAA: 4.5% RMD+TD: 1.8%
Triple-trailer Combinations	<0.1%	<0.3%	<0.06%	<0.1%
Total Number	1.3 million truck-tractors; 4.1 trailers	416,000 (20,000 LCVs; 1.5% of trucks)	168,000,000	97,400,000 (<2% for all LCVs)

*Best estimates based on 2000 Comprehensive Truck Size and Weight Study. Data inconsistency exists in that report.

Note that 2000 Comprehensive Truck Size and Weight Study reports two different and inconsistent sets of 1994 estimates for the total number commercial trucks in the US and distribution of the number among various categories of trucks.

The total number of commercial trucks in 1994 is obtained by summing all the numbers associated with 15 non-overlapping categories in Table 1 of the Summary Report, and the number is 2,390,034. However, in Chapter 3 of Volume II, it is stated, “In 1994, the total commercial truck fleet consisted of approximately 1.3 million truck-tractors and 4.1 million trailers, including semitrailers.” In addition to the inconsistency in the total number, the distribution is also inconsistent. For example, in the Summary Report, the category of tractor-semitrailer combinations is reported to account for 61% of the US truck fleet in 1994. However, in Chapter 3 of Volume II, the same category is reported to account for only 26%. Such inconsistency made it difficult to put the safety data in a proper context and added to the complexity of this and similar research projects.

In the Summary Report, it is stated, “Longer combination vehicles, which includes double-trailer combinations with 7 or more axles and triples, currently account for less than 1 percent of all trucks and just over 1 percent of all truck VMT.” Despite the inconsistencies in the total number and in the distribution, the reported percentages of

LCVs are low and are in the 1% to 2% range and the reported percentages of the LCV VMT are also low and are again in the 1% to 2% range.

Longer Combination Vehicles Involved in Fatal Crashes [Federal Highway Administration, 1999] concluded, “Based on the data presented in this brief, no conclusions can be made on the relative safety of LCVs compared to other truck combinations. First, data on mileage driven mentioned above are based strictly on trailer number and length, while the definition of LCV used in this study (ISTEA) is based partly on weight. Second, since travel by LCVs is rare, it is difficult to calculate the precise number of miles driven. Similarly, LCV fatal crashes are so infrequent that the number varies greatly from year to year. For example, LCV crashes dropped from 46 in 1992 to 31 in 1993 (down 33 percent), then rose to 43 in 1994 (up 39 percent). Based on the existing data, LCVs do not appear to be considerably more or less safe than other combination trucks. A more definitive conclusion could be reached only after further collection of data and additional analysis.”

8.6 An FHWA Study Entitled “Accident Rates For Longer Combination Vehicles”

The Federal Highway Administration [1996] funded The Scientex Corporation for a research project entitled “Crash Rates for Longer Combination Vehicles” The objectives of that research study, conducted for the Office of Motor Carriers and Highway Safety (OMCHS), were (1) to determine the relative crash rates – in crashes per million vehicle miles of travel – of LCVs and non-LCVs and (2) to determine the relative crash rates for LCV and non-LCV subgroups, including Tractors-Semitrailers, STAA Doubles, Rocky Mountain Doubles, Turnpike Doubles, and Triples.

The survey methodology, which employed a stratified systematic sample, involved site visits to commercial motor carriers that operate LCVs. Mileage and crash data, covering periods of up to five years, were collected from participating carriers and used to calculate and compare crash rates for LCV and non-LCV configurations. Where practical, comparisons in crash rates among LCV subgroups were also calculated. The differential impacts, if any, which key external factors – area, route, terrain, time-of-day, and driver experience – had on LCV and Non-LCV crash outcomes were also assessed. The severity of LCV versus non-LCV crashes was examined as well.

According to the study, the mean accident rate for LCVs per 100 million vehicle miles traveled was 0.88 compared with 1.79 for non-LCVs, and the difference was judged as statistically significant. LCV travel amounted to 22% of the vehicle-miles analyzed in the study, but accounted for only 12% of truck-related accidents. By contrast, non-LCVs accounted for 79% of the study's VMT but were involved in 88% of the accidents. Among LCVs, triple-trailer units had the lowest mean accident rate per 100 million vehicle miles, followed by Rocky Mountain doubles and turnpike doubles, according to the report. However, these accident rates were derived without consideration of roadway quality, traffic density or driver skill level. Therefore, as in the other studies already discussed, the analysis was not conclusive.

The study was the first on LCV safety of national scope that involved input from carriers. Seventy-five trucking companies in 17 states, all of which operate standard tractor-trailers as well as triples and other longer combinations, participated in the study. The study involved review of accident records and personnel interviews between January 1994 and October 1996.

8.7 A Canada Safety Council Study Entitled “Literature Review of The Safety of Long Combination Vehicles and Their Operation in Canada”

Canada Safety Council [2003], a non-profit and non-government organization, funded a study entitled “Literature Review of the Safety of Long Combination Vehicles and their Operation in Canada” and issued a final report on June 30, 2003.

The study found that, based on the safety records about LCV operations in the province of Saskatchewan (as part of the safety review of “the Special Haul programs”), Trialpha Consulting Limited [2000] determined the collision rate of LCVs to be 0.15 collisions per million vehicle kilometers, which was estimated to be one-fifth that of the provincial total for the normal fleet. This LCV collision rate and its comparison to the rate for the entire fleet are based on existing data and existing operations and may include the effect of other uncontrolled factors, e.g., road quality, traffic density, driver experience, etc.

The study stated, “While accident involvement rates of LCV’s are clearly less than those of single trailer trucks in general operations, the LCV’s are operated on higher quality road and normally with more experienced drivers. Taking these factors into account makes the relative safety of these vehicles, on a per mile basis less clear. After addressing these differences, several studies conclude that LCV’s have similar or slightly higher accident involvement rates compared to single trailers. However, some studies show LCV’s with better accident involvement rates. Some studies have shown LCV’s to have higher fatal accident involvement rates, which the researchers attribute to the higher mass of the larger vehicles.”

The study concluded, “Overall, it would appear that there is little difference in accident involvement rates of LCV’s and other trucks when operated under similar conditions of weather, road and driver experience. However, the use of LCV’s means fewer kilometers of travel (reduced exposure), compared to single trailer vehicles to move the same volume of freight. For example, a turnpike double would require 50% of the vehicle kilometers to move the same volume of freight; Rocky Mountain Doubles about 63% and triple about 58%. When these exposure factors are taken into consideration, LCV’s exhibit lower accident involvement rates than standard trucks, assuming constant freight demand.”

8.8 Safety-Improvement Potential of Reduction of Off-Tracking Through Automated Trailer Steering

Since the technology of automated trailer steering can be used to improve the safety of all large trucks, we discuss below how the technology can help improve the safety of large

truck operations. We examined the literature as well as queried the FARS database to explore the potential.

We first provide a trend about accident rate for large trucks in the past few years in order to paint a “big picture.” Since the most significant safety benefit of ATS is reduction of off-tracking and off-tracking is a serious problem when a large truck is making a turn or negotiating a curve, we then focus on these two maneuvers. We also focus on the 2004 data as an example.

Table 11 summarizes fatality counts involving crashes with a medium or large truck. Note that the fatality counts seem stable. Given the increasing vehicle miles traveled, the crash rate per 100 million miles travel has been decreasing as reported earlier in this Part. (Large Truck Crash Facts 2001 reports that over the last 20 years (1981 to 2001), the fatal crash rate for large trucks (including both single-unit trucks and combination trucks) has declined from 4.5 fatal crashes per 100 million miles traveled to 2.1 fatal crashes per 100 million miles traveled, a 53 percent decrease.)

Table 11: Persons Killed in Crashes Involving a Medium/Heavy Truck, by Person Type and Crash Type, 1994 – 2004

Year	Person Type					Total
	Truck Occupants by Crash Type			Other Vehicle Occupants	Nonmotorists	
	Single Vehicle	Multiple Vehicles	Total			
1994	451	219	670	4,013	461	5,144
1995	425	223	648	3,846	424	4,918
1996	412	209	621	4,087	434	5,142
1997	499	224	723	4,223	452	5,398
1998	486	256	742	4,215	438	5,395
1999	480	279	759	4,180	441	5,380
2000	484	270	754	4,114	414	5,282
2001	474	234	708	3,962	441	5,111
2002	449	240	689	3,886	364	4,939
2003	457	269	726	3,919	391	5,036
2004	466	295	761	4,006	423	5,190

We now focus on 2004 data about fatal crashes and use the Fatality Analysis and Reporting System (FARS) database for our data analysis. Table 12 reveals that 3,453 large trucks are involved in 2004 fatal crashes.

Table 12: 2004 Crash Facts for All vehicles and Large Trucks

Count Category	Count for All Vehicles	Count for Large Trucks (Excluding Single-Unit Trucks and “Bob-Tails”)*
Fatal Crashes	38,253	3,157
Vehicles Involved	58,414	3,453
Persons Killed	100,227	3,880

*A bobtail is a tractor hauling no trailers at all

The configuration distribution of the 3,453 large trucks involved in a 2004 fatal crash is revealed in Table 13.

Table 13: Configuration of the 3,453 Large Trucks Involved in a 2004 Fatal Crash

Vehicle Configuration	Total
Truck/Trailer(s)	86
Tractor/Semi-Trailer(one trailer)	3,074
Tractor/Doubles (two trailers)	169
Tractor/Triples (three trailers)	0
Medium/Heavy Truck, cannot classify vehicle configuration	124
Total	3,453

As indicated earlier, it is not possible to tell how many of the two-trailer Tractor/Doubles are either Rocky mountain doubles or Turnpike doubles.

Next, we look into the maneuvers of the large trucks made immediately before the crash. Table 14 results from a query to the FARS database.

It seems that automated trailer steering may help in cases where the large truck involved in a fatal crash was making a turn (right or left) and negotiating a curve. Such maneuvers account for 417 out of the 3,453 large trucks involved.

We look into the configuration distribution of the trucks involved in crashes while negotiating a curve; see Table 15.

Table 14: Maneuvers of Large Trucks Made Immediately Before the 2004 Crashes

Vehicle maneuver	Total
Blank	0
Going Straight	2,499
Slowing or Stopping in Traffic Lane	102
Starting in Traffic Lane	22
Stopped in Traffic Lane	197
Passing or Overtaking Another Vehicle	37
Leaving a Parked Position	2
Parked	3
Entering a Parked Position	4
Controlled Maneuver to Avoid an Animal, Pedestrian, Object, Another Veh., etc.	48
Turning Right: RTOR Permitted	7
Turning Right: RTOR Not Permitted	0
Turning Right: RTOR Not Known if Permitted or RTOR Not Applicable	37
Turning Left	132
Making a U-turn	18
Backing Up (other than for parking purposes)	21
Changing Lanes or Merging	61
Negotiating a Curve	241
Other	15
Unknown	7
Total	3,453

Table 15: Configuration of Trucks in a Fatal Crash While Negotiating a Curve

Vehicle Configuration	Total
Truck/Trailer(s)	4
Tractor/Semi-Trailer(one trailer)	228
Tractor/Doubles (two trailers)	7
Tractor/Triples (three trailers)	0
Medium/Heavy Truck, cannot classify vehicle configuration	2
Unknown if Light or Medium/Heavy Truck/Bus	0
Total	241

It turns out that the vast majority of the trucks involved in a fatal crash while negotiating a curve are tractor-semitrailer combinations. To clarify to what extent, automated trailer steering may help in this situation, we look into the manner of collision with Table 16.

Table 16: Manner of Collision for Large Trucks in a Fatal Crash While Curving

Manner Of Collision	Total
Blank	0
Not Collision with Motor Vehicle in Transport	123
Front-to-Rear (includes Rear-End)	11
Front-to-Front (includes Head-On)	32
Front-to-Side, Same Direction	5
Front-to-Side, Opposite Direction	31
Front-to-Side, Right Angle (includes Broadside)	8
Front -to-Side/Angle - Direction Not Specified	2
Sideswipe - Same Direction	4
Sideswipe - Opposite Direction	22
Rear-to-Side	0
Rear-to-Rear	0
Other (End Swipes and Others)	3
Unknown	0
Total	241

It turns out that about half of the fatal crashes that occurred while negotiating a curve do not involve a collision with another vehicle. Presumably, these crashes are rollovers. As mentioned earlier, automated trailer steering may help in reduction of rollover risks; investigation of this potential is a worthy subject of future research. However, rollovers have nothing to do off-tracking, and hence automated trailer steering cannot help in this situation, at least not until validation by further research. Those crashes listed in the table that involve collision on either the side of the large truck or the other vehicle(s) are candidates that can be helped by the technology of automated trailer steering. These amount to 72 crashes, which accounts for only 2% of the 3,453 large-truck fatal crashes. To pinpoint which one can indeed benefit from the technology requires more details about the collisions but the data are not available.

To clarify to what extent, automated trailer steering may help in reducing the crash risk while a large truck is making a turn, we look into the configuration distribution of the large trucks involved in a fatal crash while making a turn with Table 17.

Table 17: Configuration of Trucks Involved in a Fatal Crash While Turning

Vehicle Configuration	Total
Truck/Trailer(s)	8
Tractor/Semi-Trailer(one trailer)	159
Tractor/Doubles (two trailers)	7
Tractor/Triples (three trailers)	0
Medium/Heavy Truck, cannot classify vehicle configuration	2
Total	176

Again, it turns out that the vast majority of the trucks involved in a fatal crash while making a turn are tractor-semitrailer combinations. To clarify to what extent, automated trailer steering may help in this situation, we look into the manner of collision with Table 18.

Table 18: Manner of Collision for Large Trucks in a Fatal Crash While Turning

Manner of Collision	Total
Blank	0
Not Collision with Motor Vehicle in Transport	30
Front-to-Rear (includes Rear-End)	26
Front-to-Front (includes Head-On)	12
Front-to-Side, Same Direction	10
Front-to-Side, Opposite Direction	39
Front-to-Side, Right Angle (includes Broadside)	55
Front -to-Side/Angle - Direction Not Specified	0
Sideswipe - Same Direction	2
Sideswipe - Opposite Direction	1
Rear-to-Side	0
Rear-to-Rear	0
Other (End Swipes and Others)	0
Unknown	1
Total	176

Table 18 shows that 30 crashes involving a large truck while it is making a turn involve no collision with other motor vehicles in transport. This 17% is quite small when compared to the 50% associated with the crashes involving a large truck while it is negotiating a curve.

Table 18 also shows that 107 of the 176 crashes involve a collision on the side of one of the vehicles. No data are available to allow us to discern whether off-tracking caused or contributed to the crashes. These 107 crashes account for 3% of the 3,453 crashes having taken place in 2004, and this 3% may serve as an upper bound for the possible safety benefit in reducing fatal crashes that occurred when the large truck is making a turn. This 3% and the corresponding 2% for large-truck crashes having occurred while negotiating a curve may suggest 5% as an upper bound for the possible safety benefit in reducing large-truck fatal crashes that occurred in 2004.

Finally, we look into the large-truck crashes in which the initial impact point of the large truck is the side. Monnesinge et al. [2003] reported that, in 17% of all fatal crashes that occurred between 1996 and 2000, the initial impact point of the large truck is the side. More details can be found in Table 19.

Table 19: Impact Points of Two-Vehicle Combination Truck Crashes, 1996 – 2000

Impact Point of Comb. Truck	Impact Point of the Other Vehicle						Total
	Front	Side	Rear	% Front	% Side	% Rear	
Front	3,219	2,894	778	30%	27%	7%	64%
Side	1,648	230	35	15%	2%	0%	17%
Rear	1,755	80	25	16%	2%	0%	18%
Total	6,622	3,204	838	61%	31%	7%	100%

These analyses could provide only a vague sense of an upper bound of the benefit of off-tracking reduction on the safety of large truck operations.

9. CONCLUSION

Low-speed off-tracking occurs when the wheels of the rearmost trailer axle traverse a path inside the path of the tractor's front steering axle. We examined low-speed off-tracking for articulated systems with 1, 2 and 3 trailers at a low speed of $V_x = 5$ ft/sec (or 3.4 miles/hour) during a 90-degree turn. For a case of three trailers, off-tracking is reduced from 3.7 ft to 0.6 ft. We also examined high-speed off-tracking for 1-, 2-, and 3-trailer systems with a forward speed of $V_x = 50$ ft/sec (or 34.2 miles/hour) during a 90-degree turn. For a case of three trailers, the severe off-tracking of 22 ft is reduced significantly to 4 ft. These drastic reductions of off-tracking can benefit the operations of all large trucks, including the ubiquitous tractor-semitrailer combinations, STAA doubles and LCVs.

Automated trailer steering can provide safety benefit for all existing large trucks, including non-LCVs and LCVs. However, the degree of the benefit is difficult to assess. The reason is that current data about traffic accidents, particularly the data maintained by the Fatality Analysis and Reporting System (FARS), do not venture to pinpoint the root cause of the accidents. Our data analysis produced 5% as a preliminary upper bound for

the percentage of the fatal accidents whose occurrence may be avoided or whose effect may be reduced by the new technology of automated trailer steering.

Perhaps a real potential of the new technology of automated trailer steering lies in the expansion of LCV operations. Although virtually all analyses of existing data on the safety of LCV operations (taking place within the roadway network in which LCVs are current permitted to operate) concluded that LCV operations are no more unsafe than non-LCV operations, it is impossible to predict what the LCV crash rates will be when LCVs are allowed to operate on lower-quality roads or in denser vehicular traffic. It is entirely possible that expansion of LCV operations into non-Interstate and non-primary state routes or into urban or suburban areas may lead to significantly higher LCV crash rates if the expanded operations are based on the current fleet technology. However, advanced technologies like automated trailer steering may make a big difference in LCV operational safety.

The non-safety potential of automated trailer steering for expansion of LCV operations is perhaps more tangible. A primary source of benefit is reduction of cost for infrastructure modification. Major sources of infrastructure costs for expansion of LCV operations include bridge replacement, modification of existing interchanges and intersections, provision of staging areas at highway entrances and exits, provision of truck lanes on steep hills, etc. Automated trailer steering can help reduce the costs associated with modifying existing interchanges and intersections because such modifications are needed primarily because of LCV off-tracking. It can also help reduce the costs associated with the provision of the staging areas because, with automated trailer steering, LCVs can travel beyond highways and reach freight facilities without requiring major modifications of roadway geometry.

In response to a GAO request for an estimate of the total infrastructure cost required for nationwide use of LCVs, FHWA projected \$248 million for bridge replacement on rural interstates and \$1.1 billion for bridge replacement on urban interstates and also provided the range of \$750 million to \$2.2 billion for access improvement (including interchange improvement and staging area construction). We believe that, with the technology of automated trailer steering, access improvement will not be needed and hence only \$1.3 billion is required. The range of savings will be from \$750 million to \$2.2 billion, i.e., from 36% to over 60% of the total infrastructure improvement cost. This potential saving is drastic.

However, in the more thorough study of 2000 Comprehensive Truck Size and Weight Study, percentage of saving with respect to the total infrastructure cost is much less significant. Despite the \$7.9 billion saving potential of automated trailer steering for infrastructure modification, it becomes much less significant when the estimated total bridge replacement cost of \$206 billion, the estimated total traffic-delay cost of \$266 billion and the estimated pavement cost of \$196 billion due to construction are considered. Moreover, when the operational cost for a 20-year planning horizon (including recurrent congestion cost and fuel cost) is also considered, the estimated total cost of nationwide LCV use becomes a whopping \$7,654 billion. As a result, the \$7.9

billion potential saving due to automated trailer steering barely accounts for 1% of the total cost.

This again argues that the major contribution of automated trailer steering and other advanced vehicle control technologies may lie mostly in their enabling a safe nationwide use of LCVs, particularly on lower-quality roads and in dense vehicular traffic. If nationwide LCV use is proven safe, the estimated total cost for a 20-year planning horizon will be \$7,652 billion. Although the saving of \$53 billion from the estimated total cost of \$7,705 billion of a base case is less than 1%, the cost saving of \$568 billion for shippers (from \$4,980 billion to \$4,412 billion) is not only significant in terms of the large quantity but also in terms of large percentage – almost 15%.

The benefit of automated trailer steering in enabling short trailer combination vehicles (STCV) will be the subject of Part IV. The benefit is significant for various demand and operating scenarios. The reader is referred to Part IV for a detailed discussion.

The new technology of automated trailer steering will not only drastically reduce off-tracking but may also improve trailer handling. A major problem reported by Caltrans (1984) is the constant swaying of triples, and the potential benefit of automated trailer steering for solving this problem is a worthy subject for future research. This technology also has the potential of reducing the effect of rearward amplification of lateral acceleration, which is a major cause for vehicle instability in general and for rollover after a sudden evasive maneuver in specific. High-speed off-tracking is not a big issue for LCVs if the driver can position the tractor appropriately in the lane. However, this assumption may not be realistic. We demonstrate in Part III that this technology can drastically reduce high-speed off-tracking. A more useful result of this technology at high speeds than reduction of off-tracking may be better vehicle stability and reduced rollover hazards. This is a worthy subject for future research.

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**AUTOMATIC STEERING FOR CONVENTIONAL TRUCK TRAILERS:
DEVELOPMENT AND ASSESSMENT OF OPERATING CONCEPTS FOR
IMPROVING SAFETY, PRODUCTIVITY AND PAVEMENT DURABILITY**

FINAL REPORT

PART III:

**EFFECT OF MULTI-AXLE STEERING ON OFF-TRACKING AND DYNAMIC
LATERAL RESPONSE OF ARTICULATED TRACTOR-TRAILER COMBINATIONS**

Effect of Multi-Axle Steering on Off-tracking and Dynamic Lateral Response of Articulated Tractor-Trailer Combinations

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Abstract: Multi-axle steering systems with a tractor and one, two, and three full trailers are studied to investigate the effect of additional steering on off-tracking phenomena during a 90-degree turn at low and high speeds. Lateral responses of these systems to a high-speed lane-change manoeuvre are also investigated. A linear yaw plane model is employed to study the performance characteristics. We examine the dependence of critical speeds on the location(s) of trailer steering axle(s) via a linear stability analysis. Our analysis shows that adding non-steered trailers reduces system stability considerably. However, trailer steering reduces drastically both high- and low-speed off-tracking during a 90-degree turn. Additional advantages of trailer steering include reduction in lateral forces, reduction in yaw and slip velocities and the concomitant increase in directional stability.

Keywords: longer combination vehicle, LCV, heavy truck, off tracking, trailer steering, lateral dynamics and control.

Nomenclature

Tractor:

c_1	Cornering stiffness of front wheel
c_2	Cornering stiffness of rear wheel
f_{yf}	Lateral force in front wheel
f_{yr}	Lateral force in rear wheel
f_{x_1}	Longitudinal force in front wheel
f_{x_2}	Longitudinal force in rear wheel
I_1	Principal yaw moment of inertia of the mass of tractor
m_1	Total mass of tractors
S_1	Distance between the front axle and mass centre
S_2	Distance between the mass center and rear axle
V_x	Speed in the x direction
V_y	Sideslip velocity
δ_f	Steering angle of the front wheel
ϕ	Rotation angle of tractor

Trailers: (1, 2, and 3 respectively)

c_3, c_5, c_7	Cornering stiffness of front wheel
c_4, c_6, c_8	Cornering stiffness of rear wheel
$f_{t_1}, f_{t_3}, f_{t_5}$	Lateral forces in front wheels
$f_{t_2}, f_{t_4}, f_{t_6}$	Lateral forces in rear wheels
$f_{x_3}, f_{x_5}, f_{x_7}$	Longitudinal forces in front wheels
$f_{x_4}, f_{x_6}, f_{x_8}$	Longitudinal forces in rear wheels
I_2, I_3, I_4	Principle yaw moments of inertia
m_2, m_3, m_4	Total masses of trailers
S_3, S_7, S_{11}	Distances between the hitch and rear wheel of the preceding unit
S_4, S_8, S_{12}	Distances between front axle and the preceding hitch
S_5, S_9, S_{13}	Distances between front axle and mass centre of trailers
S_6, S_{10}, S_{14}	Distances between mass centre and rear axles
$\delta r_1, \delta r_2, \delta r_3$	Steering angles of trailers' front wheel

Connecting hinges:

ψ_1	Angle between tractor and trailer 1
ψ_2	Angle between trailer 1 and trailer 2
ψ_3	Angle between trailer 2 and trailer 3
F_{x_1}, F_{y_1}	Coupling reaction forces in connecting point between tractor and trailer 1
F_{x_2}, F_{y_2}	Coupling reaction forces in connecting point between trailer 1 and trailer 2
F_{x_3}, F_{y_3}	Coupling reaction forces in connecting point between trailer 2 and trailer 3

1 Introduction

Off-tracking has been a major source of concern for the operations associated with heavy articulated tractor-trailer systems and, in particular, a class of large trucks called longer combination vehicles (LCVs). It refers to the phenomenon that rear wheels of a trailer do not follow the track of the front wheels of the tractor. This is a safety hazard, particularly to the surrounding vehicles, and often causes damage to the infrastructure. When operating at high speeds, these systems may develop lateral velocities and accelerations that can in turn reduce system stability. However, high productivity and efficiency gains may be realized through these modes of transportation. These are some of the motivating factors for understanding the lateral dynamics of these systems and for developing control mechanisms to enhance the safety of these modes of transportation. This paper focuses on lateral dynamics.

Harkey et al. (1996) studied the operational characteristics of three major configurations of LCVs: Rocky Mountain doubles (consisting of a tractor-semitrailer plus a trailer up to 28 feet), turnpike doubles (consisting of a tractor and two trailers up to 48 feet each) and triples (consisting of a tractor and three trailers up to 28 feet each). Based on the policy on geometric design of highways and streets recommended by American Association of State Highway and Transportation Officials (AASHTO), Harkey et al. conclude that off-tracking is a major safety, infrastructure-integrity and traffic-operation concern for Rocky Mountain doubles and turnpike doubles while making turns on intersections or interchanges at low to medium speeds. They also conclude that off-tracking experienced by LCVs while traveling on a freeway at high speeds can be accommodated by freeways designed according to the AASHTO policy if the driver positions the tractor appropriately. In addition to off-tracking, they also address phenomena of lateral instability, namely, the propensity to rollover, trailer sway and rearward amplification. Trailer sway refers to the lateral movement of multiple trailers. Safety problems associated with trailer sway can be significantly reduced by appropriate choice of lane widths. Rearward amplification, which occurs most often during a sudden steering movement, refers to the amplification of lateral acceleration of the tractor in the trailers. El-Gindy et al. (2001) developed control algorithms to reduce the rearward amplification of a truck-full trailer system. They used a performance measure “rearward amplification factor” (RWA), defined as the ratio of the peak lateral acceleration at the rearmost trailer’s centre of gravity to that of the lead unit (tractor) during a lane-change manoeuvre, as a control criterion in the design of vehicle-handling controller. Their simulation results show that the RWA can be reduced significantly without

significant changes to the uncontrolled vehicle's trajectory when active yaw torque is applied to the trailer unit.

A number of researchers have addressed the lateral dynamics of articulated systems. For example, during the 1970's, Ellis (1966, 1969) developed a plane motion model that approximated Newton's equations for a vehicle in motion. Hales (1963) and Jindra (1963), through their investigations into lateral stability of tractor-semitrailer systems, concluded that these systems may admit divergent oscillations if their tires' cornering stiffness levels are reduced below their nominal values. Mallikarjuna and Fencher (1978), Mallikarjunarao and Segel (1981), and Ervin and Mallikarjunarao (1981) studied the directional dynamics of articulated vehicles, yaw stability of tractor-semitrailer combinations and directional response characteristics of double tankers, respectively.

Aurell and Edlund (1989) investigated the effect of location of steered axles of the trailing units on dynamic stability of the system. They showed that lateral acceleration and minimum turning radius could be reduced and off-tracking improved with additional steering axles. Several studies have shown that active multi-axial steering mechanisms are successful in improving the lateral-stability characteristics for tractor-trailer systems. Chen and Tomizuka (2000), in their study on lateral control of tractor-semitrailer type commercial vehicles, showed that by applying coordinated steering and independent braking-force control, trailer yaw velocities could be reduced. Wu (1994, 2001) and Wu and Lin (2003) showed that active multi-axle steering could improve lateral stability characteristics, reduce lateral loads, and provide better manoeuvrability of the system.

Following Wu and Lin (2003), we extend their model for tractor and one trailer system to include up to two additional trailers and study the lateral dynamics of the resulting systems with multi-axle steering. The primary objective of this study is to investigate the effect of multi-axle steering on low- and high-speed off-tracking for systems with multiple trailers. In addition, we study its effect on lateral-stability characteristics. The 90-degree turn and lane-change manoeuvre have also been studied to ascertain the directional performance. A linear stability analysis has been performed to study the effect of locations of trailer steering axles on the stability and to determine the critical velocities and stability boundaries.

This paper is organized as follows. Section 2 develops a linear yaw plane model for tractor-trailer systems with one, two and three trailers. Section 3 addresses system performance based on the model developed in Section 2. Section 4 summarizes our stability analysis. Concluding remarks are given in Section 5.

2 Linear Yaw Plane Model

We extend the model developed by Wu and Lin (2003) for a tractor and one trailer to include up to two additional trailers. For Wu and Lin's tractor-and-one-trailer problem, there are three degrees of freedom corresponding to side slip velocity, yawing motion of the tractor and trailer, and the articulation angle between the tractor and the trailer. For a tractor-and-three-trailers system considered in this paper, the articulation angles between trailer 1 and trailer 2, and

between trailer 2 and trailer 3 provide two additional degrees of freedom, resulting in a five-degree-of-freedom motion. Only the front axle of a trailer is equipped with steering capability. Tractor and trailer units are considered as rigid masses with body-fixed coordinates centered on the mass centers of the units. Aerodynamic forces, rolling and pitching motions, braking inputs and the longitudinal forces generated by tires and road interactions are neglected. Lateral forces generated by tires and road interactions, which constitute the main influence on yaw dynamics and lateral stability, are of course included in the model. A schematic model of the articulated system is sketched in Figure 1.

Each wheel in this zero-vehicle-width model represents an axle. Using Newton's second law, equations of motion are derived for the tractor and trailer units. These equations are linearized under the small-displacements assumption. Further simplification is achieved by assuming steady forward speed. The steering angle δ_f of the tractor's front axle and the steering angles of the trailers' front axles δr_1 , δr_2 and δr_3 are assumed to be linearly related and given by $\delta r_1 = \mu_1 \delta_f$, $\delta r_2 = \mu_2 \delta_f$ and $\delta r_3 = \mu_3 \delta_f$, where μ_1, μ_2, μ_3 represent the steering ratio of trailer 1, trailer 2, and trailer 3, respectively. Side slip velocity of the tractor is denoted by V_y , the constant forward speed is denoted by V_x , yaw angle is denoted as ϕ , and the articulation between the tractor and trailer 1 is denoted by ψ_1 . Applying Newton's Second Law, the equations of motion for the tractor in $x - y$ body-fixed moving-coordinates are given as:

$$\begin{aligned} m_1(\dot{V}_x - \omega V_y) &= F_{x_1} - f_{x_2} - f_{x_1} \cos(\delta_f) - f_{y_f} \sin(\delta_f) \\ m_1(\dot{V}_x + \omega V_y) &= -F_{y_1} + f_{y_r} + f_{y_f} \cos(\delta_f) - f_{x_1} \sin(\delta_f) \\ I_1 \dot{\omega} &= dF_{y_1} - f_{y_r} S_2 + f_{y_f} S_1 \cos(\delta_f) - f_{x_1} S_1 \sin(\delta_f) \end{aligned} \quad (1)$$

where d is given in part 1 of the appendix. The equations of motion for trailer 1 in $x' - y'$ coordinates are given as:

$$\begin{aligned} m_2(\dot{V}_x' - V_y' \omega_1) &= F_{x_2} - f_{x_4} - F_{x_1} \cos(\psi_1) - F_{y_1} \sin(\psi_1) - f_{x_3} \cos(\delta r_1) - f_{t_1} \sin(\delta r_1) \\ m_2(\dot{V}_y' + V_x' \omega_1) &= -F_{y_2} + F_{y_1} \cos(\psi_1) - F_{x_1} \sin(\psi_1) + f_{t_2} + f_{t_1} \cos(\delta r_1) - f_{x_3} \sin(\delta r_1) \\ I_2 \dot{\omega}_1 &= lF_{y_2} - f_{t_2} S_6 + eF_{y_1} \cos(\psi_1) - eF_{x_1} \sin(\psi_1) + f_{t_1} S_5 \cos(\delta r_1) \end{aligned} \quad (2)$$

where e and l are given in part 1 of the appendix. Similarly, equations of motion for trailer-2 and trailer-3 in $x'' - y''$ and $x''' - y'''$ are as follows, given by equations (3) and (4) respectively:

$$\begin{aligned} m_3(\dot{V}_x'' - V_y'' \omega_2) &= F_{x_3} - f_{x_6} - F_{x_2} \cos(\psi_2) - F_{y_2} \sin(\psi_2) - f_{x_5} \cos(\delta r_2) - f_{t_3} \sin(\delta r_2) \\ m_3(\dot{V}_y'' + V_x'' \omega_2) &= -F_{y_3} + f_{t_4} + f_{t_3} \cos(\delta r_2) + F_{y_2} \cos(\psi_2) - F_{x_2} \sin(\psi_2) - f_{x_5} \sin(\delta r_2) \\ I_3 \dot{\omega}_2 &= nF_{y_3} - f_{t_4} S_{10} + mF_{y_2} \cos(\psi_2) - mF_{x_2} \sin(\psi_2) + f_{t_3} S_9 \cos(\delta r_2) - f_{x_5} S_9 \sin(\delta r_2) \end{aligned} \quad (3)$$

and

$$\begin{aligned}
m_4(V_x''' - V_y''' \omega_3) &= -f_{x_8} - F_{x_3} \cos(\psi_3) - F_{y_3} \sin(\psi_3) - f_{x_7} \cos(\delta r_3) - f_{t_5} \sin(\delta r_3) \\
m_4(V_y''' + V_x''' \omega_3) &= f_{t_6} + f_{t_5} \cos(\delta r_3) + F_{y_3} \cos(\psi_3) - F_{x_3} \sin(\psi_3) - f_{x_7} \sin(\delta r_3) \\
I_4 \dot{\omega}_3 &= -f_{t_6} S_{14} + q F_{y_3} \cos(\psi_3) - q F_{x_3} \sin(\psi_3) + f_{t_5} S_{13} \cos(\delta r_3) - f_{x_7} S_{13} \sin(\delta r_3)
\end{aligned} \tag{4}$$

where m , and q are given in part 1 of the appendix. Here

$$\omega = \frac{d\phi}{dt}, \omega_1 = \omega - \dot{\psi}_1, \omega_2 = \omega - \dot{\psi}_1 - \dot{\psi}_2, \omega_3 = \omega - \dot{\psi}_1 - \dot{\psi}_2 - \dot{\psi}_3, \text{ and the dot } (\dot{\bullet}) \text{ denotes } \frac{d}{dt}.$$

Since the lateral tire force is the major influence on the yaw dynamics and stability of the vehicle, we assume that the longitudinal forces denoted by f_{x_i} (for $i=1,8$) at tire i are zero. To obtain a linear model, we further assume that all the steering angles ($\delta_f, \delta r_1, \delta r_2$, and δr_3) and the articulation angles (ψ_1, ψ_2 , and ψ_3) to be small. Since the tractor and trailer units travel at constant forward speed and are connected at hinge pins, the velocities of the pins should be compatible. This leads to $V_x''' \approx V_x'' \approx V_x' \approx V_x$. Further, we have:

$$\begin{aligned}
V_y' &\approx V_y + V_x \psi_1 - (d+e)\omega \\
V_y'' &\approx V_y + V_x(\psi_1 + \psi_2) - (e+l+m)\dot{\psi}_1 + m\dot{\psi}_2 - (d+e+l+m)\omega \\
V_y''' &\approx V_y + V_x(\psi_1 + \psi_2 + \psi_3) - (e+l+m+n+V)\dot{\psi}_1 + (m+n+q)\dot{\psi}_2 + q\dot{\psi}_3 - (d+e+l+m+n+q)\omega.
\end{aligned} \tag{5}$$

Expressions for d, e, l, m, n and q are given in part 1 of the appendix.

The lateral tire forces f_{yf}, f_{yr} and f_{ii} (for $i=1, 6$) are assumed to be linear functions of the side slip angles (for reasonably small side slip angles). This assumption is expressed as:

$$\begin{aligned}
f_{yf} &= \alpha_1 c_1 \\
f_{yr} &= \alpha_2 c_2 \\
f_{ii} &= \alpha_{i+2} c_{i+2} \quad \text{for } (i=1, 6)
\end{aligned} \tag{6}$$

where α_j (for $j=1,8$) is the slip angle of the j^{th} wheel and c_j (for $j=1,8$) is the cornering stiffness coefficient of tire j . Using equations (5) and (6), the sideslip angle of each tire is obtained as:

$$\begin{aligned}
\alpha_1 &= \left(\frac{V_y + S_1 \omega}{V_x} \right) - \delta_f \\
\alpha_2 &= \left(\frac{V_y + S_2 \omega}{V_x} \right) \\
\alpha_3 &= \psi_1 + \left[\frac{V_y - (d + S_4) \omega + S_4 \psi_1}{V_x} \right] - \delta r_1 \\
\alpha_4 &= \psi_1 + \{V_y - (d + e + S_6) \omega + (e + S_6) \psi_1\} / V_x \\
\alpha_5 &= (\psi_1 + \psi_2) + \{V_y - (d + e + l + S_8) \omega + (e + l + S_8) \psi_1 + S_8 \psi_2\} / V_x - \delta r_2 \\
\alpha_6 &= (\psi_1 + \psi_2) + \{V_y - (d + e + l + m + S_{10}) \omega + (e + l + m + S_{10}) \psi_1 + (m + S_{10}) \psi_2\} / V_x \\
\alpha_7 &= (\psi_1 + \psi_2 + \psi_3) + \{V_y - (d + e + l + m + n + S_{12}) \omega + (e + l + m + n + S_{12}) \psi_1 + (m + n + S_{12}) \psi_2 + S_{12} \psi_3\} / V_x - \delta r_3 \\
\alpha_8 &= (\psi_1 + \psi_2 + \psi_3) + \{V_y - (d + e + l + m + n + q + S_{14}) \omega + (e + l + m + n + q + S_{14}) \psi_1 + (m + n + q + S_{14}) \psi_2 \\
&\quad + (q + S_{14}) \psi_3\} / V_x.
\end{aligned} \tag{7}$$

Eliminating the coupling reactions F_{xi}, F_{yi} (for $i=1,3$) from equations (1) - (4), we obtain the following 5-degrees-of-freedom model for the tractor and the three trailers:

$$[M]Q + [C]Q + [K]Q = \{L\} \delta_f \tag{8}$$

where:

$$Q = \{y \ \phi \ \psi_1 \ \psi_2 \ \psi_3\}^T.$$

In Equation (8), [M], [C] and [K] are 5×5 matrices with elements m_{ij} , C_{ij} , and K_{ij} (for $i=1,5$; $j=1,5$), respectively. {L} is a 5×1 column vector associated with steering input/force. Elements of [M], [C], [K] and {L} are presented in the appendix (part 1). System parameters needed for calculating the elements are also presented in appendix (part 2).

The tractor-and-one-trailer model can be obtained by setting $m_3, m_4, I_3, I_4, c_5, c_6, c_7$ and c_8 to zero in m_{ij} , c_{ij} and k_{ij} elements. This results in a three-degrees-of-freedom system. [M], [C], and [K] reduce to 3×3 matrices and {L} becomes a 3×1 column vector.

The tractor-and-two-trailers problem is obtained by setting m_4, I_4, c_7 and c_8 to zero in m_{ij}, c_{ij} , and k_{ij} elements. In this case, we have a four-degrees-of-freedom system. [M], [C] and [K] are now 4×4 matrices and {L} a 4×1 column vector.

3 Performance Characteristics

Off-tracking occurs when rear wheels of the trailer(s) do not follow the path traversed by the front wheels of the tractor during a turn. Low-speed off-tracking occurs when the wheels of the rearmost trailer axle traverse a path inside the path of the tractor's front steering axle. We examine low-speed off-tracking for articulated systems with 1, 2 and 3 trailers. Figure 2 demonstrates the effect of trailer (front-wheel) steering on off-tracking at a low speed of $V_x = 5$ ft/sec (or 3.4 miles/hour) during a 90-degree turn. Tractor's steering angle is 18 degrees for all the three systems. Trajectories of rearmost axles of the three systems and of the front axle of the tractor, with and without trailer steering, are shown. Figure 2(a) focuses on the case of one trailer where the trailer's front axle is steered with 36 degrees in the opposite direction (steering ratio = -2). Off tracking is reduced from 1.7 ft to 0.6 ft. In Figure 2(b), the first and second trailer's front axles are steered at 18 degrees in the opposite direction as that of the tractor (steering ratio = -1). Off tracking in this case is reduced from 2.2 ft to 0.7 ft. In Figure 2(c) all three trailers' front axles are steered at 23 degrees (steering ratio = -1.3). Off tracking in this case is reduced from 3.7 ft to 0.6 ft. For all the three cases, in comparison to the base cases of no trailer steering (steering ratio = 0), trailer steering has the benefits of (1) a smaller radius of turn for the same tractor front-wheel steering angle and (2) less off-tracking, i.e., a reduced distance between the paths of the tractor's front axle and the trailers' rear axle. With trailer steering, all the vehicles are able to successfully complete the sharp 90-degree turn within the lower bound of AASHTO-recommended curb radii of 40 ft for LCVs.

In high-speed off-tracking, the trailer units move outward due to lateral accelerations. We examine high-speed off-tracking for 1-, 2-, and 3-trailer systems with a forward speed of $V_x = 50$ ft/sec (or 34.2 miles/hour) and tractor steering angle of 3.6 degrees during a 90-degree turn. Figure 3(a) corresponds to the case of a tractor with one trailer. The trailer unit is steered at 6.3 degrees (steering ratio = 1.75). As in the case of low-speed turning, off-tracking, as measured by the maximum distance between the trajectory of the rear wheel of the trailer and that of the tractor's front wheel, is reduced from 7ft to 2.0 ft, and the whole combination negotiates a wider turn radius than for the case without trailer steering.

As shown in Figure 3(b) for the case of two trailers, we see a similar performance as the case of one trailer. Off-tracking is reduced from 18 ft to 3 ft, and the whole combination negotiates a wider turn radius. Trailer-1's front wheels are steered at 2.7 degrees (steering ratio = 0.75) in the same direction as the tractor's while trailer-2's front axle is steered at 4.5 degrees opposite of the tractor's steering direction (steering ratio = -1.25). In the case of three trailers as shown in Figure 3(c), trailer 1 front axle is steered at 4.3 degrees in the same direction as the front axle of the tractor (steering ratio = 1.2), trailer 2 is steered at 3.6 degrees opposite to tractor steering (steering ratio = -1.0), and trailer 3 is not steered.. We observe a result similar to those in the cases of one- and two-trailer systems. The severe off-tracking of 22 ft experienced by a three-trailer system without trailer steering is reduced significantly to 4 ft when the trailers' front wheels are also steered.

We study the handling characteristics of tractor-multi-trailer systems by examining the transient response of these systems subject to a sinusoidal forcing (input) for one period given by $\delta_f(t) = A \sin\left(\frac{2\pi}{T}t\right)$, where A is the amplitude and T is the time period of excitation. We note that this simulates a lane-change manoeuvre. The course layout for this manoeuvre is shown in Figure 4.

For a tractor-one-trailer system traveling at $V_x = 60$ ft/sec (or 41 miles/hour), the trajectories of the front wheels of the tractor and those of the rear wheels of the trailer, without and with trailer steering, are shown in Figures 5(a) and 5(b), respectively. For the case of no trailer steering, we have $A = 0.006$ and $T = 4$ seconds. To achieve the lateral movement (i.e., to complete the lane change) of the same magnitude with trailer steering, we have $A = 0.01$ and $T = 10$ seconds. With trailer steering, we observe that the lateral forces (given by equations (1) and (2)) are reduced considerably, as shown in Figure 5(c). In Figures 5(d) and 5(e), we see that the trailer slip and yaw velocities are smaller with trailer steering than without. Similar response is observed for two- and three-trailer systems.

Lateral forces are computed from equations (1) – (4). We focus on the medium speed of $V_x = 40$ ft/sec (or 27.3 miles/hour) for the cases of two trailers and three trailers. For the case of no trailer steering, we have $A=0.005$ and $T=8$ seconds for two trailers, and $A = 0.0043$ and $T = 8$ seconds for three trailers. With trailer steering, we have $A = 0.008$ and $T = 12$ seconds for the two-trailer system, and $A = 0.0043$ and $T = 16$ seconds for the three-trailer system to complete the lane change. Lateral forces, slip and yaw velocities shown in Figures 6 and 7 correspond to the cases of two- and three-trailer systems, respectively.

One of the major concerns for the operation of longer combination vehicles is safety. Trailer steering has been demonstrated to reduce the trailer yaw velocities, slip velocities and lateral forces, as shown in Figures 5 (a-e) for one trailer, in Figures 6 (a-e) for two trailers, and Figures 7 (a-h) for three trailers. This results in improved lateral-stability characteristics. We note that the critical velocities for which two- and three-trailer systems become unstable are lower than those for the one-trailer system. A linear stability analysis of these systems is considered in the next section.

4 Stability Analysis

We perform stability analysis, first by recasting the perturbation equations defined by (8) into its first order form:

$$[A]\{\dot{p}\} + [B]\{p\} = 0 \tag{9}$$

where:

$$\begin{aligned} \{p\} &= [\delta \phi \psi]^T && \text{(Tractor with one trailer)} \\ &= [\delta \phi \psi_1 \psi_2]^T && \text{(Tractor with two trailers)} \end{aligned}$$

$$= [\psi_1 \psi_2 \psi_3]^T. \quad (\text{Tractor with three trailers})$$

Matrices [A] and [B] are given in appendix (part 3). Here, the articulated systems move at a constant speed in a straight line, and the steering input is assumed to be zero. We assume a solution for equation (12) to be of the form:

$$\{p_i\} = \{d_i\}e^{\lambda_i t} \quad \begin{cases} i = 1, 2, 3, 4 & (\text{one trailer}) \\ i = 1, 2, \dots, 6 & (\text{two trailers}) \\ i = 1, 2, \dots, 8 & (\text{three trailers}) \end{cases}$$

where $\{d_i\}$ are constants and λ_i are eigenvalues of $[A]^{-1}[B]$, corresponding to cases of tractor with 1, 2 and 3 trailers, respectively. These systems are unstable, and the perturbations will grow with time if the real parts of eigenvalues (which may be real or complex) are positive. For complex eigenvalues with positive real parts, these systems exhibit divergent oscillations and eventual loss of stability. The critical velocity (V_{cr}) depends on the location of the trailers' steering axles, and we determine, for several such locations, the critical velocity (, at which the systems become unstable). We first consider the system of tractor and one trailer and determine the critical velocity for several values of S_4 , which denotes the distance between front axle of the first trailer and the preceding hitch. Next, for a given value of S_4 ($S_4 = 8ft$) and for the case of two trailers, critical velocities are determined for several values of S_8 , which denotes the distance between front axle of the second trailer and the preceding hitch. Similarly, critical velocities are determined for the 3-trailer system for several values of S_{12} ($S_4 = S_8 = 8.0ft$). Figure 8 shows the effect of steering-axle location on the stability of the systems. Regions below the curves correspond to stable systems. Adding trailers greatly reduces the stability region. The results show that the locations of trailers' steering wheels greatly influence the critical velocities and hence the lateral stability of the systems.

5 Conclusion

Performance and stability characteristics of a combination vehicle consisting of a tractor and multiple trailers have been investigated for the case of multi-axle steering and the case of its absence. Trailer steering reduces low- and high-speed off-tracking for a 90-degree turn. For low-speed 90-degree turns, trailer steering also reduces the minimum turning radius. For high-speed 90-degree turns, trailer steering causes the whole tractor-trailer(s) combination to negotiate a larger turn radius; it also achieves reduced off-tracking. During a lane-change manoeuvre, trailer steering results in lower lateral forces and lower yaw and slip velocities for a given magnitude of a change in lateral position. The particular values of steering ratios have been chosen in an *ad hoc* fashion to reduce off tracking significantly. In this paper, we studied the linear dynamics of a tractor with multiple trailer units and found that trailer steering in an effective mechanism to reduce off tracking for such systems. For a given sinusoidal steering, the tractor-trailer combinations without trailer steering experience a larger lateral movement resulting from larger yaw, slip and lateral forces than those with trailer steering. A linear stability analysis indicates that adding non-steered trailer(s) considerably reduces system lateral

stability and that the trailer steering-axle location plays a critical role in such stability. We note that implementation of automatic control should enable the appropriate levels of trailer steering and in turn reduce LCV off-tracking significantly. Developing such control algorithms and mechanisms is a worthy research subject for reducing the safety and infrastructure hazards associated with large-truck operations.

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Appendix

Part 1:

$$\begin{cases} d = S_2 + S_3 \\ e = S_4 + S_5 \\ l = S_6 + S_7 \\ m = S_8 + S_9 \\ n = S_{10} + S_{11} \\ q = S_{12} + S_{13} \end{cases}$$

[M]:

$$\begin{cases} m_{11} = m_1 + m_2 + m_3 + m_4 \\ m_{12} = -[m_2(d + e) + m_3(d + e + l + m) + m_4(d + e + l + m + n + q)] \\ m_{13} = [m_2e + m_3(e + l + m) + m_4(e + l + m + n + q)] \\ m_{14} = [mm_3 + m_4(m + n + q)] \\ m_{15} = m_4q \\ m_{21} = -d(m_2 + m_3 + m_4) \\ m_{22} = [dm_2(d + e) + dm_3(d + e + l + m) + dm_4(d + e + l + m + n + q) + I_1] \\ m_{23} = -[dm_2e + dm_3(e + l + m) + dm_4(e + l + m + n + q)] \\ m_{24} = d[mm_3 + m_4(m + n + q)] \\ m_{25} = dm_4q \end{cases}$$

$$\begin{cases}
m_{31} = -[(l+e)(m_3+m_4)+m_2e] \\
m_{32} = [(l+e)\{m_3(d+e+l+m)+m_4(d+e+l+m+n+q)\}+m_2e(d+e)+I_2] \\
m_{33} = -[(l+e)\{m_3(e+l+m)+m_4(e+l+m+n+q)\}+m_2e^2+I_2] \\
m_{34} = -(l+e)\{mm_3+m_4(m+n+q)\} \\
m_{35} = -m_4q(l+e) \\
\\
m_{41} = -[mm_3+(m+n)m_4] \\
m_{42} = [mm_3(d+e+l+m)+(m+n)(d+e+l+m+n+q)m_4+I_3] \\
m_{43} = -[mm_3(e+l+m)+m_4(e+l+m+n+q)+I_3] \\
m_{44} = -[m^2m_3+(m+n+q)(m+n)m_4+I_3] \\
m_{45} = -(m+n)m_4q \\
\\
m_{51} = -qm_4 \\
m_{52} = [qm_4(d+e+l+m+n+q)+I_4] \\
m_{53} = -[qm_4(e+l+m+n+q)+I_4] \\
m_{54} = -[qm_4(m+n+q)+I_4] \\
m_{55} = -(q^2m_4+I_4)
\end{cases}$$

[C]:

$$\begin{cases}
c_{11} = -(c_1+c_2+c_3+c_4+c_5+c_6+c_7+c_8)/V_x \\
c_{12} = [(m_1+m_2+m_3+m_4)V_x - \{c_1S_1 - c_2S_2 - c_3(d+S_4) - c_4(d+e+S_6) - c_5(d+e+l+S_8) \\
\quad - c_6(d+e+l+m+S_{10}) - c_7(d+e+l+m+n+S_{12}) - c_8(d+e+l+m+n+q+S_{14})\}/V_x] \\
c_{13} = -\{c_3S_4 + c_4(e+S_6) + c_5(e+l+S_8) + c_6(e+l+m+S_{10}) + c_7(e+l+m+n+S_{12}) \\
\quad + c_8(e+l+m+n+q+S_{14})\}/V_x \\
c_{14} = \{c_5S_8 + c_6(m+S_{10}) + c_7(m+n+S_{12}) + c_8(q+S_{14})\}/V_x \\
c_{15} = -\{c_7S_{12} + c_8(q+S_{14})\}/V_x \\
\\
c_{21} = \{c_2S_2 - c_1S_1 + d(c_3+c_4+c_5+c_6+c_7+c_8)\}/V_x \\
c_{22} = -[d(m_2+m_3+m_4)V_x + \{c_1S_1^2 + c_2S_2^2 + dc_3(d+S_4) + dc_4(d+e+S_6) + dc_5(d+e+l+S_8) \\
\quad + dc_6(d+e+l+m+S_{10}) + dc_7(d+e+l+m+n+S_{12}) + dc_8(d+e+l+m+n+q+S_{14})\}/V_x] \\
c_{23} = d\{c_3S_4 + c_4(e+S_6) + c_5(e+l+S_8) + c_6(e+l+m+S_{10}) + c_7(e+l+m+n+S_{12}) \\
\quad + c_8(e+l+m+n+q+S_{14})\}/V_x \\
c_{24} = d\{c_5S_8 + c_6(m+S_{10}) + c_7(m+n+S_{12}) + c_8(q+S_{14})\}/V_x \\
c_{25} = d\{c_7S_{12} + c_8(q+S_{14})\}/V_x
\end{cases}$$

$$\begin{cases}
c_{41} = \{S_8c_5 + c_6(m + S_{10}) + (m + n)(c_7 + c_8)\}/V_x \\
c_{42} = -\{[mm_3 + (m + n)m_4]V_x + [c_5S_8(d + e + l + S_8) + c_6(m + S_{10})(d + e + l + m + S_{10}) \\
+ (m + n)\{c_7(d + e + l + m + n + S_{12}) + c_8(d + e + l + m + n + q + S_{14})\}]/V_x\} \\
c_{43} = \{[S_8c_5(e + l + S_8) + c_6(m + S_{10})(e + l + m + S_{10}) + (m + n)\{c_7(e + l + m + n + S_{12}) \\
+ c_8(e + l + m + n + q + S_{14})\}]/V_x\} \\
c_{44} = \{c_5S_8^2 + c_6(m + S_{10})^2 + (m + n)[c_7(m + n + S_{12}) + c_8(m + n + q + S_{14})]/V_x\} \\
c_{45} = \{(m + n)[c_7S_{12} + c_8(q + S_{14})]\}/V_x \\
c_{51} = \{S_{12}c_7 + (q + S_{14})c_8\}/V_x \\
c_{52} = -\{qm_4V_x + [c_7S_{12}(d + e + l + m + n + S_{12}) + (q + S_{14})(d + e + l + m + n + q + S_{14})]/V_x\} \\
c_{53} = \{c_7S_{12}(e + l + m + n + S_{12}) + c_8(q + S_{14})(e + l + m + n + q + S_{14})\}/V_x \\
c_{54} = \{S_{12}c_7(m + n + S_{12}) + c_8(q + S_{14})(e + l + m + n + q + S_{14})\}/V_x \\
c_{55} = \{c_7S_{12}^2 + c_8(q + S_{14})^2\}/V_x
\end{cases}$$

$$\begin{cases}
c_{31} = \{(e + l)(c_5 + c_6 + c_7 + c_8) + c_4(e + S_6) + c_3S_4\}/V_x \\
c_{32} = -\{[(m_3 + m_4)(l + e) + m_2e]V_x + \{c_3S_4(d + S_4) + c_4(e + S_6)(d + e + S_6) + (e + l)[c_5(d + e + l + S_8) \\
+ c_6(d + e + l + m + S_{10}) + c_7(d + e + l + m + n + S_{12}) + c_8(d + e + l + m + n + q + S_{14})]\}/V_x\} \\
c_{33} = \{c_4(e + S_6)^2 + c_3S_4^2 + (e + l)(c_5(e + l + S_8) + c_6(e + l + m + S_{10}) + c_7(e + l + m + n + S_{12}) \\
+ c_8(d + e + l + m + n + q + S_{14}))\}/V_x \\
c_{34} = \{(e + l)[c_5S_8 + c_6(m + S_{10}) + c_7(m + n + S_{12}) + c_8(m + n + q + S_{14})]\}/V_x \\
c_{35} = \{(e + l)[c_7S_{12} + c_8(q + S_{14})]\}/V_x
\end{cases}$$

[K]:

$$\begin{cases}
k_{11} = k_{12} = k_{21} = k_{22} = k_{31} = k_{32} = k_{41} = k_{42} = k_{51} = k_{52} = 0 \\
k_{13} = -(c_3 + c_4 + c_5 + c_6 + c_7 + c_8) \\
k_{14} = -(c_5 + c_6 + c_7 + c_8) \\
k_{15} = -(c_7 + c_8) \\
k_{23} = d(c_3 + c_4 + c_5 + c_6 + c_7 + c_8) \\
k_{24} = d(c_5 + c_6 + c_7 + c_8) \\
k_{25} = d(c_7 + c_8) \\
k_{33} = \{(e + l)(c_5 + c_6 + c_7 + c_8) + c_4(e + S_6) + c_3S_4\} \\
k_{34} = (e + l)(c_6 + c_7 + c_8 + c_5) \\
k_{35} = (e + l)(c_7 + c_8)
\end{cases}$$

$$\begin{cases} k_{43} = \{s_8 c_5 + c_6(m + s_{10}) + (m + n)(c_7 + c_8)\} \\ k_{44} = \{s_8 c_5 + c_6(m + s_{10}) + (m + n)(c_7 + c_8)\} \\ k_{45} = (m + n)(c_7 + c_8) \\ k_{53} = k_{54} = k_{55} = \{S_{12}c_7 + (q + S_{14})c_8\} \end{cases}$$

{L}:

$$\begin{cases} L_{15} = -(c_1 + c_3\mu_1 + c_5\mu_2 + c_7\mu_3) \\ L_{15} = (c_1S_1 - dc_3\mu_1 - dc_5\mu_2 - dc_7\mu_3) \\ L_{35} = \{c_7(e+l)\mu_3 + c_5(e+l)\mu_2 + c_3S_4\mu_1\} \\ L_{45} = \{S_8c_5\mu_2 + (m+n)c_7\mu_3\} \\ L_{55} = c_7S_{12}\mu_3 \end{cases}$$

Part 2:

Data for tractor and trailer units (all trailer units considered in this paper are identical)

Tractor:

Weight, loaded = 15,000 lb;

$$I_1 = 16,000 \text{ lb-ft-sec}^2$$

$$S_1 = 8.4 \text{ ft}$$

$$S_2 = 3.6 \text{ ft}$$

$$S_3 = 3.0 \text{ ft}$$

$$c_1 = -14.766 \text{ lb/rad}$$

$$c_2 = -29,532 \text{ lb/rad}$$

Trailer Units:

Weight, loaded = 12,000 lb

$$I_1 = I_2 = I_3 = 9,250 \text{ lb-ft-sec}^2$$

$$S_4 = S_8 = S_{12} = 8.0 \text{ ft}$$

$$S_5 = S_9 = S_{13} = 5.5 \text{ ft}$$

$$S_6 = S_{10} = S_{14} = 4.5 \text{ ft}$$

$$c_3 = c_4 = c_5 = c_6 = c_7 = c_8 = -17,089 \text{ lb/rad}$$

Part 3:

Tractor and one trailer:

$$[A] = \begin{bmatrix} m_{11} & m_{12} & m_{13} & 0 \\ m_{21} & m_{22} & m_{23} & 0 \\ m_{31} & m_{32} & m_{33} & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}, [B] = \begin{bmatrix} c_{11} & c_{12} & c_{13} & k_{13} \\ c_{21} & c_{22} & c_{23} & k_{23} \\ c_{31} & c_{32} & c_{33} & k_{33} \\ 0 & 0 & -1 & 0 \end{bmatrix}$$

Tractor and two trailers:

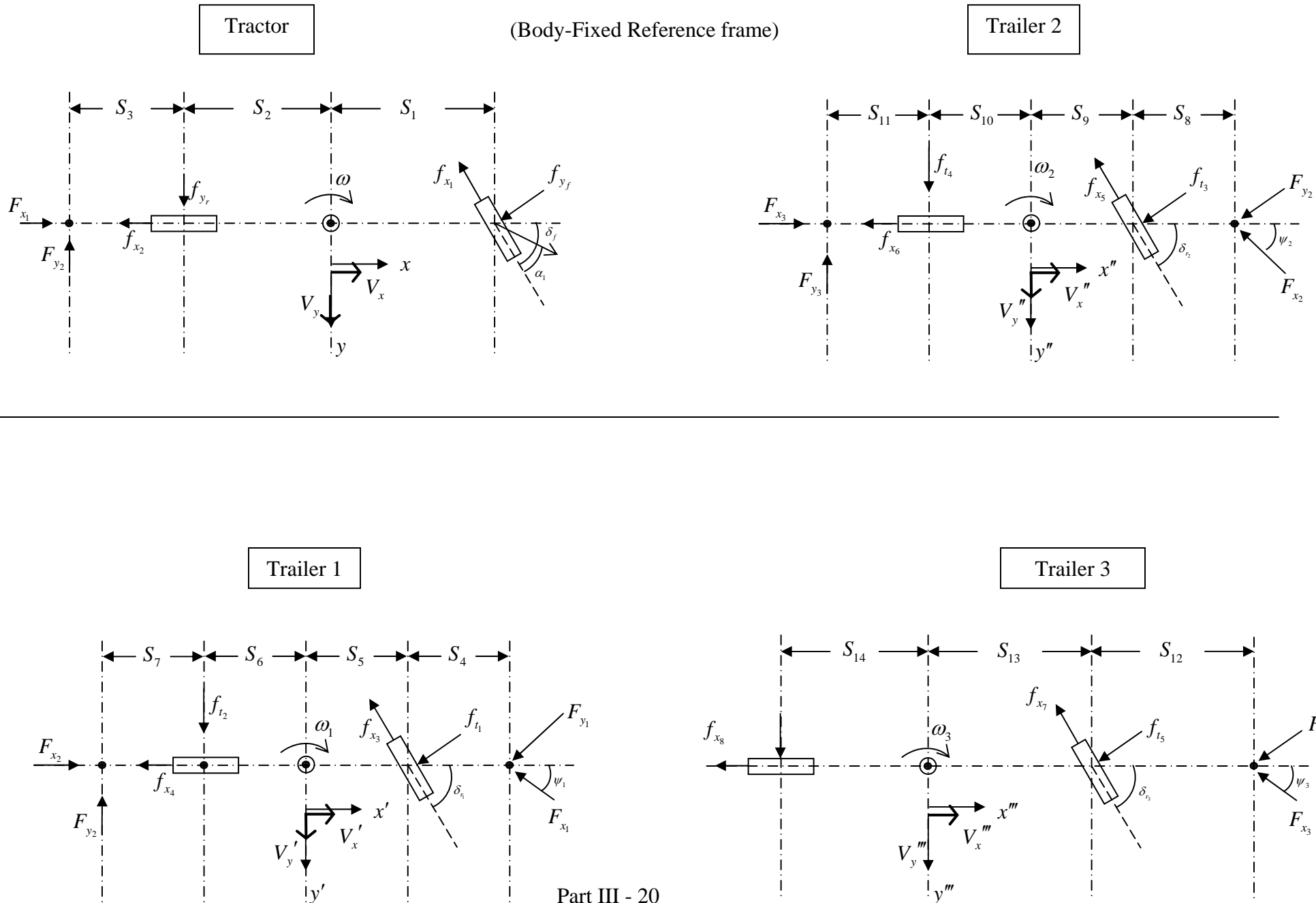
$$[A] = \begin{bmatrix} m_{11} & m_{12} & m_{13} & m_{14} & 0 & 0 \\ m_{21} & m_{22} & m_{23} & m_{24} & 0 & 0 \\ m_{31} & m_{32} & m_{33} & m_{34} & 0 & 0 \\ m_{41} & m_{42} & m_{43} & m_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}, [B] = \begin{bmatrix} c_{11} & c_{12} & c_{13} & c_{14} & k_{13} & k_{14} \\ c_{21} & c_{22} & c_{23} & c_{24} & k_{23} & k_{24} \\ c_{31} & c_{32} & c_{33} & c_{34} & k_{33} & k_{34} \\ c_{41} & c_{42} & c_{43} & c_{44} & k_{43} & k_{44} \\ 0 & 0 & -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 & 0 & 0 \end{bmatrix}$$

Tractor and three trailers:

$$[A] = \begin{bmatrix} m_{11} & m_{12} & m_{13} & m_{14} & m_{15} & 0 & 0 & 0 \\ m_{21} & m_{22} & m_{23} & m_{24} & m_{25} & 0 & 0 & 0 \\ m_{31} & m_{32} & m_{33} & m_{34} & m_{35} & 0 & 0 & 0 \\ m_{41} & m_{42} & m_{43} & m_{44} & m_{45} & 0 & 0 & 0 \\ m_{51} & m_{52} & m_{53} & m_{54} & m_{55} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}, [B] = \begin{bmatrix} c_{11} & c_{12} & c_{13} & c_{14} & c_{15} & k_{13} & k_{14} & k_{15} \\ c_{21} & c_{22} & c_{23} & c_{24} & c_{25} & k_{23} & k_{24} & k_{25} \\ c_{31} & c_{32} & c_{33} & c_{34} & c_{35} & k_{33} & k_{34} & k_{35} \\ c_{41} & c_{42} & c_{43} & c_{44} & c_{45} & k_{43} & k_{44} & k_{45} \\ c_{51} & c_{52} & c_{53} & c_{54} & c_{55} & k_{53} & k_{54} & k_{55} \\ 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 & 0 & 0 & 0 \end{bmatrix}$$

Figure Captions

- Figure 1 Linear Yaw plane model for a system of a tractor and 3 trailers.
- Figure 2 The 90-degree turn trajectories of tractor and trailers at low speed ($V_x = 5 \text{ ft/sec}$) and $\delta_f = 0.1\pi$: (a) Tractor-and-one-trailer system, (b) Tractor-and-two-trailers system, (c) Tractor-and-three-trailers system.
- Figure 3 The 90-degree turn trajectories of tractor and trailers at high speed ($V_x = 50 \text{ ft/sec}$) and ($\delta_f = 0.02\pi$) (a) Tractor-and-one-trailer system (b) Tractor-and-two-trailers system ($\delta_f = 0.02\pi$) (c) Tractor-and-three-trailers with ($\delta_f = 0.02\pi$).
- Figure 4 Course lay out for lane-change simulation.
- Figure 5 Lane-change manoeuvre for one trailer ($V_x = 60 \text{ ft/sec}$) (a) Trajectories of tractor and trailer with $\mu_1 = 0$, (b) Trajectories of tractor and trailer with $\mu_1 \neq 0$, (c) Comparison of lateral force with $\mu_1 = 0$ and $\mu_1 \neq 0$, (d) Comparison of trailer slip velocity with $\mu_1 = 0$ and $\mu_1 \neq 0$, (e) Comparison of trailer yaw velocity with $\mu_1 = 0$ and $\mu_1 \neq 0$.
- Figure 6 Lane-change manoeuvre for two trailers ($V_x = 40 \text{ ft/sec}$) (a) Trajectories of tractor and trailers ($\mu_1 = \mu_2 = 0$), (b) Trajectories of tractor and trailers for $\mu_1 \neq 0$ and $\mu_2 \neq 0$, (c) Comparison of lateral forces with $\mu_1 = 0$ and $\mu_1 \neq 0$, (d) Comparison of trailer slip velocities with $\mu_1 = 0$ and $\mu_1 \neq 0$, (e) Comparison of trailer yaw velocities with $\mu_1 = 0$ and $\mu_1 \neq 0$.
- Figure 7 Lane-change manoeuvre for three trailers ($V_x = 40 \text{ ft/sec}$) (a) Trajectories of tractor and trailers $\mu_1 = 0, \mu_2 = 0, \mu_3 = 0$, (b) Trajectories of tractor and trailers with $\mu_1 \neq 0, \mu_2 \neq 0, \mu_3 \neq 0$, (c) Lateral forces with $\mu_1 = \mu_2 = \mu_3 = 0$, (d) Lateral forces with $\mu_1 \neq 0, \mu_2 \neq 0, \mu_3 \neq 0$, (e) Yaw velocities of trailers with $\mu_1 = \mu_2 = \mu_3 = 0$, (f) Yaw velocities of trailers with $\mu_1 \neq 0, \mu_2 \neq 0, \mu_3 \neq 0$, (g) Slip velocities of trailers with $\mu_1 = \mu_2 = \mu_3 = 0$, (h) slip velocities of trailers with $\mu_1 \neq 0, \mu_2 \neq 0, \mu_3 \neq 0$.
- Figure 8 Critical velocities vs. distances between front axle and hitches of the trailers (S_4, S_8, S_{12}).



Part III - 20
Figure 1

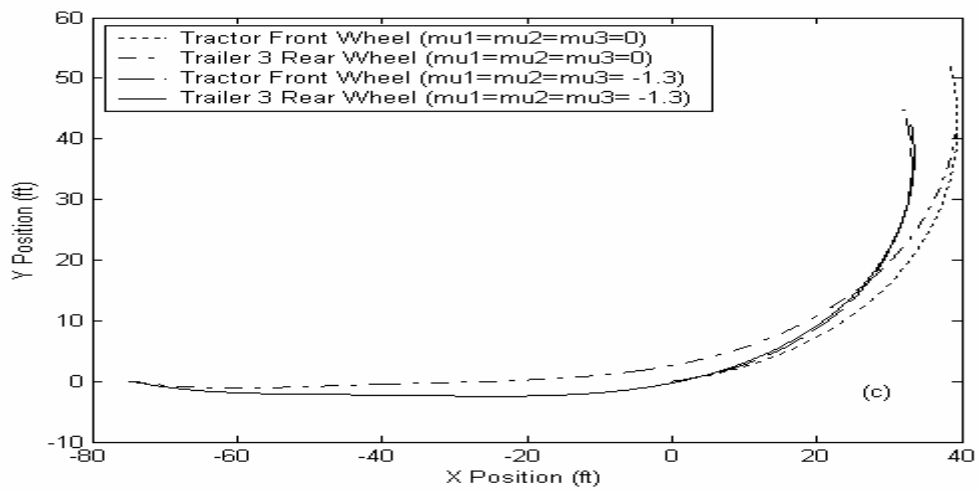
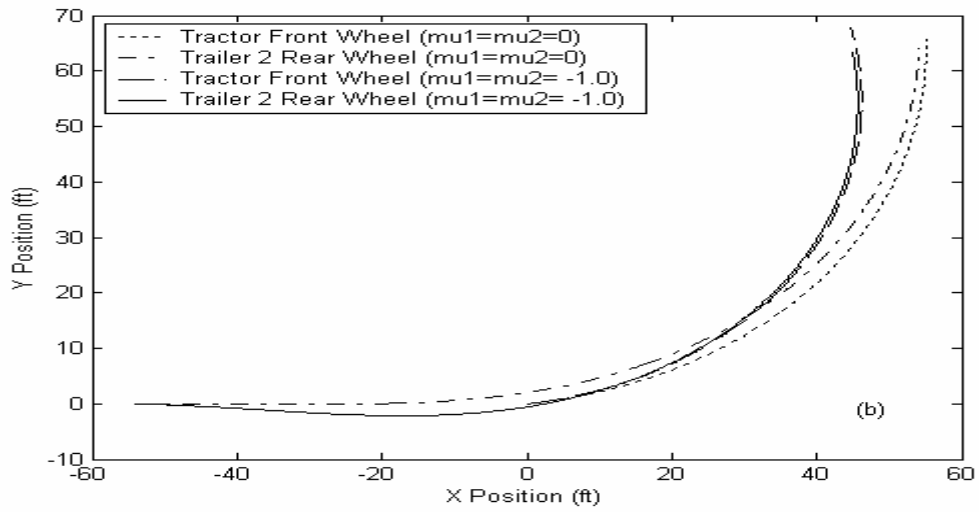
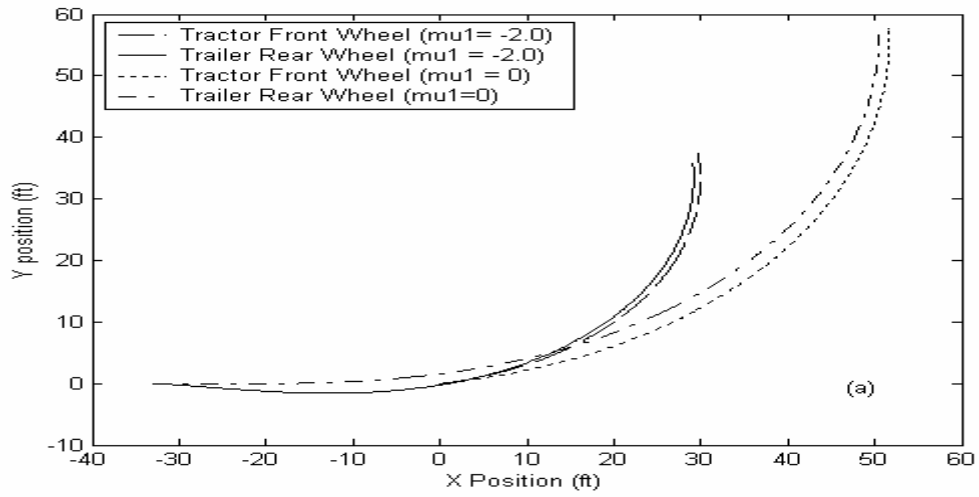


Figure 2 (a, b, c)

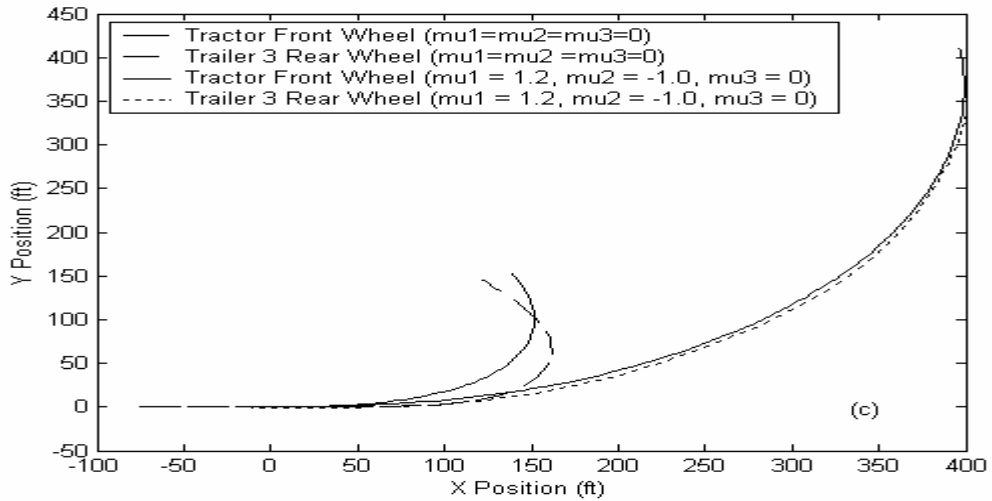
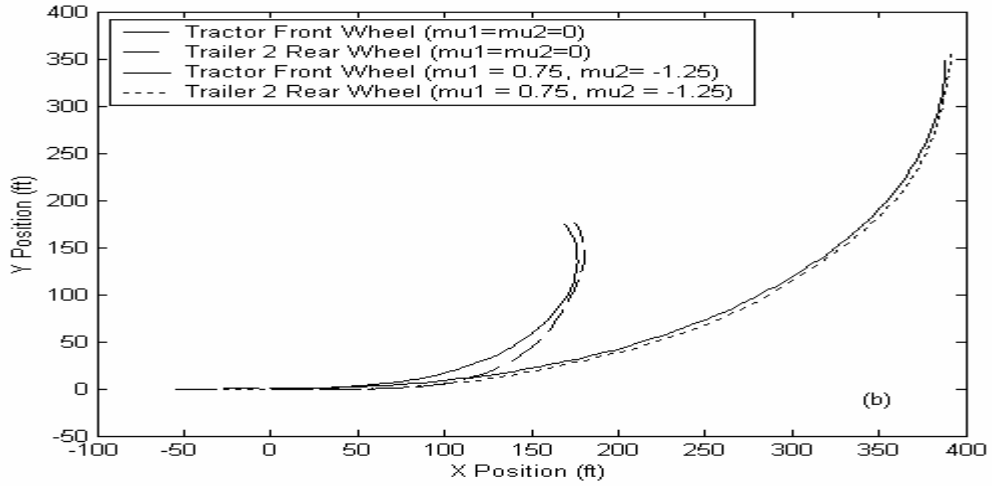
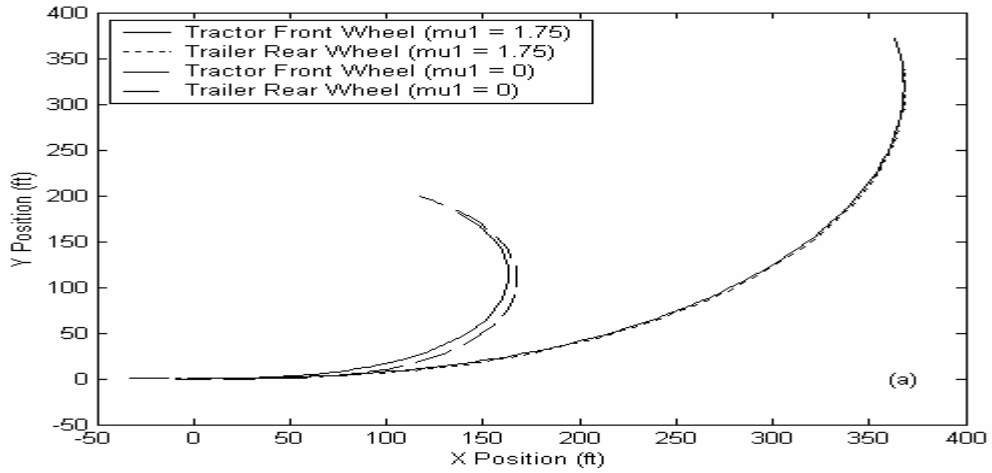


Figure 3(a, b, c)

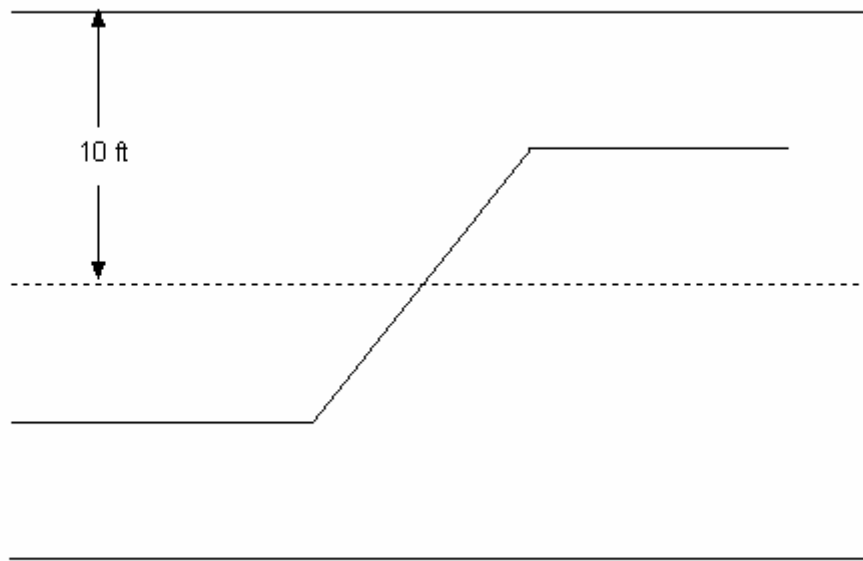


Figure 4

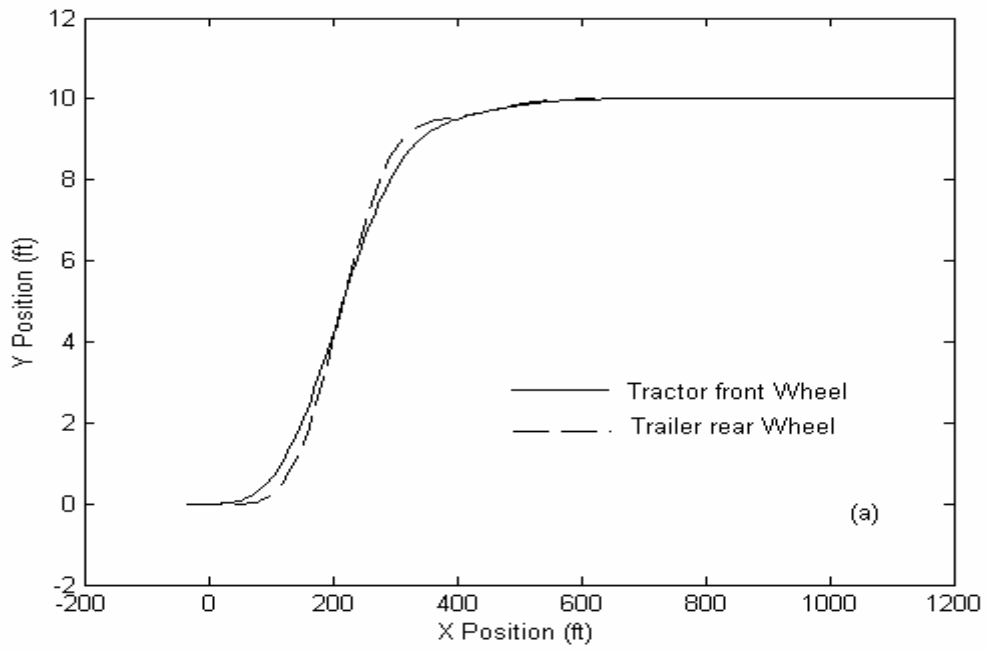


Figure 5(a)

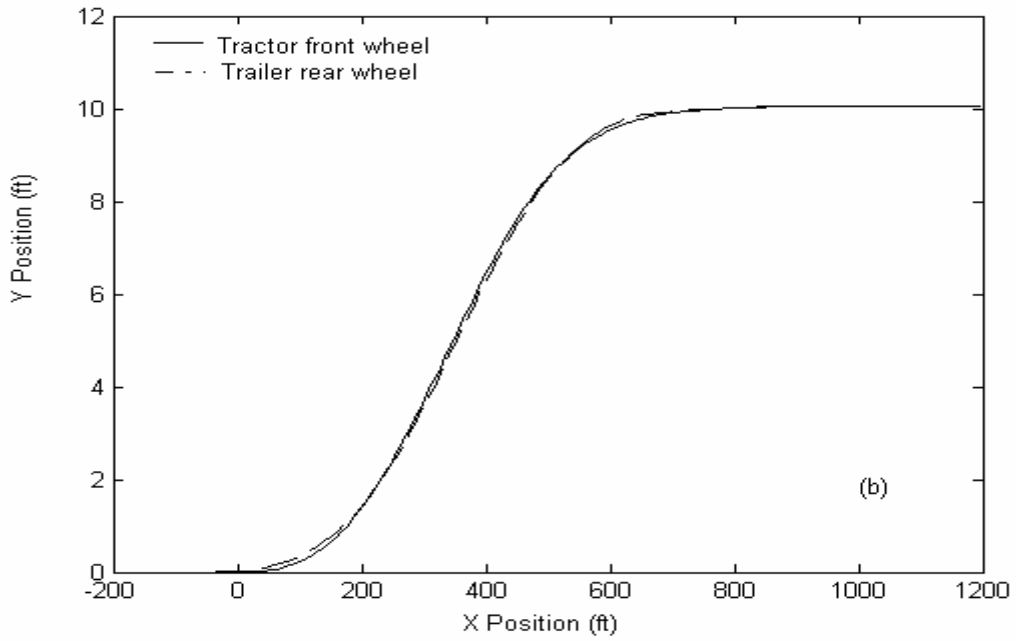


Figure 5(b)

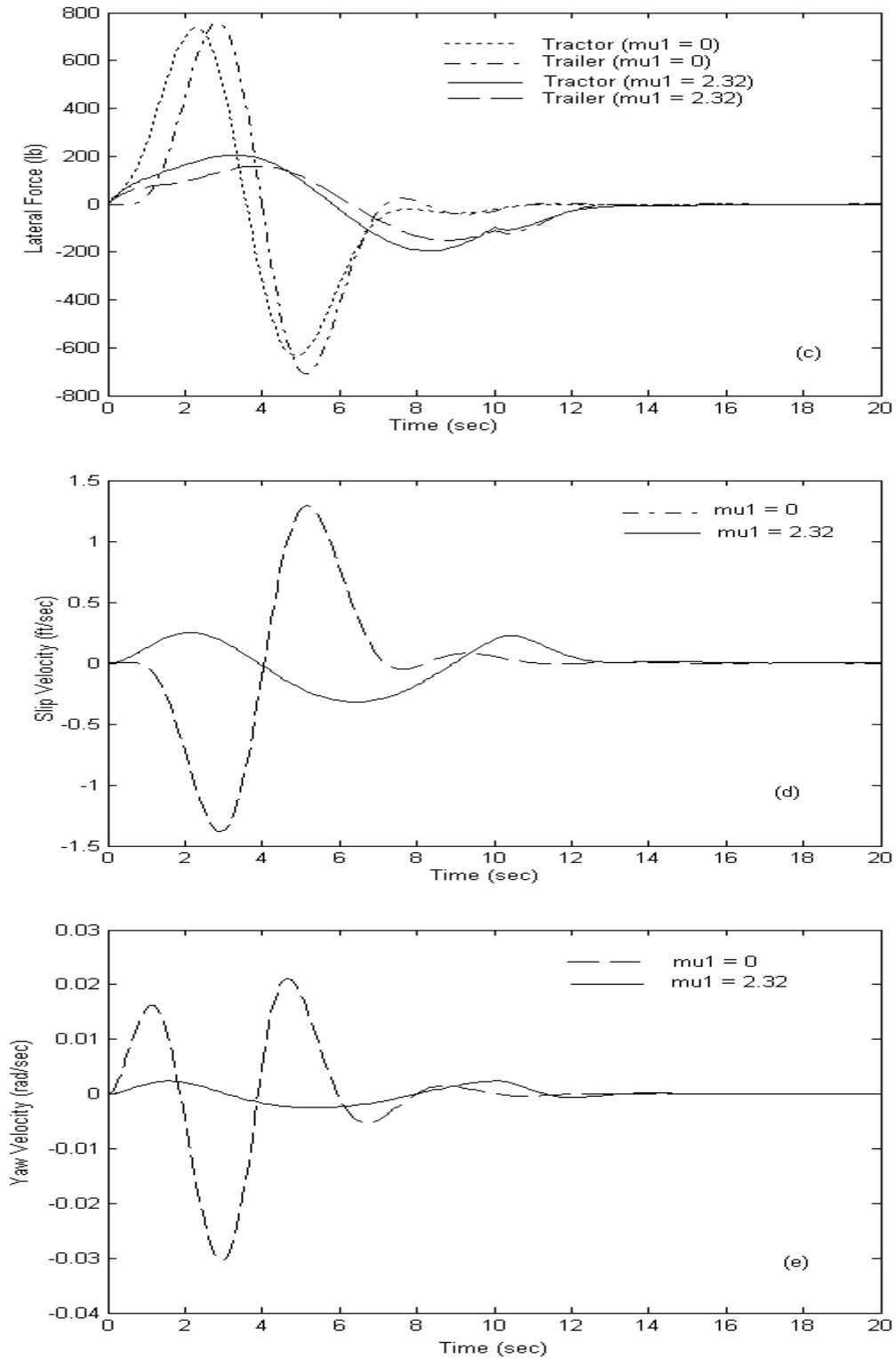


Figure 5(c, d, e)

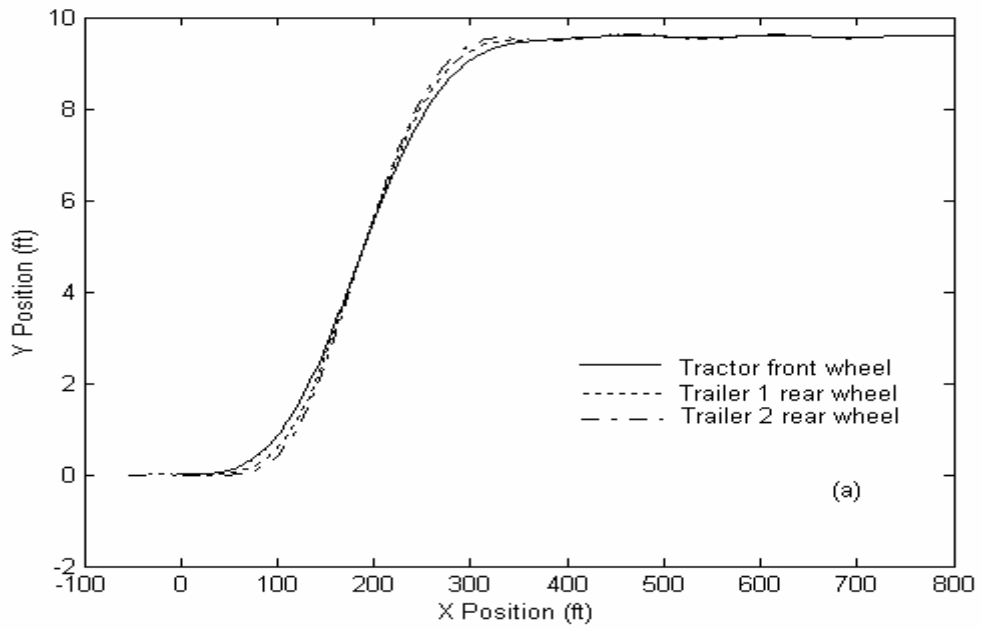


Figure 6(a)

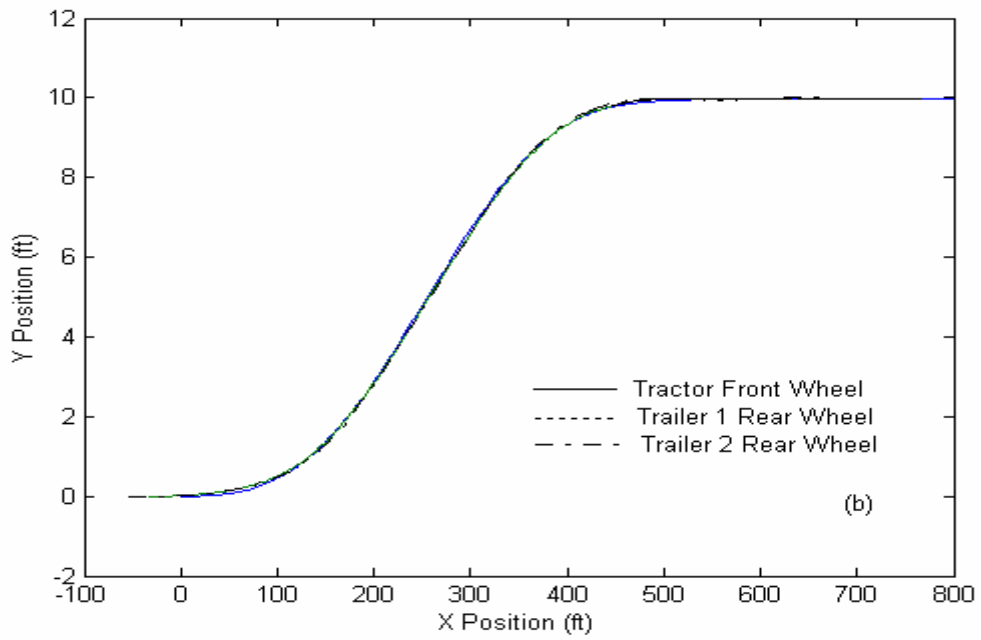


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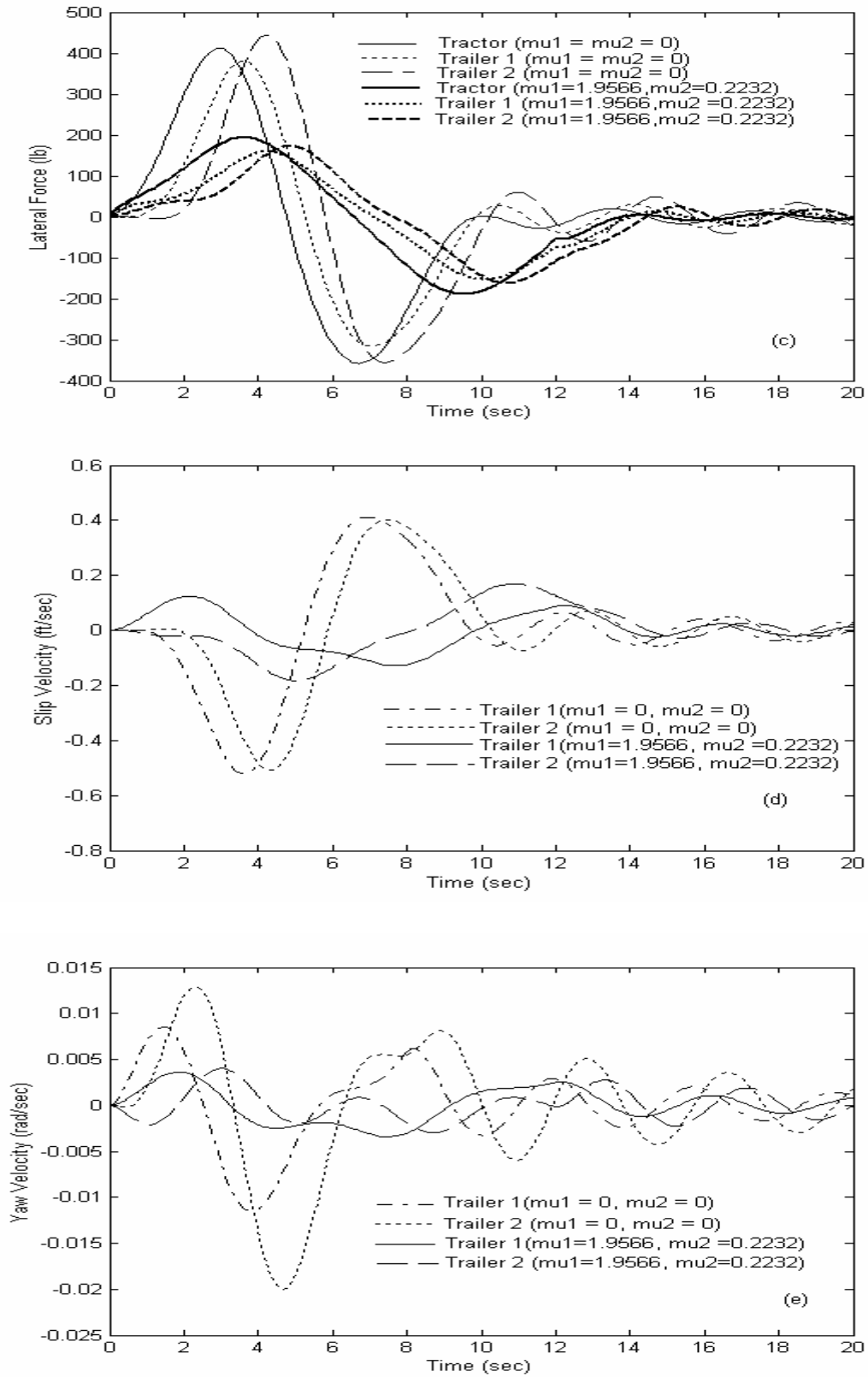


Figure 6(c, d, e)

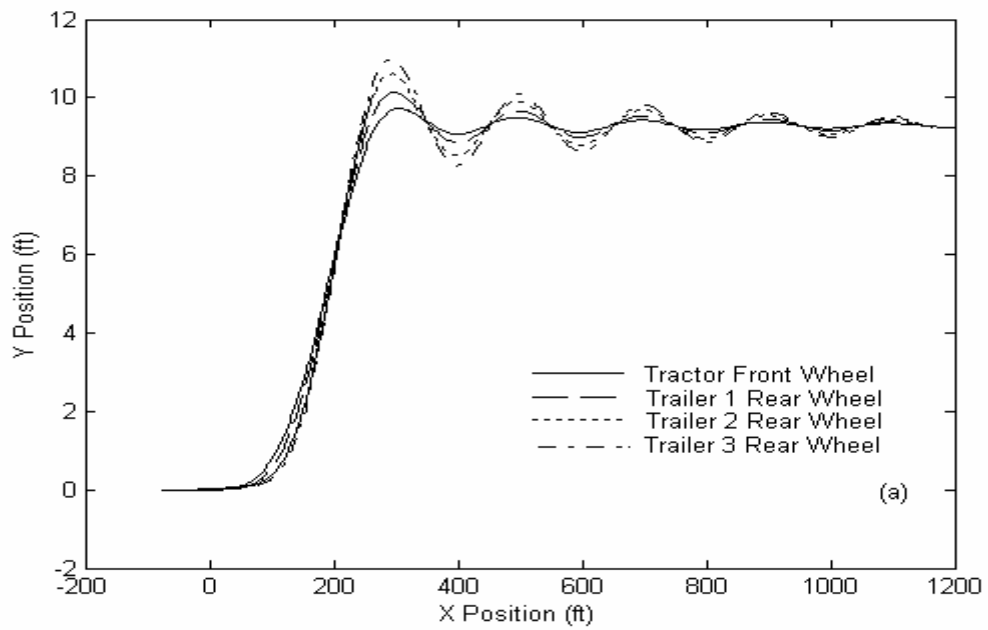


Figure 7(a)

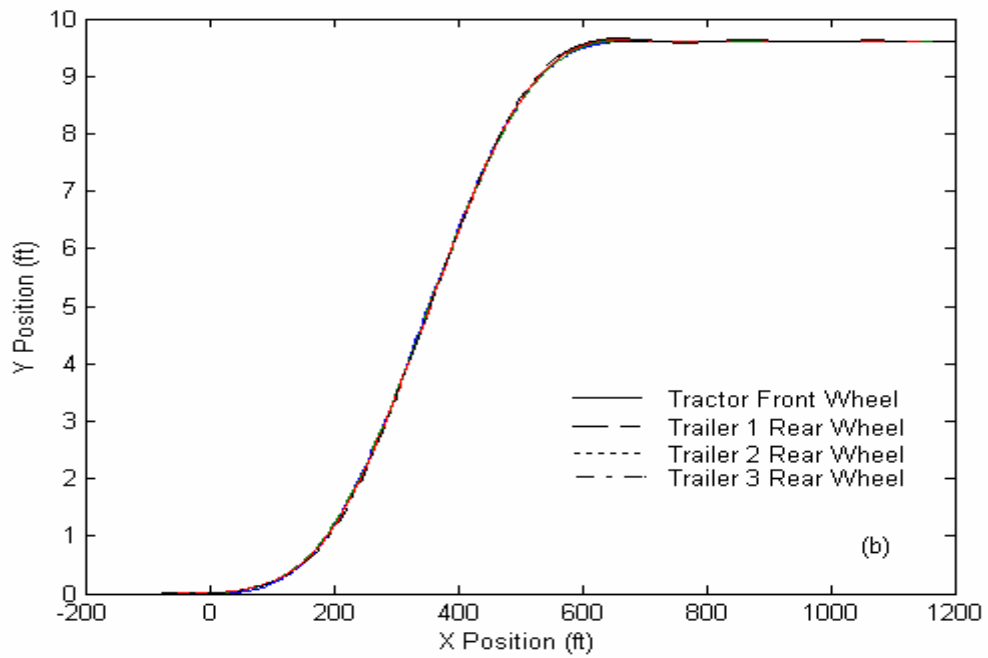


Figure 7(b)

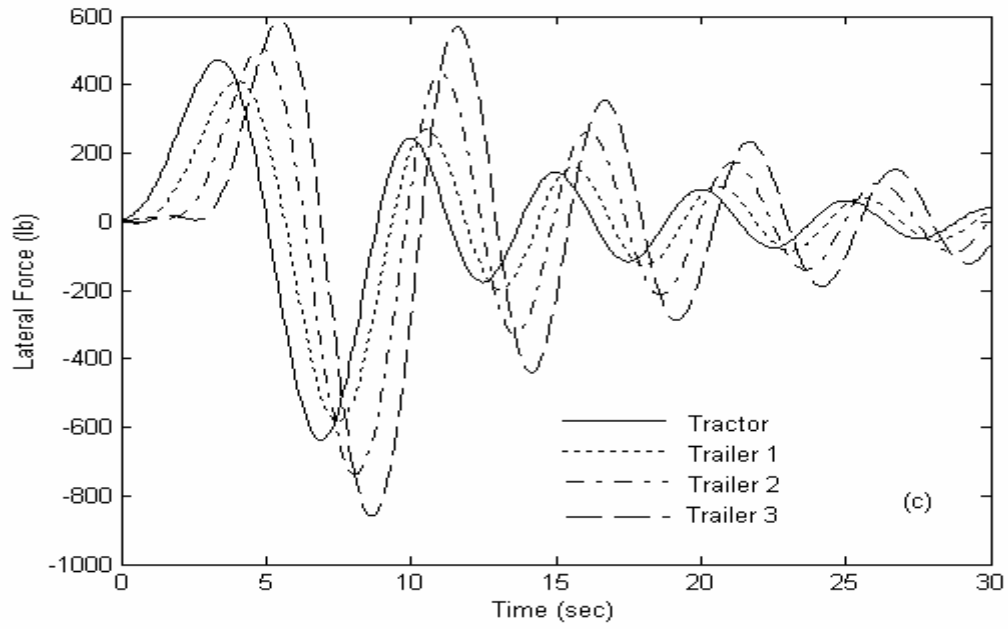


Figure 7(c)

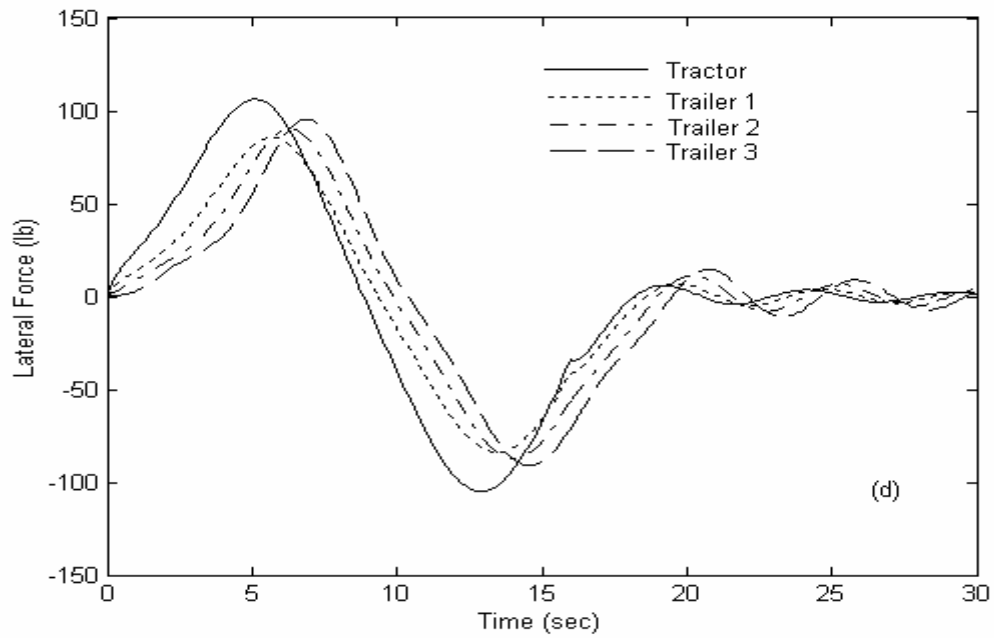


Figure 7(d)

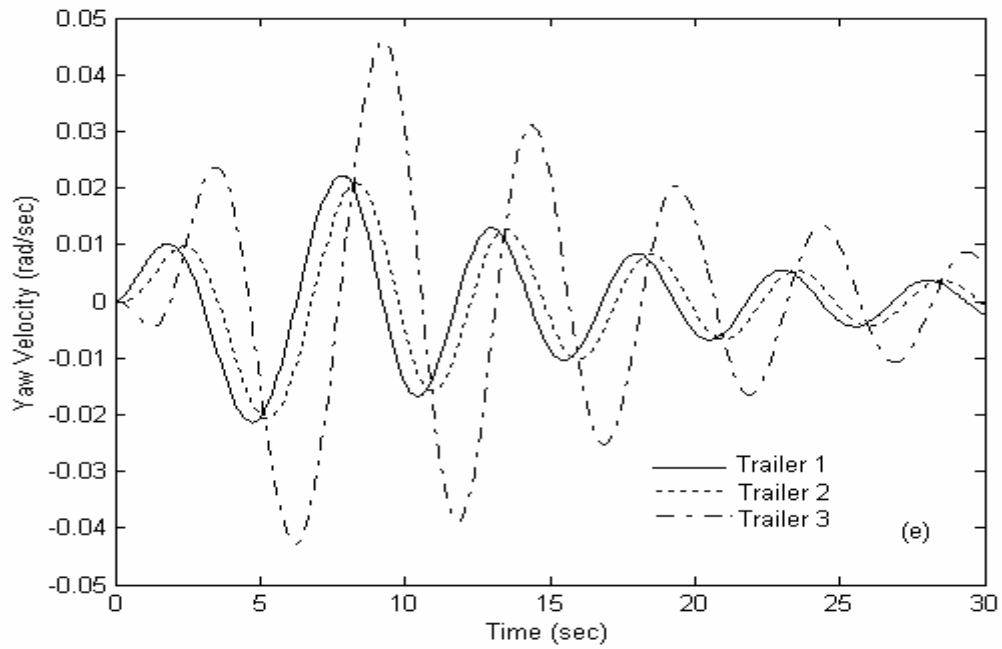


Figure 7(e)

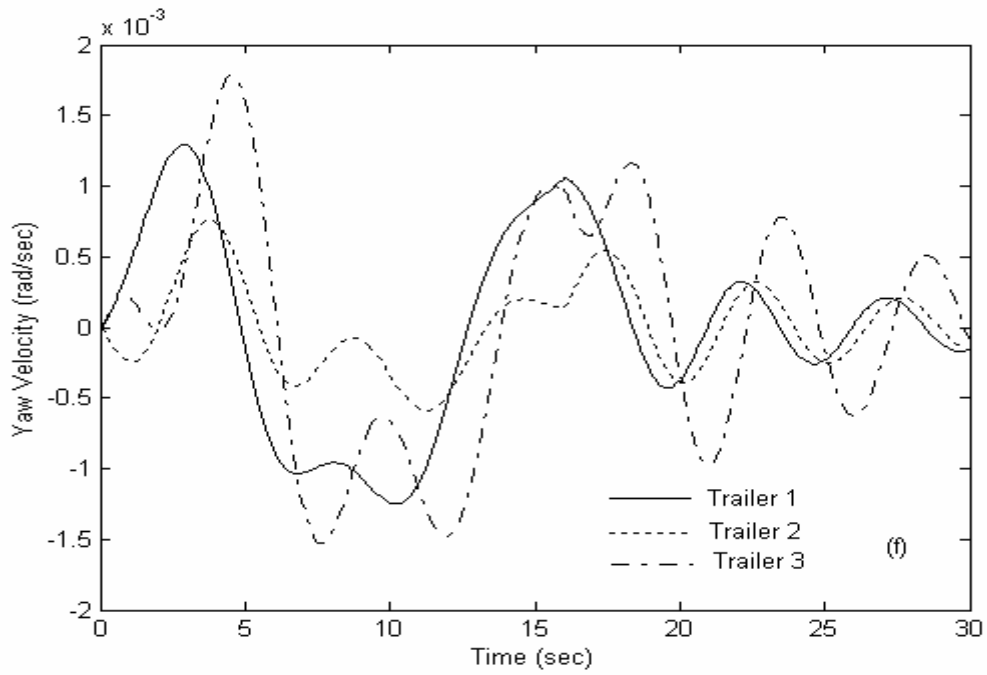


Figure 7(f)

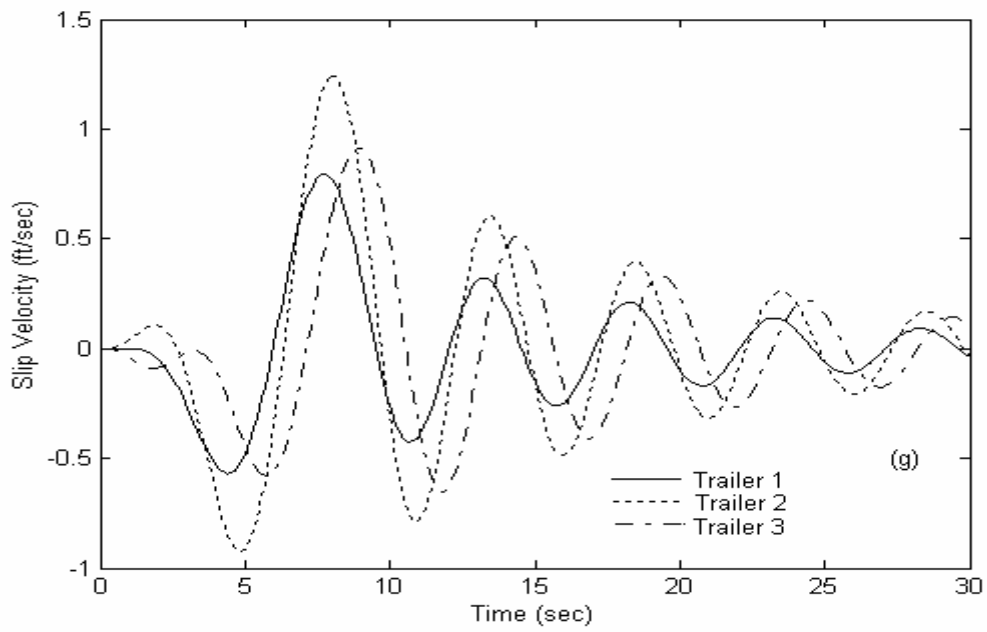


Figure 7(g)

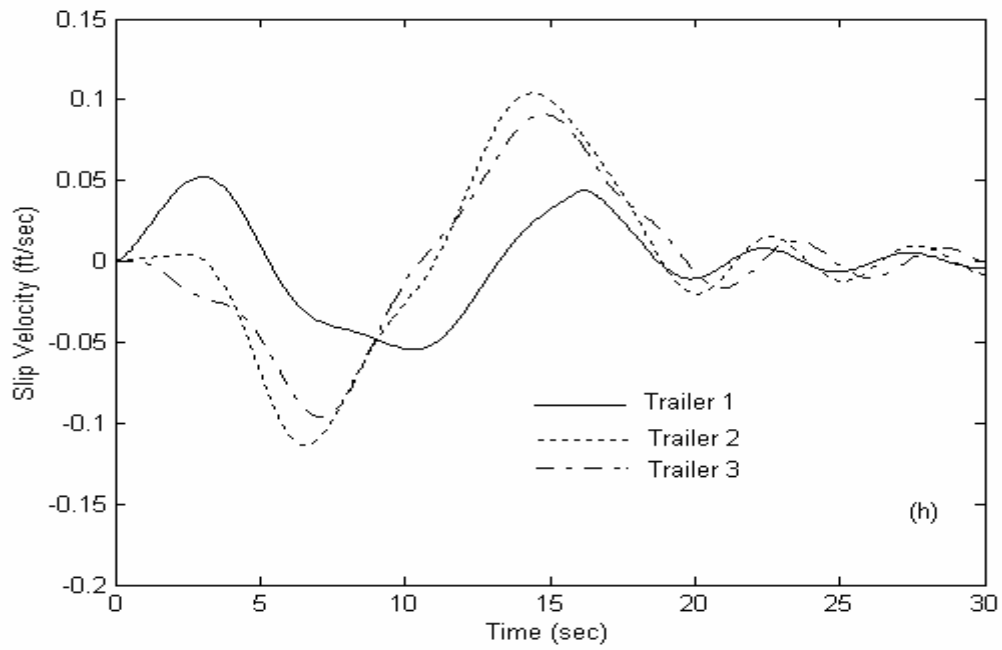


Figure 7(h)

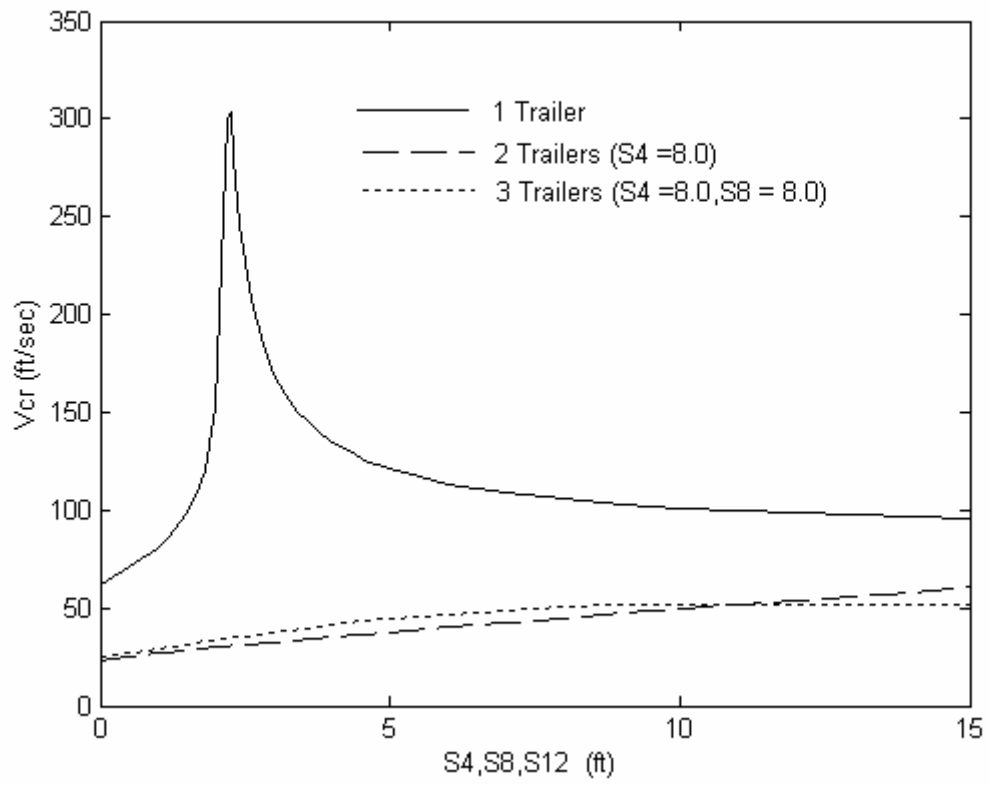


Figure 8

**AUTOMATIC STEERING FOR CONVENTIONAL TRUCK TRAILERS:
DEVELOPMENT AND ASSESSMENT OF OPERATING CONCEPTS FOR
IMPROVING SAFETY, PRODUCTIVITY AND PAVEMENT DURABILITY**

FINAL REPORT

PART IV:

**SIMULATION STUDY OF PRODUCTIVITY GAINS WITH
SHORT TRAILER COMBINATION VEHICLE (STCV)**

SIMULATION STUDY OF PRODUCTIVITY GAINS WITH SHORT TRAILER COMBINATION VEHICLE (STCV)

This Part presents the productivity study for using shorter trailers with a lighter load on each trailer versus their conventional counterparts. For example, a truck may safely haul a larger number of shorter trailers. Hence this mode of operation can have a higher productivity potential for the Less-Than-Truck-Load (LTL) freight industry, particularly those segments of the LTL industry in which loading, packing, load balancing, picking and unloading, account for a significant amount of the total time of truck operation.

For example, a 18-wheeler used to move house-hold personal belongings typically hauls belongings of multiple households and parks at a destination for either loading or unloading while the rest of the load or at least the tractor waits for hours or even a day. A solution to this problem is the use of the short trailers that can be easily coupled and decoupled from the tractor, and hence the trailers can be dropped off for loading and unloading by the customer before and after transportation. This allows the truck to do what it is meant to do: traveling, not waiting. This cuts down on the idle time for truck, the driver and the freight.

Computer simulation models are developed to represent and analyze the operating concepts and the logistics for Small Trailer Combination Vehicles (STCV) mode versus the conventional mode. Different operational strategies are evaluated by varying different input parameters that impact the productivity of the system. ProModel is the simulation software used for this study. A quantitative evaluation of the expected gain in logistics efficiency is performed from the simulation output results. The objective of the study is to vary the number of trucks and trailers required to optimize various performance measures in particular the cycle time (time in system) and tardiness of a demand order for both the STCV mode and the conventional mode of operation.

Both operational modes assume the same truck weight capacity. However, the weight for the STCV mode is distributed across a larger number of trailers. In the conventional mode of operation, the simulation assumes one large trailer for each truck whereas the STCV model assumes a truck can pull three smaller trailers of total equal weight as the conventional model. Furthermore, the STCV simulation model allows the decoupling of the small trailers from the tractor for loading and unloading operations. Therefore, the tractor is freed to travel to other pickup and/or delivery locations during the loading and unloading operation for the trailer.

The simulation requirements are to determine the number of trucks and trailers, the pickup and delivery dispatch rule, and the type of transportation network that optimize various performance measures. The dispatch rule determines which location a truck should visit next. The same dispatch rule is used regardless of whether the task is pick or delivery. Both tasks have equal priority depending on the value provided by the dispatch rule as long as the truck has sufficient capacity to pickup another load. The

various dispatch rules evaluated in the study are shortest distance, earliest due date, longest time in system and smallest slack time.

A path network design defines the method a truck travels between the locations. Two different truck distribution networks are simulated: Point-to-point and hub and spoke. The former is used for the conventional mode of operation whereas the latter is used for the STCV mode of operation. Twenty cities in California are selected as demand origins and destinations. All path segments are bi-directional.

The various performance measures used to evaluate both system designs are waiting time for truck, cycle time, average lateness, variance of lateness, average tardiness, maximum lateness, truck utilization, average truck weight, number of tardy orders, percent of tardy orders and throughput.

Cycle time is measured from the arrival of demand until it is delivered and unloaded. Lateness is the difference between delivery time and due date. If lateness is negative, the demand is delivered early. For tardiness, if lateness is negative, tardiness is set to zero. Otherwise, tardiness is set equal to lateness. Tardiness is the measure of the actual delay of a demand point. Truck utilization is the ratio of the time the truck is used (move, loading and unloading time) over the total simulated time. Throughput is defined as the total number of exits in the system (number of satisfied demand).

1 PHYSICAL SYSTEM

Two networks are evaluated: point-to-point (Figure 1) and, hub and spoke network (Figure 2). In the point-to-point network, trucks always travel directly from city to city. For hub network, empty trailers are stored in a hub. A hub serves several cities. This study is limited to 20 cities within California as shown in Figure 3. Table 1 shows the distances between the cities. Every city can both serve as a pickup and delivery demand point. In this study, the following cities were selected as hubs:

- one hub model: Fresno
- two hub model: Oakland and Los Angeles
- three hub model: Oakland, Fresno, and Los Angeles

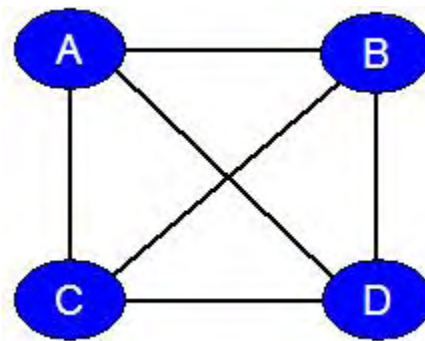


Figure 1 Point-to-Point Network

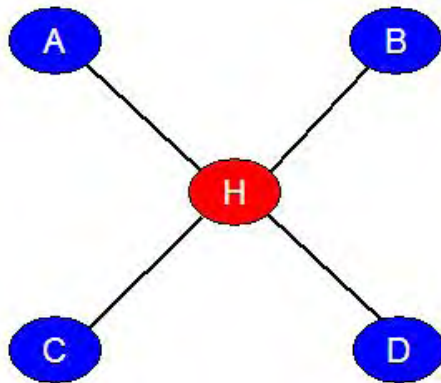


Figure 2 Hub and Spoke Network



Figure 3 Map of Cities Selected for Study

	Redding	Chico	Sacramento	Palm Springs	Stockton	Santa Rosa	San Francisco	Oakland	San Jose	Fresno	Bakersfield	Los Angeles	Long Beach	Barstow	San Bernardino	San Diego	Santa Barbara	San Luis Obispo	Irvine	Monterey
Redding	0.0	71.7	160.9	648.3	207.8	231.4	214.8	209.5	243.2	333.3	444.5	541.9	565.3	578.3	598.9	660.8	530.6	426.1	509.5	313.6
Chico	71.7	0.0	88.5	576.8	136.4	147.7	165.3	160.0	193.7	261.8	373.0	470.4	493.8	504.2	527.4	589.3	481.2	376.7	509.1	264.1
Sacramento	160.9	88.5	0.0	489.3	48.9	101.9	85.2	79.9	113.6	174.3	285.5	382.9	406.3	416.7	439.9	501.8	401.1	296.6	421.6	184.0
Palm Springs	648.3	576.8	489.3	0.0	442.4	532.2	485.8	475.8	446.9	323.8	216.7	107.9	115.4	124.4	55.6	140.7	202.0	306.3	94.2	436.5
Stockton	207.8	136.4	48.9	442.4	0.0	127.9	81.5	71.5	75.5	125.7	238.5	335.9	359.3	369.7	392.8	454.7	363.0	258.5	374.5	145.9
Santa Rosa	231.4	147.7	101.9	532.2	127.9	0.0	53.8	57.8	96.7	231.9	328.2	425.6	449.0	459.4	482.5	544.5	384.8	280.3	464.2	167.7
San Francisco	214.8	165.3	85.2	485.8	81.5	53.8	0.0	11.5	46.2	185.6	281.9	379.3	402.7	413.1	436.3	498.2	334.3	229.9	417.9	117.2
Oakland	209.5	160.0	79.9	475.8	71.5	57.8	11.5	0.0	38.8	174.9	271.2	368.6	392.0	402.4	425.5	487.5	327.1	222.6	407.2	110.0
San Jose	243.2	193.7	113.6	446.9	75.5	96.7	46.2	38.8	0.0	152.1	242.4	339.7	363.1	242.4	396.7	458.6	289.8	185.3	378.4	72.7
Fresno	333.3	261.8	174.3	323.8	125.7	231.9	185.6	174.9	152.1	0.0	109.6	217.0	240.4	238.5	274.0	335.9	253.0	137.6	255.6	152.4
Bakersfield	444.5	373.0	285.5	216.7	238.5	328.2	281.9	271.2	242.4	109.6	0.0	110.0	133.4	129.1	167.0	228.9	146.0	120.6	148.7	232.5
Los Angeles	541.9	470.4	382.9	107.9	335.9	425.6	379.3	368.6	339.7	217.0	110.0	0.0	24.1	113.5	58.4	119.0	94.3	198.6	38.7	329.9
Long Beach	565.3	493.8	406.3	115.4	359.3	449.0	402.7	392.0	363.1	240.4	133.4	24.1	0.0	125.9	69.7	111.0	114.2	218.4	30.3	372.1
Barstow	578.3	504.2	416.7	124.4	369.7	459.4	413.1	402.4	242.4	238.5	129.1	113.5	125.9	0.0	70.1	175.1	201.7	306.0	111.2	363.0
San Bernardino	598.9	527.4	439.9	55.6	392.8	482.5	436.3	425.5	396.7	274.0	167.0	58.4	69.7	70.1	0.0	106.4	148.4	252.7	49.3	382.3
San Diego	660.8	589.3	501.8	140.7	454.7	544.5	498.2	487.5	458.6	335.9	228.9	119.0	111.0	175.1	106.4	0.0	212.4	316.7	83.7	448.5
Santa Barbara	530.6	481.2	401.1	202.0	363.0	384.8	334.3	327.1	289.8	253.0	146.0	94.3	114.2	201.7	148.4	212.4	0.0	105.0	135.0	258.6
San Luis Obispo	426.1	376.7	296.6	306.3	258.5	280.3	229.9	222.6	185.3	137.6	120.6	198.6	218.4	306.0	252.7	316.7	105.0	0.0	240.0	150.1
Irvine	580.5	509.1	421.6	94.2	374.5	464.2	417.9	407.2	378.4	255.6	148.7	38.7	30.3	111.2	49.3	83.7	135.0	240.0	0.0	368.1
Monterey	313.6	264.1	184.0	436.5	145.9	167.7	117.2	110.0	72.7	152.4	232.5	329.9	372.1	363.0	382.3	448.5	258.6	150.1	368.1	0.0

Table 1 Distances between the cities (miles)

Two modes of transportation are used: truck attached to one large trailer (conventional mode) or a truck with detachable trailers (STCV mode). An example of a conventional mode of operation is shown in Figure 4 while an example of a STCV mode of operation is shown in Figure 5. In this simulation study, it is assumed that conventional mode uses the point-to-point configuration while the STCV mode uses the hub and spoke network. In the STCV mode, a trailer is dropped for loading and unloading, and the truck is then freed for the next pickup or delivery task. Two different trucks are used in the STCV mode. A local truck to delivery an empty trailer to a requested pickup location for loading, and for returning an empty trailer after unloading back to the hub. The other truck type deliveries loaded trailers between the cities.



Figure 4 An Example Truck Configuration for the Conventional Mode



Figure 5 An Example Truck Configuration for the STCV Mode

2 CONVENTIONAL SIMULATION MODEL

The complete ProModel simulation model listing for the conventional model is attached in Appendix A. The simulation determines the next task based on the dispatch priority rule value of the order demand point and the availability of the truck. If a truck is available the nearest truck to the requested demand location is assigned. The next task can be either a pickup or delivery. If the task is pickup, a truck is routed for loading, and if the task is delivery the trucking is routed for unloading. The modeling assumptions for the point to point simulation are listed below:

1. Same truck for pickup and delivery.
2. No delivery until there is a pickup.
3. Each city has equal likelihood as being selected as a pickup location.

4. Each city has equal likelihood as being selected as a delivery location.
5. The nearest truck with available capacity is selected to perform the next task.
6. Truck speed is 5,720 feet per minute, which is equivalent to 65 miles per hour.
7. Maximum truck capacity is 50,000 pounds.
8. Each truck is coupled with only one large trailer.
9. Demand is exponential distributed with the following arrival rates (λ): .5 per hour, .25 per hour, .167 per hour, .125 per hour.
10. Average truck load is one-half the maximum truck capacity with $\mu=25000$ lbs and $\sigma = 5000$ lbs.
11. Truck loading and unloading time is uniformly distributed over the interval [4,8] hours.
12. A demand due date is between 6 and 10 days from the time it requests a truck.
13. Simulation model is run to characterize the steady state behavior of the system.
14. An eight hour business day is simulated.

The inputs and outputs of the point to point simulation model are shown in Figure 6.

6. The input consists of demand characteristics (inter-arrival, pickup location, delivery location and weight), type of network used, dispatch rule and the maximum number of trucks in the system.

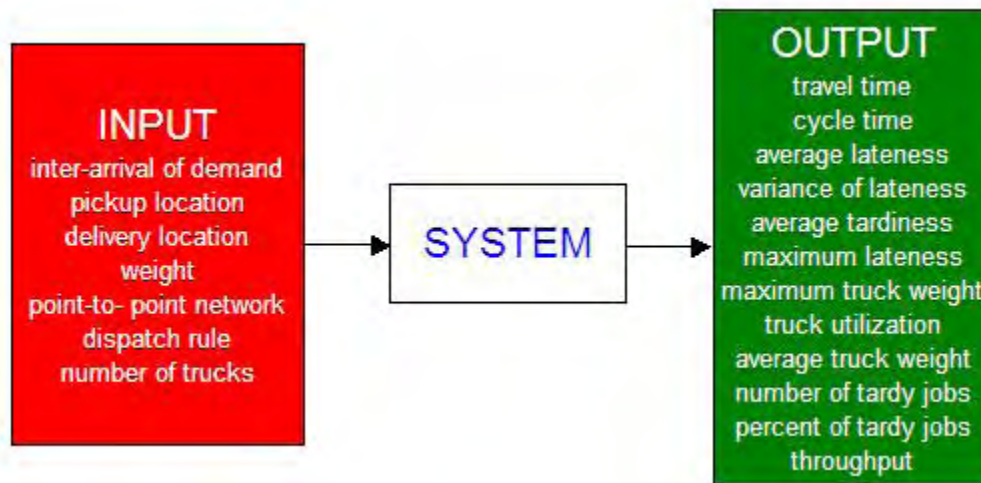


Figure 6 Inputs and Outputs for the Point to Point Simulation Model

The logic for the truck selection is shown in Figure 7. The truck is represented as a resource since they transport the demand between the cities. The truck searches for a demand point based on the dispatch rule. The truck's speed is 5,720 feet per minute, which is equivalent to 65 miles per hour. The truck has a maximum capacity of 50,000 pounds. The simulation monitors the current capacities and locations of the trucks. The model also ensures that the same truck is used for pickup and delivery of a demand.

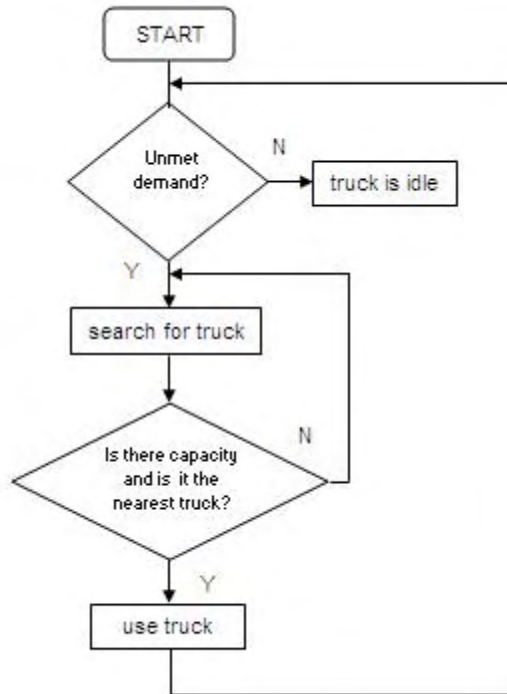


Figure 7 Truck Selection Logic for the Conventional Model

Four dispatch rules are evaluated namely: shortest distance, earliest due date, longest time in system and smallest slack time. These are represented by subroutines in the model. A subroutine is a user-defined command that is called to perform a block of logic statements with the option of returning a value. In addition, the truck capacity, truck location and the availability of the truck are evaluated in the subroutine. If a truck does not have enough capacity, another truck is searched. The subroutine returns the selected truck number. The rule attribute is the priority value given to the demand based on the selected dispatch rule.

The shortest distance rule computes the distance between the demand pickup location and the current location of the truck for a pickup task, and distance between the delivery location and the current location of the truck for a delivery task.

For earliest due date, the rule attribute is set at the demand arrival logic. A demand is randomly assigned a due date 6 to 10 days from the current time. Thus, the actual due date is the sum of the arrival hour and due date multiplied by 8 hours per day.

$$\text{Actual due date} = \text{arrival hour} + (\text{random due date} * 8 \text{ hours per day})$$

The longest waiting time is defined in hours, and is represented as follows:

$$\text{Time in system} = \text{current clock} - \text{arrival hour}$$

Smallest slack time is the remaining processing time of the demand point. This is a result of the due date in hours minus the sum of current clock, travel, and load and unload time. The expected travel time is based on the distance between the pickup and delivery location, and truck speed.

$$\text{Slack} = \text{due date} - (\text{current clock} + \text{travel time} + \text{load time} + \text{unload time})$$

Entities are materials that flow through the system. In this case, an entity is the demand order. When an order is created, it is assigned a pickup, destination, weight, load time and unloading time attribute. Pickup and delivery locations are randomly selected with a probability of 5%. Integers from 1 to 20 represent the 20 locations. Each weight is defined by a normal distribution with a mean of 25,000 and standard deviation of 5,000 pounds. The load and unload time have a uniform distribution with mean of 6 and half-width of 2 hours respectively. The entity flow logic is shown in Figure 8.

If a pickup task is selected, the truck load is updated, and the entity then waits in a queue until its delivery task is selected based on its assigned dispatch rule value. No delivery task is selected until at least one pickup task occurs. If an outstanding demand order exists, and there is no available truck for pickup, the entity again waits in a queue. In the waiting queue, the priority value is updated for each incoming demand. A sorting queue is placed after the waiting queue to arrange the demand with the highest priority. This is to ensure the truck selects the correct demand order. If a delivery task is selected, the truck is routed to the delivery location. At the delivery location, the demand is unloaded and the truck is freed and truck weight is decremented by the load amount. System statistics are also updated as the entity exits.

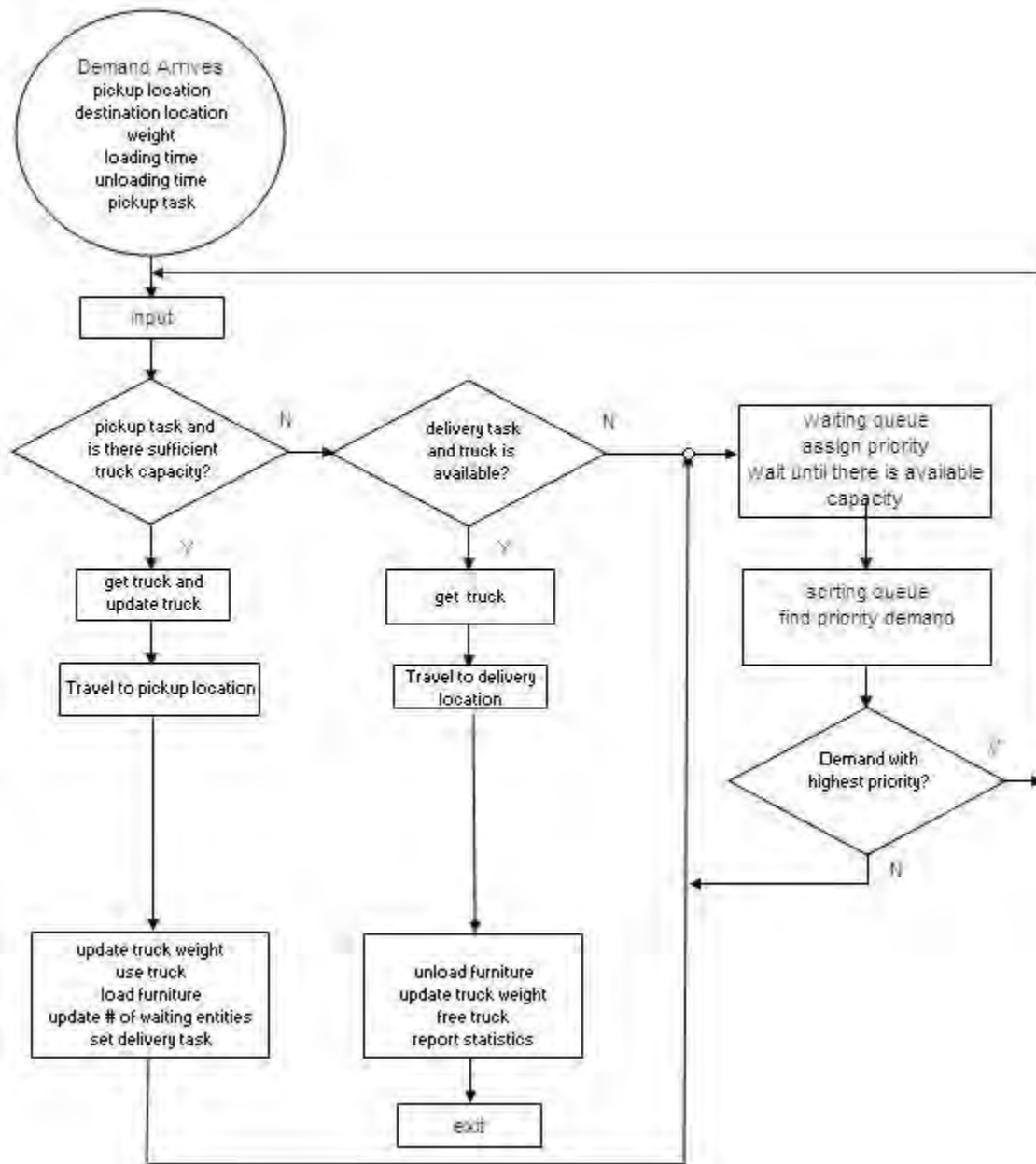


Figure 8 Entity Flow logic for Conventional Model

3 EXPERIMENTATION AND RESULTS FOR THE CONVENTIONAL MODE SIMULATION MODEL

The experiment consists of varying the following inputs:

1. inter-arrival time of demand (exponential distribution of 2, 4, 6 and 8 hours)
2. dispatch rule (shortest distance, earliest due date, longest time in system and smallest slack time)
3. number of trucks (2 thru 13 trucks)

ProModel is used to build the simulation and conduct the experiments of this system. 100 replications were made, and each replication has 40 hours of warm-up and 1000 hours of run-time. These simulation run parameters were verified to ensure steady state behavior is characterized.

Statistics were collected on the following performance measures:

- average time customer order spends in the system (cycle time)
- average lateness of a customer order
- average tardiness of a customer order
- average truck utilization
- average number of tardy orders
- average percent of tardy orders
- average throughput (number of completed orders)

A 95% confidence interval was used to test for statistical significance between different scenarios. The detailed calculations are shown in Appendix C. An asterisk symbol (*) indicates no significant difference exists between the dispatch rules as shown on the figures displaying the statistical comparisons. The name of the dispatch rule is given in the table if it is statistical significant at $\alpha = .05$. The dispatch rules are represented by the following abbreviations:

SD – Shortest Distance
EDD – Earliest Due Date
LTIS – Longest Time in System
SST – Smallest Slack Time

Time in System Results

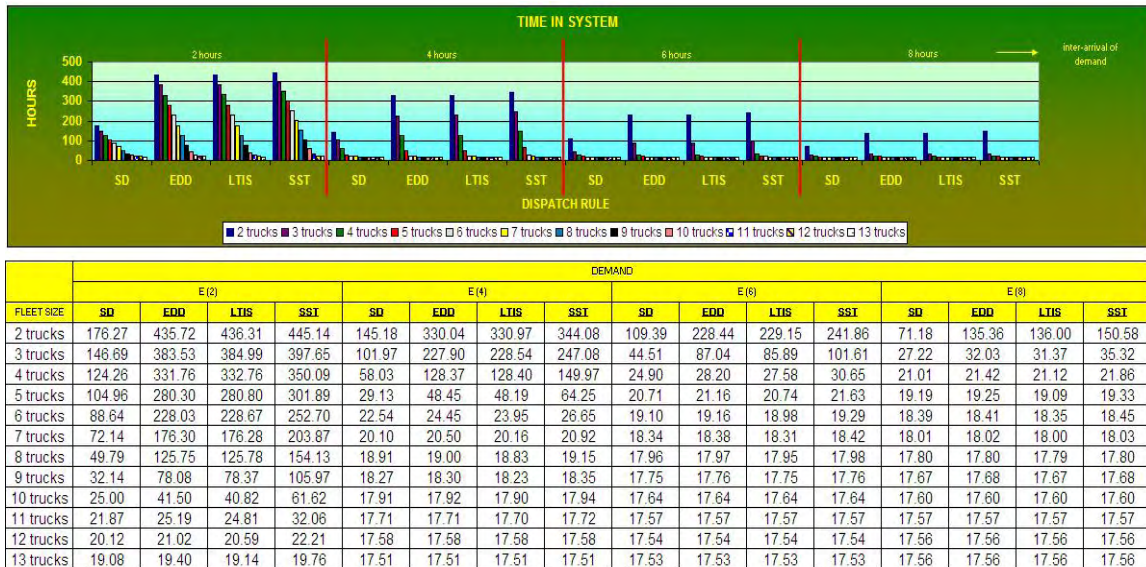


Figure 9 Average Time in System Results for Conventional Model

As the fleet size and inter-arrival time of customer demand increases, the time in system decreases significantly. The ideal cycle time is 18 hours because on average 12 hours are spent for loading and unloading, and 6 hours for average travel time. As shown in Figure 9, at peak demand, E(2), approximately 11 trucks are required to achieve the minimum cycle time, while at low demand volumes, E(8), only 4 trucks are required to obtain the minimum. Table 2 shows the statistical significance between the dispatch rules for the different scenarios. When there is insufficient truck capacity (when the minimum cycle time is not achieved), the shortest distance dispatch rule always yields the lowest cycle times.

FLEET SIZE	DEMAND			
	E (2)	E (4)	E (6)	E (8)
2 trucks	SD	SD	SD	SD
3 trucks	SD	SD	SD	SD
4 trucks	SD	SD	SD	*
5 trucks	SD	SD	*	*
6 trucks	SD	SD	*	*
7 trucks	SD	*	*	*
8 trucks	SD	*	*	*
9 trucks	SD	*	*	*
10 trucks	SD	*	*	*
11 trucks	SD	*	*	*
12 trucks	SD	*	*	*
13 trucks	*	*	*	*

Table 2 Statistical Comparison Average Time in System Results for Conventional Model

Average Lateness Results

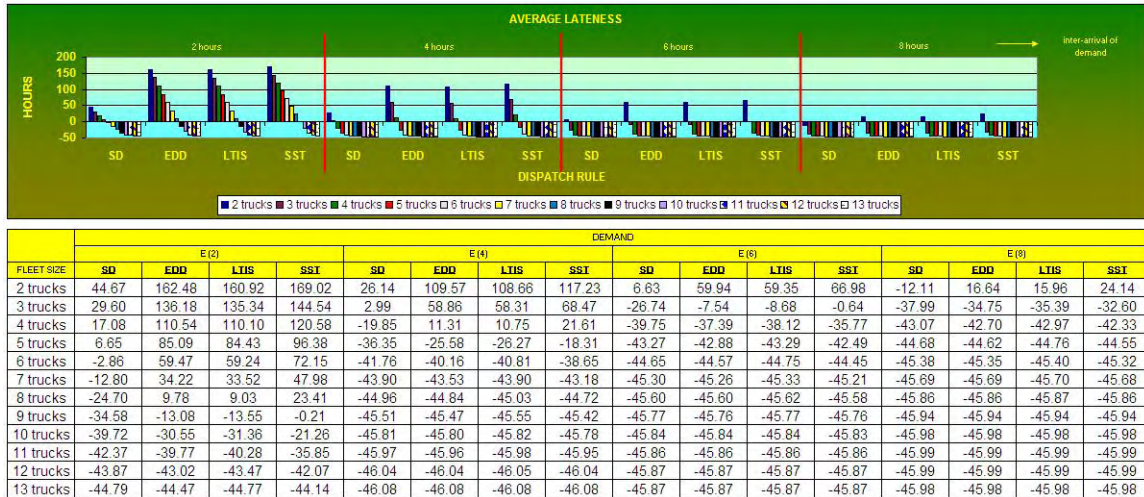


Figure 10 Average Lateness Results for Conventional Model

Negative lateness indicates early deliveries. As demand arrives at an average every 8 hours, it is expected that almost all deliveries are early since due dates are assumed to be 6 to 10 days from the current simulated time. During peak demand (2 hours), 6 trucks are required to obtain a negative average lateness for the shortest distance rule while 9 trucks for the other dispatch rules. Very early deliveries may be a disadvantage since it indicates excess truck capacity. Therefore, optimizing the number of trucks to minimize late orders should also consider other measures such as average tardiness and the number of tardy orders.

FLEET SIZE	DEMAND			
	E (2)	E (4)	E (6)	E (8)
2 trucks	SD	SD	SD	SD
3 trucks	SD	SD	SD	SD
4 trucks	SD	SD	SD	*
5 trucks	SD	SD	*	*
6 trucks	SD	*	*	*
7 trucks	SD	*	*	*
8 trucks	SD	*	*	*
9 trucks	SD	*	*	*
10 trucks	SD	*	*	*
11 trucks	SD	*	*	*
12 trucks	*	*	*	*
13 trucks	*	*	*	*

Table 3 Statistical Comparison Average Lateness Results for Conventional Model

Average Tardiness Results

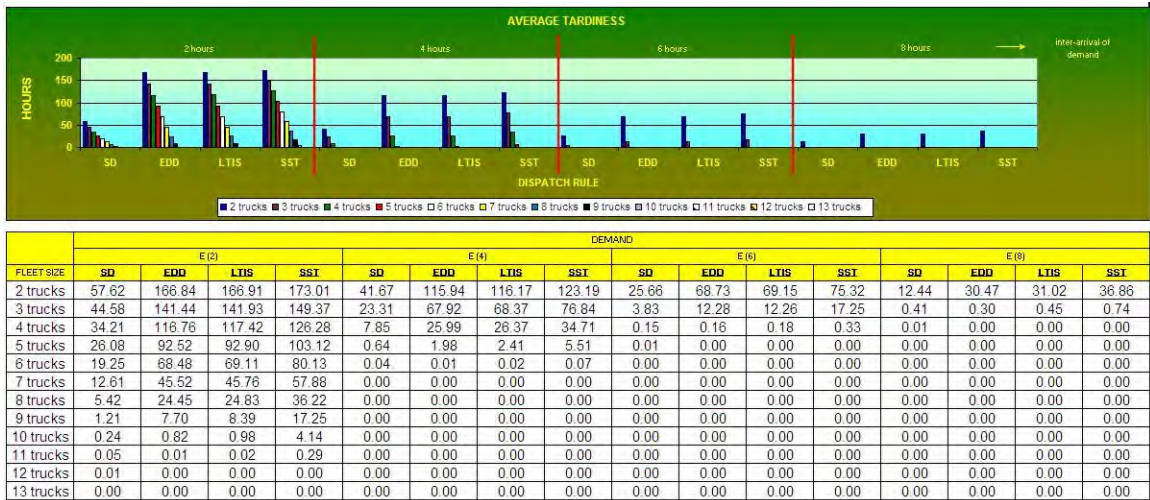


Figure 11 Average Tardiness Results for Conventional Model

Tardiness only measures the late deliveries. If it is early, tardiness is set to zero. Tardy deliveries occur mostly during peak demand of every 2 hours. Order Tardiness is basically eliminated at approximately 9 trucks for the shortest distance rule. Using a fleet size of 2 or 3 trucks for most cases generates a poor delivery performance.

FLEET SIZE	DEMAND			
	E (2)	E (4)	E (6)	E (8)
2 trucks	SD	SD	SD	SD
3 trucks	SD	SD	SD	*
4 trucks	SD	SD	*	*
5 trucks	SD	SD	*	*
6 trucks	SD	*	*	*
7 trucks	SD	*	*	*
8 trucks	SD	*	*	*
9 trucks	SD	*	*	*
10 trucks	SD	*	*	*
11 trucks	*	*	*	*
12 trucks	*	*	*	*
13 trucks	*	*	*	*

Table 4 Statistical Comparison Average Tardiness Results for Conventional Model

Number of Tardy Orders Results

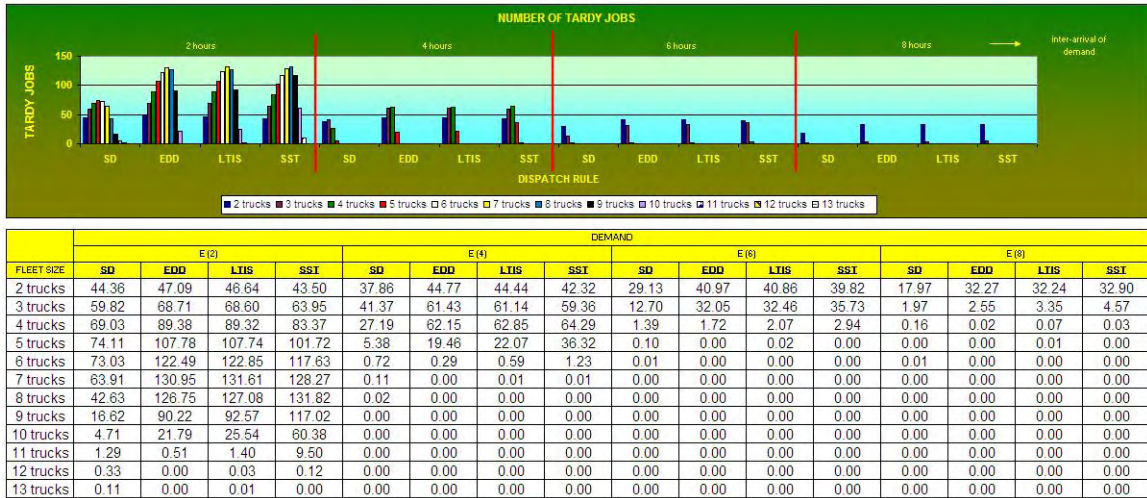


Figure 12 Number of Tardy Results for Conventional Model

Again, the critical information in Figure 12 is the peak demand results. When truck capacity is less than 10, there are between 16 to 75 expected tardy orders for the SD dispatch rule. A fleet size of 10 to 13 trucks will reduce the number of tardy orders during peak demand (2 hours). The number of tardy orders can be a misleading statistic since it is also a function of the number of completed orders (throughput). For example, the 2 truck system yields a lower value for the number of tardy orders than the 3 truck system. However, the 3 truck system can approximately complete 60 more orders than the 2 truck system (see Figure 15), and hence as a percentage of tardy orders the 3 truck system performs better than the 2 truck system. Figure 13 shows the number of tardy orders in terms of percentage of total completed orders.

FLEET SIZE	DEMAND			
	E (2)	E (4)	E (6)	E (8)
2 trucks	*	SD	SD	SD
3 trucks	*	SD	SD	*
4 trucks	*	SD	*	*
5 trucks	SD	SD	*	*
6 trucks	SD	*	*	*
7 trucks	SD	*	*	*
8 trucks	SD	*	*	*
9 trucks	SD	*	*	*
10 trucks	SD	*	*	*
11 trucks	*	*	*	*
12 trucks	*	*	*	*
13 trucks	*	*	*	*

Table 5 Statistical Comparison Number of Tardy Results for Conventional Model

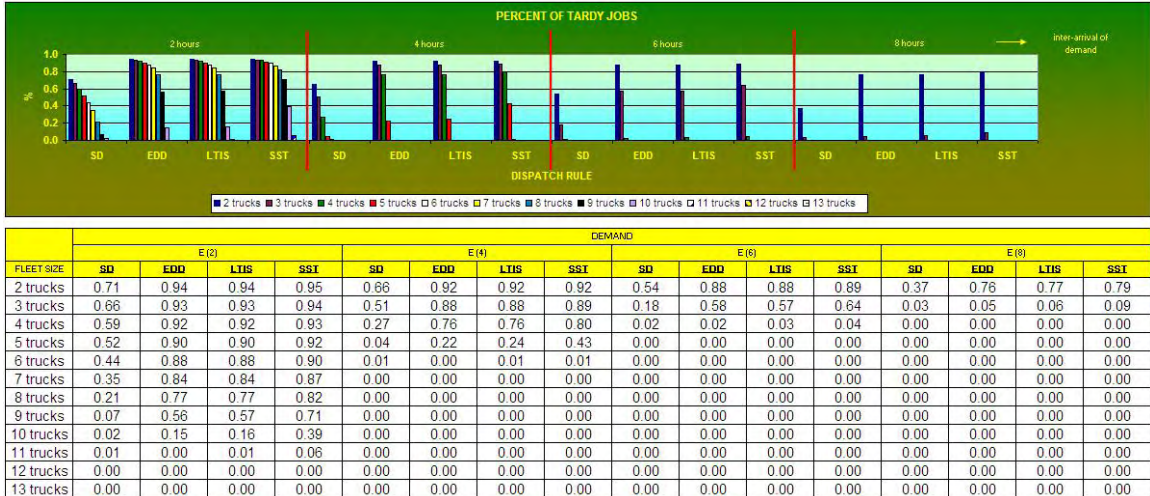


Figure 13 Percent of Tardy Results for Conventional Model

Average Truck Utilization Results

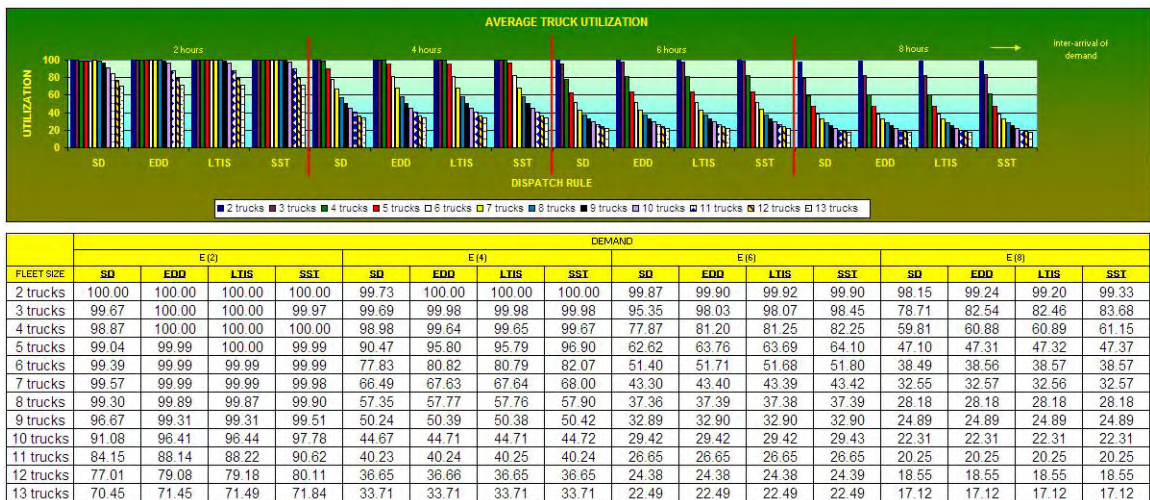


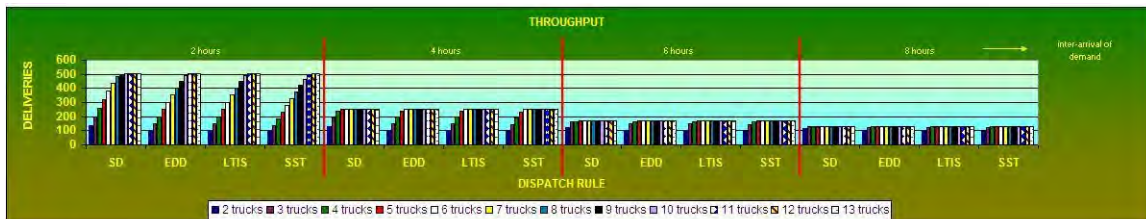
Figure 14 Average Truck Utilization Results for Conventional Model

Truck utilization varies from 70 to 100 % for the peak demand case. A fleet size of 2 to 9 trucks results in 100% utilization of the trucks. When inter-arrival time is every 6 or 8 hours, underutilization occurs for more than 4 trucks. In this statistic, shortest distance rule does not always yield the best result in contrast to the previous performance measures. The reason for this is because the other dispatch rules on average yield a longer traveling distance, and hence artificially providing a slightly higher utilization statistic than the shortest distance rule. Hence, to measure system capacity, the statistic throughput is a better performance measure.

FLEET SIZE	DEMAND			
	E (2)	E (4)	E (6)	E (8)
2 trucks	*	*	*	EDD / LTIS / SST
3 trucks	*	*	EDD / LTIS / SST	EDD / LTIS / SST
4 trucks	*	EDD / LTIS / SST	EDD / LTIS / SST	*
5 trucks	*	EDD / LTIS / SST	*	*
6 trucks	*	EDD / LTIS / SST	*	*
7 trucks	*	*	*	*
8 trucks	EDD / LTIS / SST	*	*	*
9 trucks	EDD / LTIS / SST	*	*	*
10 trucks	EDD / LTIS / SST	*	*	*
11 trucks	SST	*	*	*
12 trucks	*	*	*	*
13 trucks	*	*	*	*

Table 6 Statistical Comparison Average Truck Utilization Results for Conventional Model

Throughput Results



FLEET SIZE	DEMAND															
	E (2)				E (4)				E (6)				E (8)			
	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST
2 trucks	133.70	100.57	100.06	92.42	130.50	100.71	100.50	94.30	125.06	100.44	100.21	95.89	116.05	100.00	99.60	98.39
3 trucks	199.09	150.90	150.64	138.47	189.21	151.15	150.88	141.88	162.83	147.80	147.97	142.55	126.32	125.42	125.55	124.67
4 trucks	261.10	201.02	200.60	184.94	236.48	200.13	200.01	189.23	187.04	166.00	166.01	165.44	126.96	126.93	126.87	126.88
5 trucks	323.01	251.02	250.84	231.79	249.01	241.15	241.02	233.67	167.30	167.20	167.22	167.21	127.10	127.04	127.05	127.02
6 trucks	382.39	301.62	301.31	279.06	250.39	249.85	249.72	249.21	167.38	167.36	167.31	167.40	127.12	127.12	127.12	127.12
7 trucks	437.53	351.59	351.44	326.22	250.55	250.50	250.61	250.43	167.31	167.32	167.29	167.34	127.13	127.13	127.13	127.13
8 trucks	480.81	401.63	401.32	373.48	250.66	250.69	250.61	250.75	167.29	167.30	167.27	167.32	127.14	127.14	127.14	127.14
9 trucks	498.49	450.00	449.13	420.75	250.76	250.79	250.75	250.80	167.32	167.32	167.32	167.33	127.16	127.16	127.16	127.16
10 trucks	501.97	487.65	487.94	465.84	250.73	250.75	250.73	250.77	167.31	167.31	167.31	167.32	127.19	127.19	127.19	127.19
11 trucks	503.06	501.22	501.15	496.30	250.75	250.77	250.74	250.78	167.32	167.32	167.32	167.33	127.18	127.18	127.18	127.18
12 trucks	503.57	503.28	503.26	502.57	250.76	250.77	250.73	250.78	167.34	167.34	167.34	167.35	127.19	127.19	127.19	127.19
13 trucks	503.94	503.90	503.80	503.74	250.76	250.76	250.74	250.76	167.34	167.34	167.34	167.35	127.19	127.19	127.19	127.19

Figure 15 Throughput Results for Conventional Model

Throughput is expressed in terms of number of completed deliveries. Since maximum throughput is equal to the demand rate, the optimum throughputs are 500, 250,

167, and 125 respectively. The shortest distance rule again always provides the best results for all scenarios, and the approximate number of trucks to achieve maximum throughput are 9, 5, 3, and 2 respectively.

FLEET SIZE	DEMAND			
	E (2)	E (4)	E (6)	E (8)
2 trucks	SD	SD	SD	SD
3 trucks	SD	SD	SD	*
4 trucks	SD	SD	*	*
5 trucks	SD	SD	*	*
6 trucks	SD	*	*	*
7 trucks	SD	*	*	*
8 trucks	SD	*	*	*
9 trucks	SD	*	*	*
10 trucks	SD	*	*	*
11 trucks	*	*	*	*
12 trucks	*	*	*	*
13 trucks	*	*	*	*

Table 7 Statistical Comparison Throughput Results for Conventional Model

Table 8 provides the recommended fleet sizes for the various demand rates for the shortest distance rule. This rule tends to yield the best results since the shortest distance dispatch rule attempts to minimize the travel distance.

Inter-arrival of demand	Fleet Size	Advantage
2 hours	10 trucks	- close to 0 late deliveries - approximate cycle time of 21-25 hours - maximum throughput
4 hours	6 trucks	
6 hours	4 trucks	
8 hours	3 trucks	

Table 8 Recommended Fleet Sizes for Conventional Model

4 STCV SIMULATION MODEL

The complete ProModel simulation model listing for the STCV is attached in Appendix B. There are several significant differences between the conventional simulation model and STCV model. It is assumed that conventional mode uses the point-to-point configuration while the STCV mode uses the hub and spoke network. In the STCV mode, a trailer is dropped for loading and unloading, and the truck is freed for the next pickup or delivery task. Two different trucks are used in the STCV model. A local truck to delivery an empty trailer to a requested pickup location for loading, and for returning an empty trailer after unloading back to the hub. This type of truck is referred to as the hub truck. The other truck type deliveries loaded trailers between the cities and is referred to as the delivery truck. The modeling assumptions for the hub and spoke network model are listed below:

1. Only 1, 2 and 3 hub locations are simulated.
2. The hub location for the 1 hub model is Fresno.
3. The hub locations for the 2 hub model are Oakland and Los Angeles.
4. The hub locations for the 3 hub model are Fresno, Oakland and Los Angeles.
5. A hub truck is assigned to transport empty trailers to/from only one hub.
6. No delivery until there is a pickup.
7. Each city has equal likelihood as being selected as a pickup location.
8. Each city has equal likelihood as being selected as a delivery location.
9. The nearest truck with available capacity (trailers) is selected to perform the next task.
10. Truck speed is 5,720 feet per minute, which is equivalent to 65 miles per hour.
11. Maximum trailer weight capacity is 17,000 pounds.
12. Each truck can be coupled with a maximum of three trailers.
13. More than one order can be coupled to a delivery truck.
14. Trucks can be decoupled from the trailers, and hence the loading and unloading times only require the use of the trailer.
15. Empty trailers are stored at the hub.
16. Demand is exponential distributed with the following arrival rates (λ): .5 per hour, .25 per hour, .167 per hour, .125 per hour.
17. Average truck load is one-half the maximum truck capacity with $\mu=25000$ lbs and $\sigma = 5000$ lbs.
15. Truck loading and unloading time is uniformly distributed over the interval [4,8] hours.
16. A demand due date is between 6 and 10 days from the time it requests a truck.
17. Simulation model is run to characterize the steady state behavior of the system.
18. An eight hour business day is simulated.

The inputs and outputs of the hub and spoke simulation model are shown in Figure 16. They are almost identical to the point to point model except for the addition of hub trucks and trailer resources.

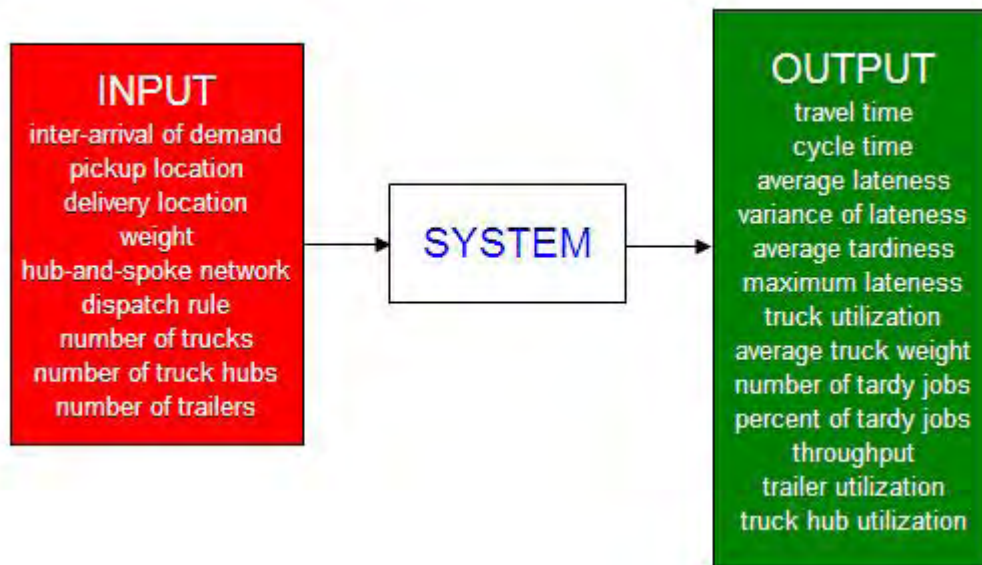


Figure 16 Inputs and Outputs for the Hub and Spoke Simulation Model

Hubs were predetermined by their map location. An order demand is assigned to the nearest hub for retrieving an empty trailer for loading at a pickup location or for returning an empty trailer back to the hub after unloading at a delivery location. Hence, the hub assignment is the nearest distance between a hub and pickup location, and a hub and delivery location. The model can accommodate scenarios from 1 to 3 hub locations as defined in the assumptions. Macros are assigned to enable the user to input the exact hub location and the total number of hubs simulated.

The logic for the truck selection is shown in Figure 17. Three resources are used in this model: delivery truck, truck hub and trailers. The trucks still have same assumption as model 1 in terms of speed (5,720 feet per minute). However, capacity is expressed in terms of number of trailers. A truck can attach a maximum of 3 trailers, and a delivery truck can be coupled to more than one demand order. The number of trailers required for each demand is defined at the arrival of the order. The simulation again monitors the current capacities and locations of the trucks. The model also ensures that a hub truck only retrieves and returns empty trailers to/from hubs to pickup/delivery locations, and that a delivery truck only transports loaded trailers from a pickup location to a delivery location. Trailers are sent to a requested pickup location only if the required number of trailers and the hub truck are available while the nearest available delivery truck is assigned to perform the next delivery task.

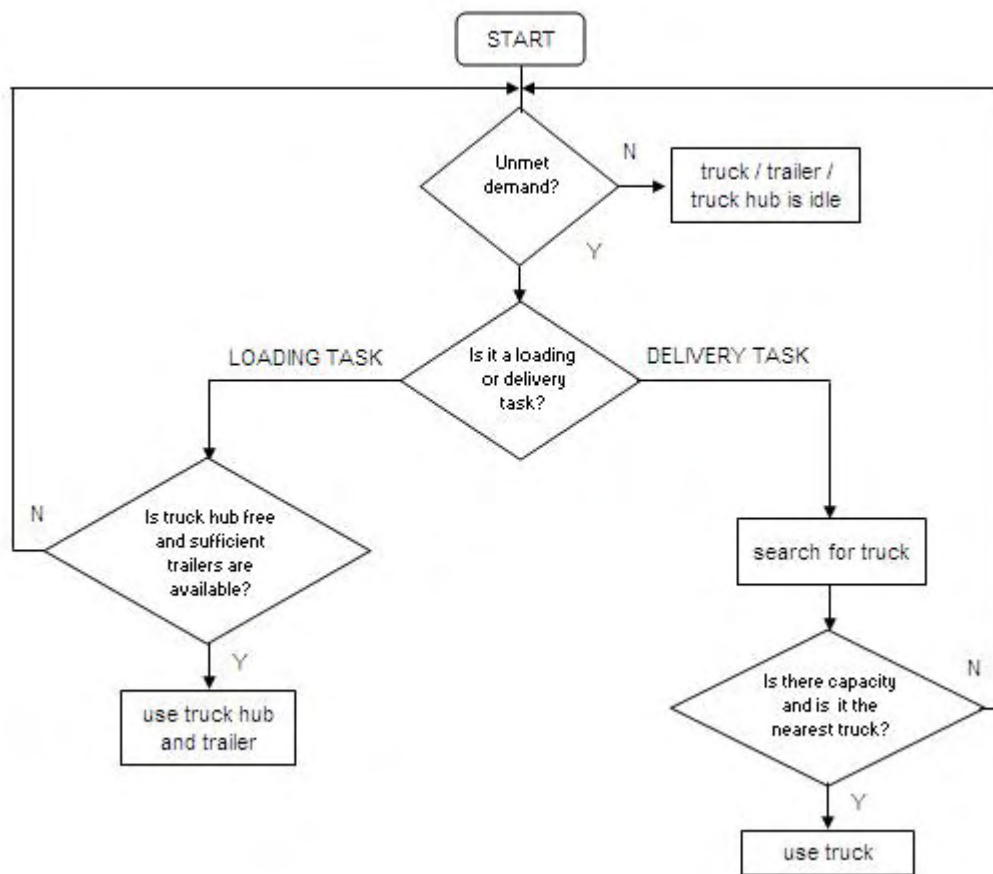


Figure 17 Truck and Trailer Selection Logic STCV Model

Figure 18 shows the flow logic of the order demand (entity) for the STCV model. As demand arrives, it is assigned a pickup location, destination location, loading time and unloading time. It is also assigned a hub(s) based on its pickup and delivery locations. If the next task is a pickup task, the truck hub and trailers are checked for availability. If both are available, they are sent to the pickup location for loading. Upon arrival at the pickup location, the truck hub is released and freed to be assigned to the next task. After loading, the order becomes a delivery task and requests a delivery truck. More than one order can be coupled to a delivery truck as long as the number of trailers does not exceed three. The next order to fulfill is always based on the priority value assigned to the demand point based on its assigned dispatch rule value. The same four dispatch rules are evaluated as before (shortest distance, earliest due date, longest time in system and smallest slack time). Upon arrival to its delivery destination, the delivery truck is released. After unloading, the trailer is returned back to nearest hub location when a hub truck becomes available.

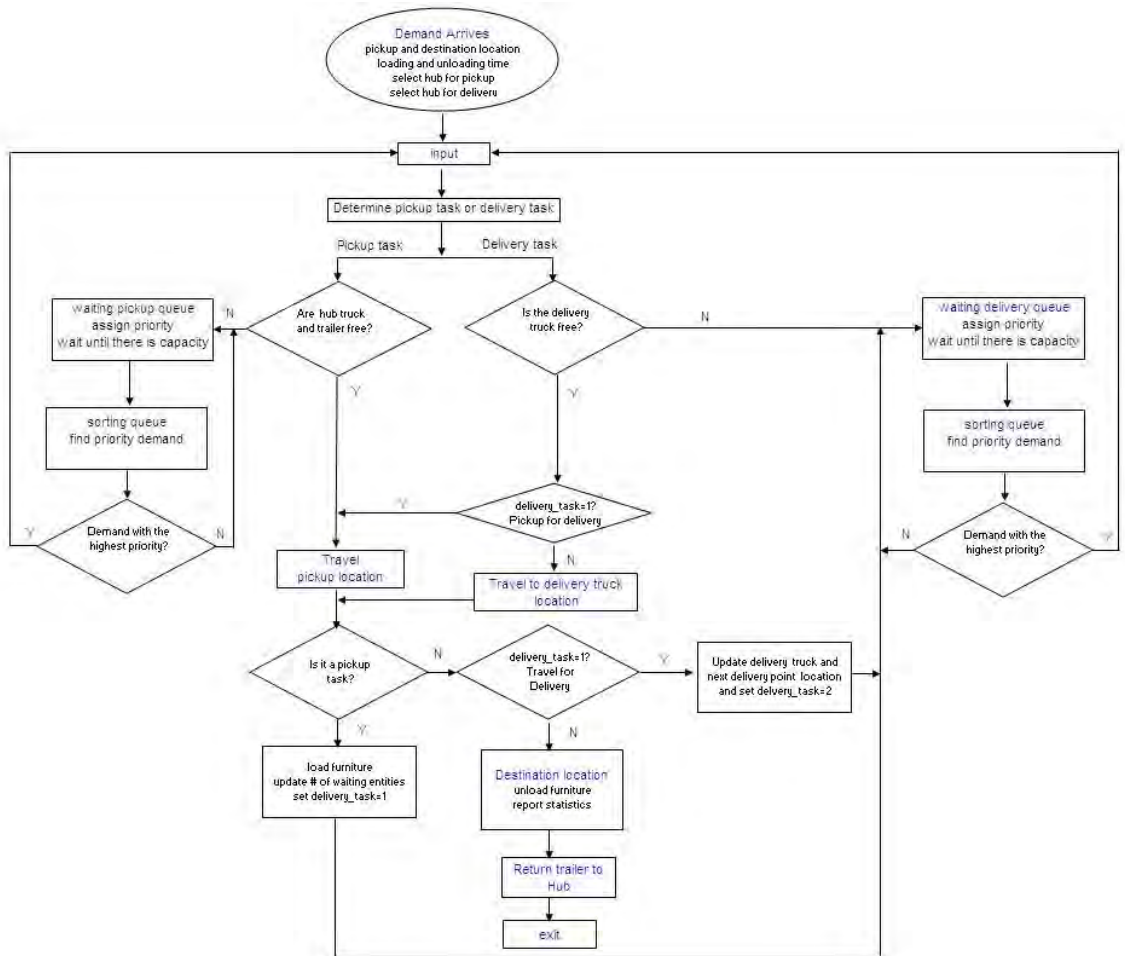


Figure 18 Entity Flow logic for STCV Model

5 EXPERIMENTATION AND RESULTS FOR THE STCV MODE SIMULATION MODEL

The experiment consists of varying the following inputs:

1. inter-arrival time of demand (exponential distribution of 2, 4, 6 and 8 hours)
2. dispatch rule (shortest distance, earliest due date, longest time in system and smallest slack time)
3. number of delivery trucks (2, 3 or 4 trucks)
4. number of truck hubs (1, 2 or 3 at each hub)
5. number of trailers = total number of trucks * 3

ProModel is used to build the simulation and conduct the experiments of this system. 100 replications were made, and each replication has 40 hours of warm-up and 1000 hours of run-time. These simulation run parameters were verified to ensure steady state behavior is characterized. A detailed comparison and analysis between the Conventional and STCV models is provided in section 6.

Statistics were collected on the following performance measures:

- average time customer order spends in the system (cycle time)
- average lateness of a customer order
- average tardiness of a customer order
- average delivery truck utilization
- average truck hub utilization
- average trailer utilization
- average number of tardy orders
- average percent of tardy orders
- average throughput (number of completed orders)

A 95% confidence interval was used to test for statistical significance between different scenarios. The detailed calculations for the 1, 2, and 3 hub models are shown in Appendices D, E, and F respectively. An asterisk symbol (*) indicates no significant difference exists between the dispatch rules as shown on the figures displaying the statistical comparisons. The name of the dispatch rule is given in the table if it is statistical significant at $\alpha = .05$. The dispatch rules are represented by the following abbreviations:

SD – Shortest Distance
EDD – Earliest Due Date
LTIS – Longest Time in System
SST – Smallest Slack Time

5.1 Experimentation and Results for the One Hub Model Scenario

This section presents the experimentation and output results for the STCV simulation model for the one hub scenario. The hub is located in Fresno, CA. The truck hub column in the figures refers to the number of trucks simulated to delivery empty trailers to pickup and from delivery locations, and the fleet size column refers to the number of trucks simulated for the delivery task.

Time in System Results

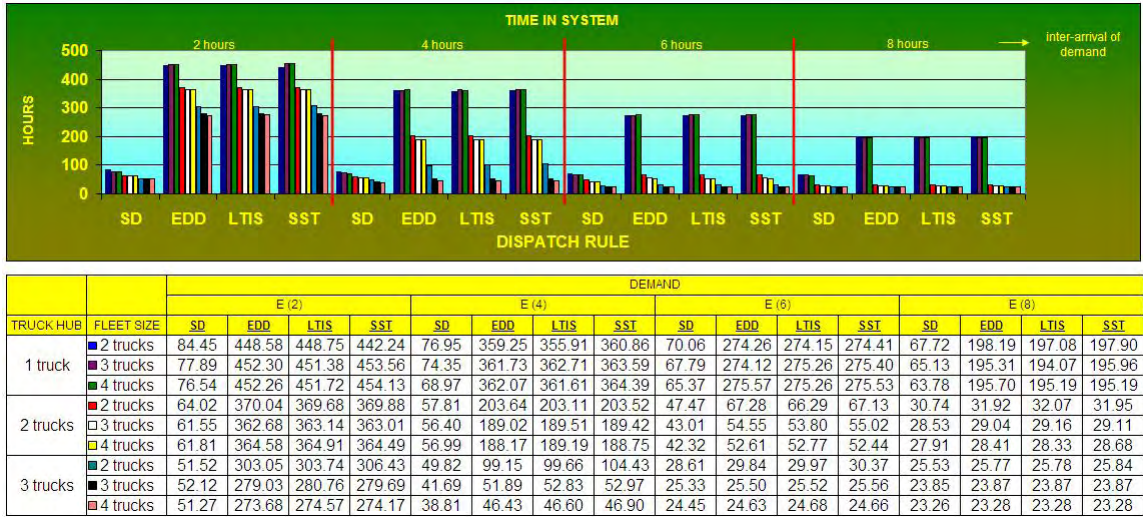


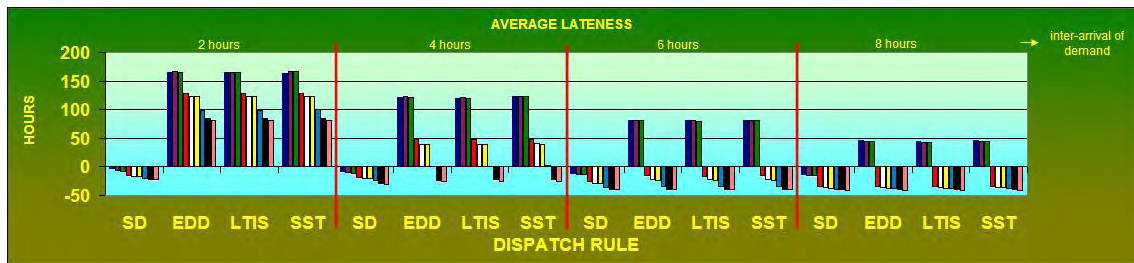
Figure 19 Average Time in System Results for the One Hub Scenario

Figure 19 and Table 9 show that the shortest distance dispatch rule always results in the lowest value (or tie) for the average time in system performance measure regardless of the simulated experimental parameters. The one hub simulation results also indicate that increasing the number of hub trucks from 1 to 2, 3 improves the system performance more than increasing the number of delivery trucks from 2 to 3, 4. It is also observed for cases which have low truck capacities (as defined by total number of trucks in the system) the SCTV one hub system significantly out performs the conventional system. This is because freeing the trucks from the loading and unloading time increases the systems capabilities. However, for cases which have high truck capacities the conventional system does yield lower values for average time in the system. Since the trucks are no longer bottlenecks, the extra travel time from the hub to the pickup location and the random waiting time for two different types of trucks (instead of one type) become a factor.

TRUCK HUB	FLEET SIZE	DEMAND			
		E (2)	E (4)	E (6)	E (8)
1 truck	2 trucks	SD	SD	SD	SD
	3 trucks	SD	SD	SD	SD
	4 trucks	SD	SD	SD	SD
2 trucks	2 trucks	SD	SD	SD	*
	3 trucks	SD	SD	SD	*
	4 trucks	SD	SD	SD	*
3 trucks	2 trucks	SD	SD	SD	*
	3 trucks	SD	SD	*	*
	4 trucks	SD	SD	*	*

Table 9 Statistical Comparison Average Time in System Results for One Hub Scenario

Average Lateness Results



TRUCK HUB	FLEET SIZE	DEMAND															
		E (2)				E (4)				E (6)				E (8)			
		SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST
1 truck	2 trucks	-2.86	164.98	164.43	163.44	-7.36	121.64	119.24	122.35	-11.02	81.32	81.06	81.94	-12.92	46.28	45.05	45.96
	3 trucks	-6.83	166.35	165.09	166.99	-9.25	122.33	121.28	123.12	-12.95	80.34	80.37	80.85	-14.82	44.28	42.93	44.60
	4 trucks	-7.83	165.81	164.57	166.63	-11.57	121.89	120.34	122.84	-13.92	80.44	80.12	80.50	-15.49	43.97	42.73	43.81
2 trucks	2 trucks	-15.43	128.62	127.98	128.92	-18.79	48.15	47.23	48.17	-25.47	-14.99	-16.06	-15.01	-34.83	-33.93	-33.84	-33.90
	3 trucks	-16.75	123.30	122.64	123.62	-20.10	39.88	39.63	40.11	-28.63	-21.73	-22.59	-21.42	-36.61	-36.20	-36.21	-36.19
	4 trucks	-16.15	123.29	122.51	123.33	-20.44	38.63	38.71	38.92	-29.39	-23.21	-23.32	-23.21	-37.34	-36.92	-36.92	-36.77
3 trucks	2 trucks	-20.83	98.80	98.30	101.15	-24.33	-0.09	-0.04	2.71	-36.14	-35.04	-35.13	-34.73	-38.78	-38.54	-38.52	-38.48
	3 trucks	-21.94	84.44	84.83	84.96	-29.28	-23.06	-22.56	-22.27	-38.90	-38.72	-38.73	-38.66	-40.30	-40.26	-40.28	-40.26
	4 trucks	-22.58	80.61	80.61	80.77	-31.21	-25.90	-26.11	-25.76	-39.76	-39.65	-39.58	-39.61	-40.99	-40.97	-40.96	-40.96

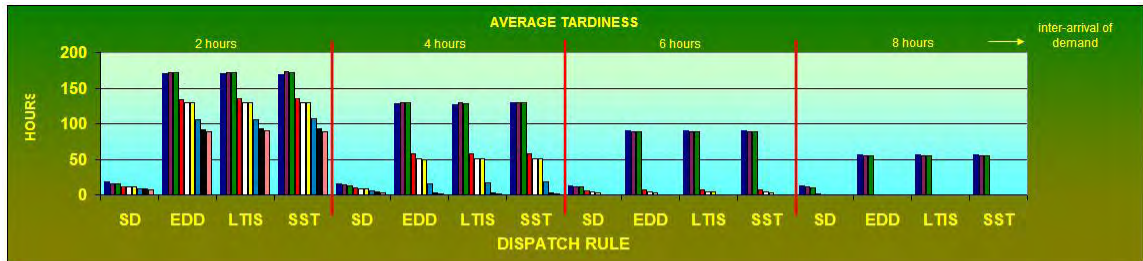
Figure 20 Average Lateness Results for the One Hub Scenario

The shortest distance dispatch rule yields early deliveries (negative lateness) for all simulated cases. However, it should be noted that this statistic can be misleading since the SD rule ignores the due date and the lateness of an order is only computed when the order is completed. Hence, there are orders that are waiting for a truck in the queue which would yield large positive lateness values if they were selected for delivery, but are never selected for delivery since there always are outstanding orders that have smaller distances to travel than these orders. This effect is particular true for high demand and low capacity scenarios.

TRUCK HUB	FLEET SIZE	DEMAND			
		E (2)	E (4)	E (6)	E (8)
1 truck	2 trucks	SD	SD	SD	SD
	3 trucks	SD	SD	SD	SD
	4 trucks	SD	SD	SD	SD
2 trucks	2 trucks	SD	SD	SD	*
	3 trucks	SD	SD	SD	*
	4 trucks	SD	SD	SD	*
3 trucks	2 trucks	SD	SD	*	*
	3 trucks	SD	SD	*	*
	4 trucks	SD	SD	*	*

Table 10 Statistical Comparison Lateness Results for One Hub Scenario

Average Tardiness Results



TRUCK HUB	FLEET SIZE	DEMAND															
		E (2)				E (4)				E (6)				E (8)			
		SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST
1 truck	2 trucks	18.44	170.56	170.95	169.18	15.43	128.36	126.90	129.13	12.84	89.50	89.89	90.12	12.17	56.87	56.39	56.47
	3 trucks	15.58	171.97	171.79	172.66	14.11	129.22	129.06	130.04	11.48	88.79	89.42	89.29	10.76	55.05	54.56	55.34
	4 trucks	14.86	171.55	171.36	172.42	12.31	128.93	128.28	129.90	10.72	89.06	89.33	89.10	10.47	55.16	54.70	54.98
2 trucks	2 trucks	11.83	134.41	134.59	134.73	9.39	57.74	57.61	57.79	5.25	7.02	6.86	6.75	0.83	0.18	0.38	0.18
	3 trucks	10.66	129.91	130.00	130.19	8.58	50.79	51.24	50.95	3.78	3.78	3.84	3.90	0.51	0.08	0.14	0.08
	4 trucks	10.71	130.11	130.13	130.15	8.32	49.97	50.70	50.33	3.46	3.26	3.72	3.37	0.38	0.05	0.13	0.07
3 trucks	2 trucks	8.02	105.37	105.49	107.51	6.05	15.95	16.73	18.10	0.36	0.04	0.09	0.08	0.03	0.00	0.01	0.00
	3 trucks	8.15	91.90	93.00	92.42	3.82	2.48	3.27	2.76	0.04	0.00	0.01	0.00	0.00	0.00	0.00	0.00
	4 trucks	7.71	88.74	89.54	88.90	3.05	1.66	2.06	1.71	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00

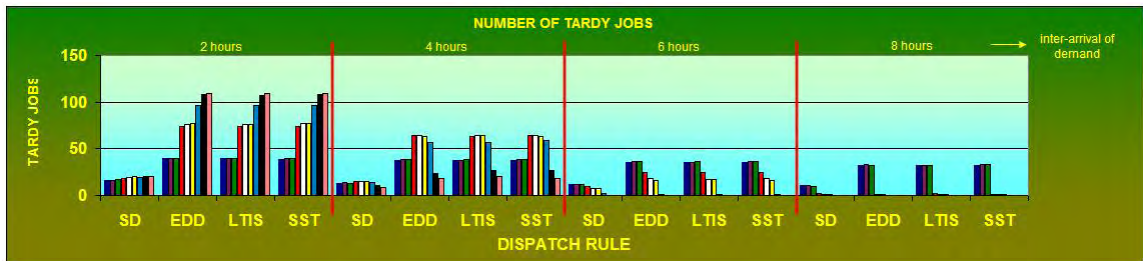
Figure 21 Average Tardiness Results for the One Hub Scenario

In order to achieve on time deliveries for random demand patterns of every 6 and 8 hours, 6 and 5 trucks are required respectively. For mid demand patterns (E(6)) with high capacities (3 hub trucks) and low demand patterns (E(8)) with mid capacities (2 hub trucks) scenarios the shortest distance rule does not yield the minimum tardiness. This is because in these cases some waiting occurs, but there is sufficient capacity to complete most orders. Hence, these scenarios capture accurately the dispatch rule effect on due date related statistics.

TRUCK HUB	FLEET SIZE	DEMAND			
		E (2)	E (4)	E (6)	E (8)
1 truck	2 trucks	SD	SD	SD	SD
	3 trucks	SD	SD	SD	SD
	4 trucks	SD	SD	SD	SD
2 trucks	2 trucks	SD	SD	*	EDD / LTIS / SST
	3 trucks	SD	SD	*	EDD / LTIS / SST
	4 trucks	SD	SD	*	EDD / LTIS / SST
3 trucks	2 trucks	SD	SD	EDD / LTIS / SST	EDD / SST
	3 trucks	SD	*	EDD / LTIS / SST	*
	4 trucks	SD	*	EDD / LTIS / SST	*

Table 11 Statistical Comparison Average Tardiness Results for One Hub Scenario

Number of Tardy Orders Results



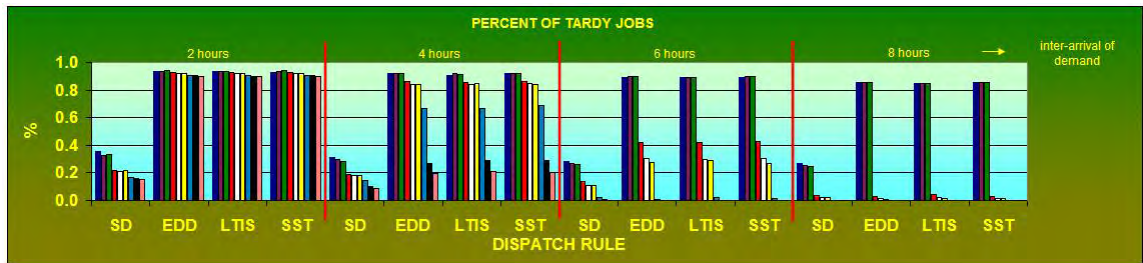
TRUCK HUB	FLEET SIZE	DEMAND															
		E (2)				E (4)				E (6)				E (8)			
		SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST
1 truck	2 trucks	15.94	39.32	39.16	39.11	13.32	37.94	37.27	37.70	11.76	35.76	35.52	35.81	10.52	32.47	32.22	32.50
	3 trucks	16.28	39.91	39.41	39.64	13.60	38.38	38.02	38.26	11.60	36.16	35.79	36.11	10.20	32.94	32.47	32.83
	4 trucks	16.80	40.01	39.40	39.81	13.34	38.44	38.06	38.33	11.51	36.03	35.93	36.08	10.04	32.62	32.27	32.73
2 trucks	2 trucks	18.44	74.46	73.92	74.46	14.99	64.03	63.52	63.90	9.61	24.82	24.70	25.15	2.32	1.48	2.63	1.51
	3 trucks	18.89	76.54	76.12	76.75	14.99	63.89	63.99	64.20	7.72	18.40	17.65	18.21	1.53	0.84	1.29	0.82
	4 trucks	19.94	76.84	76.58	76.92	14.72	63.73	64.01	63.38	7.62	16.41	17.63	16.28	1.36	0.53	1.09	0.79
3 trucks	2 trucks	18.87	96.57	96.16	95.92	13.96	56.53	57.29	58.79	1.71	0.69	1.34	0.99	0.21	0.01	0.11	0.01
	3 trucks	20.28	107.93	107.40	107.85	10.59	23.16	26.74	26.29	0.41	0.03	0.14	0.04	0.03	0.00	0.01	0.00
	4 trucks	20.22	109.57	109.18	109.50	8.94	18.07	20.12	18.65	0.21	0.02	0.09	0.00	0.02	0.00	0.00	0.00

Figure 22 Number of Tardy Orders Results for the One Hub Scenario

The analysis for the number of tardy orders is similar to the discussion presented for the average tardiness.

TRUCK HUB	FLEET SIZE	DEMAND			
		E (2)	E (4)	E (6)	E (8)
1 truck	2 trucks	SD	SD	SD	SD
	3 trucks	SD	SD	SD	SD
	4 trucks	SD	SD	SD	SD
2 trucks	2 trucks	SD	SD	SD	*
	3 trucks	SD	SD	SD	*
	4 trucks	SD	SD	SD	*
3 trucks	2 trucks	SD	SD	*	EDD / SST
	3 trucks	SD	SD	EDD / SST	EDD / SST
	4 trucks	SD	SD	SST	EDD / LTIS / SST

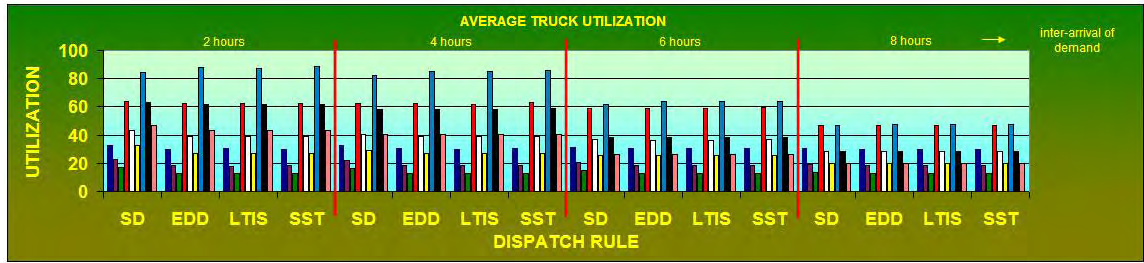
Table 12 Statistical Comparison Number of Tardy Orders Results for One Hub Scenario



TRUCK HUB	FLEET SIZE	DEMAND															
		E (2)				E (4)				E (6)				E (8)			
1 truck	2 trucks	0.35	0.94	0.93	0.93	0.31	0.92	0.91	0.92	0.28	0.89	0.89	0.89	0.27	0.85	0.85	0.85
	3 trucks	0.33	0.94	0.93	0.94	0.30	0.92	0.92	0.92	0.27	0.90	0.89	0.90	0.25	0.86	0.85	0.86
	4 trucks	0.33	0.94	0.93	0.94	0.28	0.92	0.92	0.92	0.26	0.90	0.89	0.90	0.25	0.85	0.85	0.85
2 trucks	2 trucks	0.22	0.93	0.92	0.93	0.19	0.86	0.86	0.86	0.14	0.42	0.42	0.43	0.04	0.03	0.05	0.03
	3 trucks	0.21	0.92	0.92	0.92	0.18	0.84	0.84	0.84	0.11	0.30	0.29	0.30	0.02	0.01	0.02	0.01
	4 trucks	0.21	0.92	0.92	0.92	0.18	0.84	0.84	0.84	0.11	0.27	0.29	0.27	0.02	0.01	0.02	0.01
3 trucks	2 trucks	0.17	0.90	0.90	0.91	0.14	0.67	0.67	0.69	0.02	0.01	0.02	0.02	0.00	0.00	0.00	0.00
	3 trucks	0.16	0.90	0.90	0.90	0.10	0.27	0.29	0.29	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	4 trucks	0.16	0.90	0.90	0.90	0.09	0.20	0.21	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure 23 Percent of Tardy Orders Results for the One Hub Scenario

Utilization Results



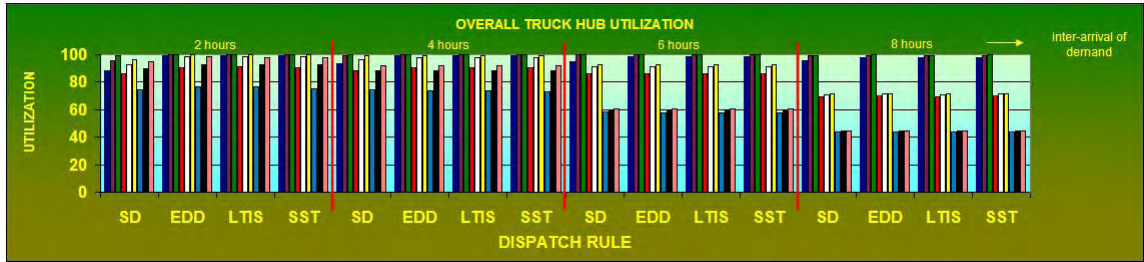
TRUCK/HUB	FLEET SIZE	DEMAND															
		E (2)				E (4)				E (6)				E (8)			
		SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST
1 truck	2 trucks	32.47	30.10	30.19	29.90	32.82	30.39	30.02	30.15	31.56	30.40	30.33	30.26	30.63	29.64	29.85	29.79
	3 trucks	22.64	18.14	18.05	18.12	22.01	18.13	18.18	18.10	20.36	18.26	18.30	18.21	19.15	18.10	18.10	18.14
	4 trucks	17.00	12.80	12.78	12.79	16.34	12.82	12.88	12.81	14.75	12.90	12.94	12.92	13.70	12.78	12.79	12.82
2 trucks	2 trucks	64.18	62.19	62.24	62.74	62.13	62.22	62.01	63.03	58.68	59.14	58.90	59.37	46.80	47.03	46.92	46.99
	3 trucks	43.47	39.29	39.00	39.20	40.57	39.19	39.16	39.25	36.72	36.48	36.42	36.69	28.32	28.22	28.14	28.23
	4 trucks	32.87	27.00	26.89	26.91	28.92	26.99	27.00	27.08	25.59	25.32	25.28	25.33	19.72	19.69	19.71	19.67
3 trucks	2 trucks	84.45	87.70	87.37	88.69	81.96	84.97	84.85	86.03	61.98	63.65	63.96	64.16	47.02	47.47	47.50	47.63
	3 trucks	63.20	61.61	61.47	61.85	58.16	58.49	58.08	58.86	38.42	38.59	38.61	38.55	28.46	28.51	28.48	28.49
	4 trucks	46.99	43.05	43.06	43.06	40.54	40.22	40.25	40.43	26.49	26.58	26.54	26.58	19.84	19.85	19.85	19.85

Figure 24 Delivery Truck Utilization Results for the One Hub Scenario

The E(2) and E(4) demand patterns for 3 truck hubs and 2 delivery trucks yield high utilization for the delivery truck. However, in all other cases, the delivery truck is not a bottleneck since there are an insufficient number of hub trucks to deliver empty trailers for loading.

TRUCK HUB	FLEET SIZE	DEMAND			
		E (2)	E (4)	E (6)	E (8)
1 truck	2 trucks	SD	SD	SD	*
	3 trucks	SD	SD	SD	*
	4 trucks	SD	SD	SD	*
2 trucks	2 trucks	SD	*	*	*
	3 trucks	SD	SD	*	*
	4 trucks	SD	SD	*	*
3 trucks	2 trucks	SST	EDD / LTIS / SST	*	*
	3 trucks	SD	*	*	*
	4 trucks	SD	*	*	*

Table 13 Statistical Comparison Delivery Truck Utilization Results for One Hub Scenario



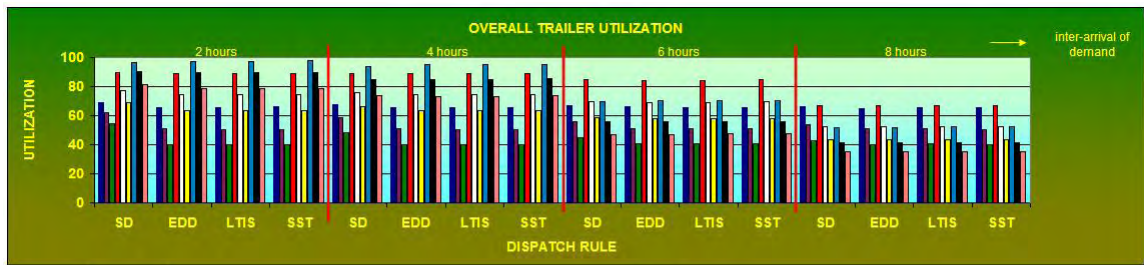
TRUCK HUB	FLEET SIZE	DEMAND															
		E (2)				E (4)				E (6)				E (8)			
		SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST
1 truck	2 trucks	88.67	99.19	99.10	99.19	93.14	98.99	99.03	98.91	94.82	98.54	98.44	98.66	95.86	98.04	97.95	97.93
	3 trucks	95.84	99.96	99.96	99.96	99.04	99.98	99.95	99.96	99.66	99.92	99.89	99.93	99.45	99.58	99.53	99.58
	4 trucks	99.20	100.00	100.00	100.00	99.93	100.00	100.00	100.00	99.95	99.96	99.95	99.96	99.80	99.64	99.63	99.64
2 trucks	2 trucks	85.81	90.81	90.90	90.58	88.08	90.27	90.26	90.17	85.92	85.87	85.78	85.99	69.63	69.79	69.68	69.86
	3 trucks	92.84	98.30	98.39	98.29	96.37	97.72	97.80	97.82	91.07	91.26	91.11	91.18	71.04	71.26	71.02	71.26
	4 trucks	96.71	99.79	99.77	99.76	99.28	99.61	99.55	99.60	92.41	92.66	92.75	92.57	71.48	71.42	71.21	71.57
3 trucks	2 trucks	74.32	76.49	76.48	75.17	74.73	73.94	74.07	72.97	58.08	57.78	57.81	57.56	44.12	44.03	44.05	43.99
	3 trucks	89.66	92.94	92.69	92.99	88.37	88.35	88.40	88.39	60.20	60.20	60.15	60.21	44.81	44.67	44.69	44.69
	4 trucks	95.22	98.19	98.00	98.10	92.01	92.00	91.84	92.08	60.43	60.44	60.57	60.52	44.77	44.75	44.78	44.77

Figure 25 Hub Truck Utilization Results for the One Hub Scenario

Hub trucks have very high utilization rates especially when demand arrives every 2 and 4 hours. Thus, there is clearly a need for more hub trucks to balance the system. In this statistic, shortest distance rule does not always yield the best result. The reason for this is because the other dispatch rules on average yield a longer traveling distance, and hence artificially providing a slightly higher utilization statistic than the shortest distance rule. Hence, to measure system capacity, the statistic throughput is a better performance measure.

TRUCK HUB	FLEET SIZE	DEMAND			
		E (2)	E (4)	E (6)	E (8)
1 truck	2 trucks	EDD / LTIS / SST	EDD / LTIS / SST	EDD / LTIS / SST	EDD / LTIS / SST
	3 trucks	EDD / LTIS / SST	EDD / LTIS / SST	EDD / LTIS / SST	*
	4 trucks	EDD / LTIS / SST	EDD / LTIS / SST	*	*
2 trucks	2 trucks	EDD / LTIS / SST	EDD / LTIS / SST	*	*
	3 trucks	EDD / LTIS / SST	EDD / LTIS / SST	*	*
	4 trucks	EDD / LTIS / SST	EDD / LTIS / SST	*	*
3 trucks	2 trucks	EDD / LTIS	*	*	*
	3 trucks	EDD / LTIS / SST	*	*	*
	4 trucks	EDD / LTIS / SST	*	*	*

Table 14 Statistical Comparison Hub Truck Utilization Results for One Hub Scenario



TRUCK HUB	FLEET SIZE	DEMAND															
		E (2)				E (4)				E (6)				E (8)			
		SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST
1 truck	2 trucks	68.84	65.57	65.52	65.90	67.59	65.66	65.73	65.32	67.01	65.93	65.70	65.81	66.34	65.17	65.32	65.22
	3 trucks	61.78	50.78	50.42	50.39	58.59	50.99	50.67	50.61	55.68	51.06	51.09	50.91	53.50	50.83	50.73	50.63
	4 trucks	54.19	40.31	40.02	40.10	48.62	40.32	40.24	40.22	45.11	40.59	40.56	40.40	42.97	40.33	40.36	40.25
2 trucks	2 trucks	89.98	88.91	88.95	88.95	89.30	88.85	88.82	89.17	84.59	84.43	84.34	84.76	66.57	66.87	66.68	66.86
	3 trucks	77.28	74.51	74.48	74.61	75.98	74.52	74.52	74.56	69.50	69.23	69.16	69.36	52.57	52.61	52.53	52.70
	4 trucks	69.11	63.46	63.37	63.30	65.92	63.42	63.29	63.41	58.47	58.23	58.26	58.20	43.61	43.51	43.42	43.59
3 trucks	2 trucks	96.42	97.37	97.26	97.59	93.93	94.91	94.93	95.28	69.45	70.33	70.51	70.67	51.80	52.04	52.07	52.13
	3 trucks	90.56	89.50	89.33	89.60	85.08	85.09	84.84	85.39	56.05	56.15	56.15	56.17	41.56	41.52	41.53	41.52
	4 trucks	81.17	78.64	78.52	78.57	73.67	73.42	73.29	73.49	47.17	47.23	47.27	47.27	34.98	34.98	34.99	34.98

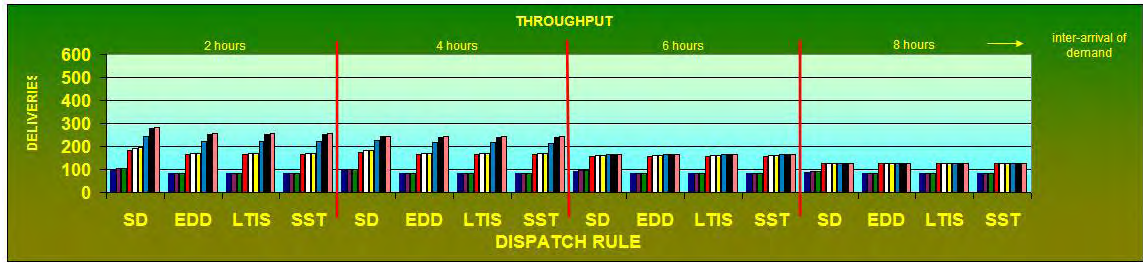
Figure 26 Trailer Utilization Results for the One Hub Scenario

The trailers are the bottleneck for the E(2) and E(4) demand patterns for the 3 hub trucks and 2 delivery trucks scenarios. However, for the other cases, the trailer utilization is lower than the hub truck utilization, and hence the number of trailers simulated is sufficient.

TRUCK HUB	FLEET SIZE	DEMAND			
		E (2)	E (4)	E (6)	E (8)
1 truck	2 trucks	SD	SD	SD	SD
	3 trucks	SD	SD	SD	SD
	4 trucks	SD	SD	SD	SD
2 trucks	2 trucks	SD	*	*	*
	3 trucks	SD	SD	*	*
	4 trucks	SD	SD	*	*
3 trucks	2 trucks	EDD / LTIS / SST	EDD / LTIS / SST	*	*
	3 trucks	SD	*	*	*
	4 trucks	SD	*	*	*

Table 15 Statistical Comparison Trailer Utilization Results for One Hub Scenario

Throughput Results



TRUCK HUB	FLEET SIZE	DEMAND															
		E (2)				E (4)				E (6)				E (8)			
		SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST
1 truck	2 trucks	96.40	83.56	83.54	82.76	93.60	84.06	83.14	83.62	91.11	84.15	83.88	84.06	88.55	83.62	84.12	83.81
	3 trucks	103.53	84.25	83.94	83.86	98.27	84.10	84.40	84.01	94.08	84.71	84.62	84.64	90.12	84.61	84.75	84.39
	4 trucks	106.37	84.11	83.66	83.97	99.22	84.26	84.47	84.08	94.38	84.42	84.70	84.67	89.98	84.50	84.48	84.35
2 trucks	2 trucks	184.57	163.24	163.86	163.18	174.35	163.38	163.26	163.73	158.02	155.73	155.59	155.86	126.14	125.96	125.97	125.86
	3 trucks	192.21	169.09	169.17	169.67	181.02	169.22	169.67	169.93	161.30	159.85	159.65	159.78	126.34	126.24	126.22	126.25
	4 trucks	196.56	169.13	169.25	169.17	183.40	170.08	169.90	169.70	161.53	160.28	160.18	160.39	126.39	126.31	126.44	126.28
3 trucks	2 trucks	244.63	222.96	222.59	220.13	224.22	217.04	216.78	214.70	166.68	166.31	166.36	166.22	126.89	126.82	126.83	126.84
	3 trucks	276.63	252.01	251.15	251.67	242.66	240.72	240.34	240.96	167.14	167.22	167.11	167.24	126.92	126.94	126.93	126.94
	4 trucks	283.40	256.35	256.56	256.58	244.70	243.04	242.87	243.05	167.11	167.10	167.10	167.10	126.96	126.94	126.97	126.92

Figure 27 Throughput Results for the One Hub Scenario

Aside from time in the system, throughput is another vital performance measure. Throughput is expressed in terms of number of completed deliveries. Since maximum throughput is equal to the demand rate, the optimum throughputs are 500, 250, 167, and 125 respectively. The simulated cases for the 1 hub and for average demand every 2 hours can not yield the maximum throughput. Hence, the number of hub trucks or the number of hubs needs to be increased to achieve the maximum throughput for this demand case. For average demand every 4 hours, approximately 3 hub trucks are required to achieve maximum throughput, while for average demand every 6 and 8 hours only 2 hub trucks are required to achieve the maximum throughput.

TRUCK HUB	FLEET SIZE	DEMAND			
		E (2)	E (4)	E (6)	E (8)
1 truck	2 trucks	SD	SD	SD	SD
	3 trucks	SD	SD	SD	SD
	4 trucks	SD	SD	SD	SD
2 trucks	2 trucks	SD	SD	*	*
	3 trucks	SD	SD	*	*
	4 trucks	SD	SD	*	*
3 trucks	2 trucks	SD	SD	*	*
	3 trucks	SD	*	*	*
	4 trucks	SD	*	*	*

Table 16 Statistical Comparison Throughput Results for One Hub Scenario

Table 17 provides the recommended fleet sizes for the various demand rates for the one hub shortest distance rule simulation models. This rule tends to yield the best results since the shortest distance dispatch rule attempts to minimize the travel distance. The system is more efficient when using the SD rule since unnecessary long trips are

avoided. However, the one hub SCTV system performs quite poorly for the average demand rate of 2 hours.

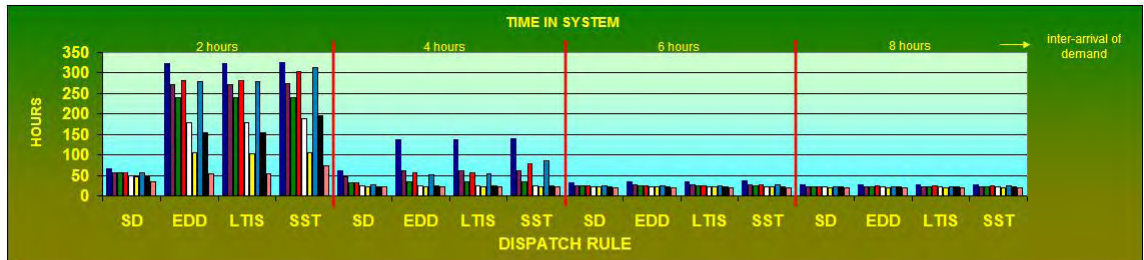
Inter-arrival of demand	Truck Hub	Delivery Truck
2 hours	3	3
4 hours	3	3
6 hours	2	2
8 hours	2	2

Table 17 Recommended Fleet Sizes for SCTV Model One Hub Scenario

5.2 Experimentation and Results for the Two Hub Model Scenario

This section presents the experimentation and output results for the STCV simulation model for the two hub scenario. The hubs are located in Oakland and Los Angeles. The truck hub column in the figures refers to the number of trucks simulated to delivery empty trailers to pickup and from delivery locations for each hub, and the fleet size column refers to the number of trucks simulated for the delivery task. The hub trucks are assigned to only one hub location, and hence if two trucks are allocated per hub then the system contains a total of four hub trucks.

Time in System Results



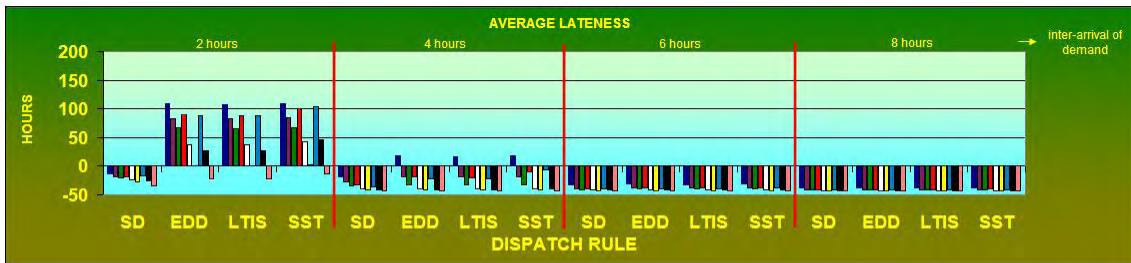
TRUCK HUB	FLEET SIZE	DEMAND															
		E (2)				E (4)				E (6)				E (8)			
		SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST
1 truck	2 trucks	65.74	323.07	322.75	324.49	60.33	137.39	136.47	138.51	33.04	34.93	34.65	35.61	25.90	26.23	26.29	26.29
	3 trucks	56.91	272.61	271.57	274.25	47.13	60.92	60.21	60.66	25.50	25.90	25.85	25.86	23.11	23.16	23.23	23.18
	4 trucks	56.65	240.71	239.72	240.49	32.30	34.85	34.89	35.22	23.44	23.70	23.70	23.73	22.12	22.19	22.19	22.19
2 trucks	2 trucks	55.76	281.33	281.94	303.98	33.01	56.53	56.18	78.17	24.35	25.64	25.63	26.45	23.03	23.46	23.40	23.61
	3 trucks	49.56	178.39	179.23	187.40	23.88	24.43	24.48	24.78	21.79	21.90	21.89	21.92	21.31	21.33	21.34	21.34
	4 trucks	46.10	104.27	103.90	105.54	21.77	21.87	21.86	21.90	20.88	20.90	20.90	20.90	20.62	20.63	20.63	20.62
3 trucks	2 trucks	56.75	280.24	279.89	312.79	27.50	52.38	52.85	84.94	23.67	25.10	25.15	26.03	22.67	23.15	23.08	23.36
	3 trucks	45.87	154.46	154.19	195.53	22.59	23.35	23.39	23.90	21.41	21.52	21.52	21.57	21.04	21.06	21.07	21.09
	4 trucks	33.28	54.76	54.63	74.13	21.10	21.19	21.20	21.23	20.58	20.58	20.58	20.59	20.39	20.39	20.39	20.39

Figure 28 Average Time in System Results for the Two Hub Scenario

The two hub scenario as expected reduces the cycle time as compared to the one hub scenario. Minimum cycle times can be achieved at mid-level demand patterns (average demand every four hours) whereas this is not the case for the one hub scenario. Again, the shortest distance dispatch rule always results in the lowest value (or tie) for the average time in system performance measure regardless of the simulated experimental parameters.

TRUCK HUB	FLEET SIZE	DEMAND			
		E (2)	E (4)	E (6)	E (8)
1 truck	2 trucks	SD	SD	*	*
	3 trucks	SD	SD	*	*
	4 trucks	SD	SD	*	*
2 trucks	2 trucks	SD	SD	SD	SD
	3 trucks	SD	SD	*	*
	4 trucks	SD	*	*	*
3 trucks	2 trucks	SD	SD	SD	SD
	3 trucks	SD	SD	*	*
	4 trucks	SD	*	*	*

Table 18 Statistical Comparison Average Time in System Results for Two Hub Scenario
Average Lateness Results



TRUCK HUB	FLEET SIZE	DEMAND															
		E (2)				E (4)				E (6)				E (8)			
		SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST
1 truck	2 trucks	-13.12	108.57	107.80	109.68	-18.23	17.49	16.89	18.25	-33.16	-31.47	-31.78	-31.03	-38.35	-38.00	-38.01	-37.99
	3 trucks	-18.44	82.82	82.29	83.98	-26.44	-18.35	-18.83	-18.26	-38.74	-38.42	-38.45	-38.44	-40.83	-40.77	-40.71	-40.73
	4 trucks	-19.87	66.29	65.60	66.29	-34.46	-32.28	-32.39	-32.12	-40.61	-40.36	-40.38	-40.35	-41.84	-41.76	-41.77	-41.76
2 trucks	2 trucks	-18.11	89.22	88.98	100.17	-32.94	-19.28	-19.71	-9.40	-39.44	-38.39	-38.29	-37.82	-40.81	-40.40	-40.47	-40.27
	3 trucks	-23.31	37.67	38.03	42.88	-40.14	-39.59	-39.57	-39.31	-41.82	-41.71	-41.72	-41.68	-42.40	-42.37	-42.36	-42.37
	4 trucks	-26.59	1.04	0.57	1.92	-42.13	-42.05	-42.05	-42.02	-42.77	-42.75	-42.74	-43.17	-43.16	-43.16	-43.17	
3 trucks	2 trucks	-17.42	88.88	87.88	103.60	-36.85	-21.35	-21.42	-6.67	-39.97	-38.72	-38.70	-38.08	-41.11	-40.62	-40.70	-40.44
	3 trucks	-25.55	26.51	26.12	46.24	-41.20	-40.45	-40.49	-40.06	-42.12	-42.01	-42.02	-41.96	-42.60	-42.58	-42.57	-42.56
	4 trucks	-33.90	-21.97	-22.06	-12.85	-42.71	-42.61	-42.62	-42.57	-43.01	-43.00	-43.00	-43.00	-43.35	-43.35	-43.35	-43.35

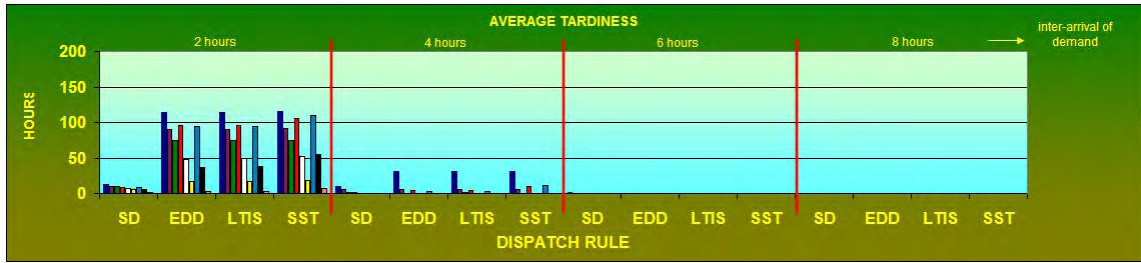
Figure 29 Average Lateness Results for the Two Hub Scenario

As expected, the results for average lateness for the two hub scenario also yield early deliveries similar to the one hub scenario.

TRUCK HUB	FLEET SIZE	DEMAND			
		E (2)	E (4)	E (6)	E (8)
1 truck	2 trucks	SD	SD	*	*
	3 trucks	SD	SD	*	*
	4 trucks	SD	*	*	*
2 trucks	2 trucks	SD	SD	SD	*
	3 trucks	SD	*	*	*
	4 trucks	SD	*	*	*
3 trucks	2 trucks	SD	SD	SD	*
	3 trucks	SD	*	*	*
	4 trucks	SD	*	*	*

Table 19 Statistical Comparison Average Lateness Results for Two Hub Scenario

Average Tardiness Results



TRUCK HUB	FLEET SIZE	DEMAND															
		E (2)				E (4)				E (6)				E (8)			
		SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST
1 truck	2 trucks	12.85	114.77	114.76	115.78	9.71	30.65	30.71	31.21	1.33	0.57	0.64	0.68	0.15	0.02	0.04	0.02
	3 trucks	9.58	90.57	90.84	91.63	5.55	5.17	5.36	5.26	0.16	0.01	0.03	0.01	0.03	0.00	0.00	0.00
	4 trucks	9.36	75.09	75.04	75.01	1.54	0.57	0.71	0.51	0.04	0.00	0.01	0.00	0.01	0.00	0.00	0.00
2 trucks	2 trucks	8.79	95.32	95.73	105.87	1.10	3.71	4.01	9.89	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.00
	3 trucks	6.77	47.71	48.62	52.24	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	4 trucks	5.73	17.21	17.46	17.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3 trucks	2 trucks	8.39	94.82	94.54	109.29	0.11	2.63	3.25	11.74	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00
	3 trucks	5.13	37.26	37.70	55.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	4 trucks	1.71	2.80	3.33	7.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

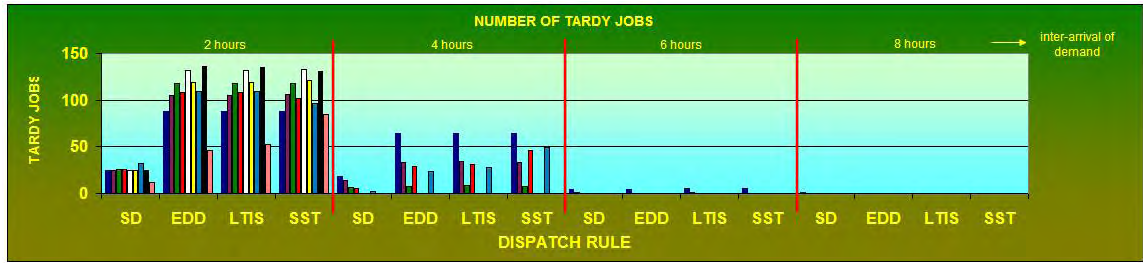
Figure 30 Average Tardiness Results for the Two Hub Scenario

The two hub system is able to provide a significant improvement in average tardiness results when demand arrives on average every 4 hours. Additional resources are required to further improve delivery performance when demand arrives every 2 hours.

TRUCK HUB	FLEET SIZE	DEMAND			
		E (2)	E (4)	E (6)	E (8)
1 truck	2 trucks	SD	SD	*	EDD / LTIS/ SST
	3 trucks	SD	*	EDD / LTIS/ SST	EDD / LTIS/ SST
	4 trucks	SD	EDD / LTIS/ SST	EDD / LTIS/ SST	*
2 trucks	2 trucks	SD	SD	*	*
	3 trucks	SD	*	*	*
	4 trucks	SD	*	*	*
3 trucks	2 trucks	SD	SD	*	*
	3 trucks	SD	*	*	*
	4 trucks	SD / EDD / LTIS	*	*	*

Table 20 Statistical Comparison Average Tardiness Results for Two Hub Scenario

Number of Tardy Orders Results



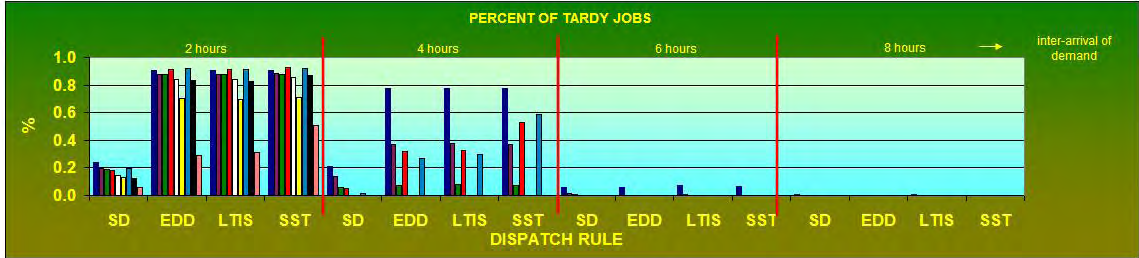
TRUCK HUB	FLEET SIZE	DEMAND															
		E (2)				E (4)				E (6)				E (8)			
		SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST
1 truck	2 trucks	24.25	88.14	88.04	87.83	18.64	63.83	64.49	64.43	4.56	4.38	5.37	4.85	0.68	0.18	0.39	0.15
	3 trucks	24.77	105.41	104.70	105.64	13.89	32.79	34.04	33.64	1.05	0.19	0.60	0.17	0.16	0.02	0.08	0.02
	4 trucks	26.20	117.75	118.04	117.57	6.58	7.05	8.47	7.01	0.35	0.02	0.16	0.06	0.05	0.00	0.03	0.00
2 trucks	2 trucks	25.65	108.68	108.05	101.53	5.80	29.08	30.63	45.87	0.10	0.05	0.13	0.22	0.03	0.00	0.02	0.01
	3 trucks	24.72	131.96	132.19	132.52	0.24	0.02	0.11	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	4 trucks	24.59	118.73	118.59	120.71	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3 trucks	2 trucks	31.99	109.56	109.70	96.72	1.61	23.87	28.05	49.64	0.08	0.01	0.13	0.19	0.02	0.00	0.01	0.00
	3 trucks	24.45	135.72	135.08	130.99	0.03	0.00	0.03	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	4 trucks	12.15	46.05	52.96	84.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure 31 Number of Tardy Orders Results for the Two Hub Scenario

With the improvement in performance for a demand pattern of every 4 hours, focus shifts to peak demand of every 2 hours. Additional resources are needed to eliminate tardy deliveries.

TRUCK HUB	FLEET SIZE	DEMAND			
		E (2)	E (4)	E (6)	E (8)
1 truck	2 trucks	SD	SD	*	*
	3 trucks	SD	SD	EDD / SST	*
	4 trucks	SD	*	*	EDD / SST
2 trucks	2 trucks	SD	SD	*	*
	3 trucks	SD	*	*	*
	4 trucks	SD	*	*	*
3 trucks	2 trucks	SD	SD	*	*
	3 trucks	SD	*	*	*
	4 trucks	SD	*	*	*

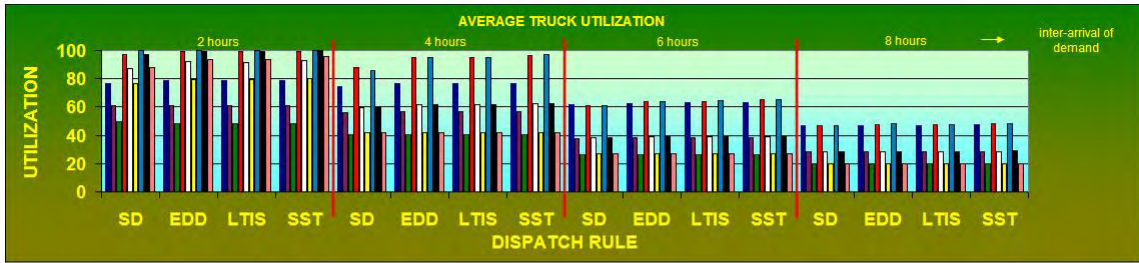
Table 21 Statistical Comparison Number of Tardy Orders Results for Two Hub Scenario



TRUCK HUB	FLEET SIZE	DEMAND															
		E (2)				E (4)				E (6)				E (8)			
		SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST
1 truck	2 trucks	0.24	0.90	0.90	0.91	0.21	0.77	0.78	0.78	0.06	0.06	0.07	0.07	0.01	0.00	0.01	0.00
	3 trucks	0.20	0.88	0.88	0.88	0.14	0.37	0.37	0.37	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00
	4 trucks	0.19	0.88	0.88	0.88	0.06	0.07	0.08	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2 trucks	2 trucks	0.18	0.92	0.91	0.92	0.05	0.32	0.33	0.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	3 trucks	0.14	0.84	0.84	0.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3 trucks	4 trucks	0.13	0.70	0.70	0.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2 trucks	0.20	0.92	0.92	0.92	0.01	0.27	0.30	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	3 trucks	0.12	0.83	0.83	0.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	4 trucks	0.06	0.29	0.31	0.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure 32 Percent of Tardy Orders Results for the Two Hub Scenario

Utilization Results



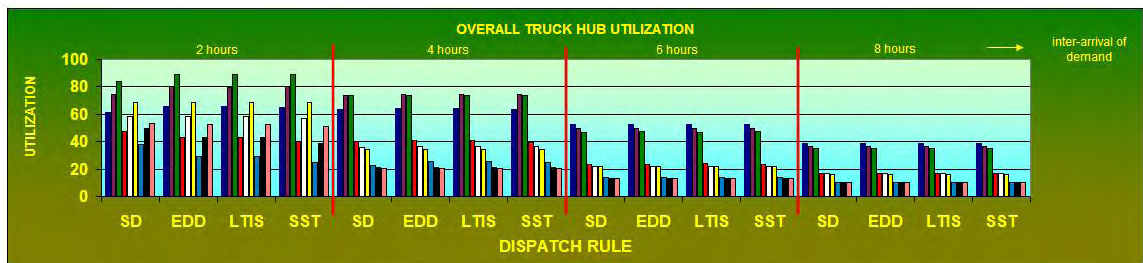
TRUCK HUB	FLEET SIZE	DEMAND															
		E (2)				E (4)				E (6)				E (8)			
		SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST
1 truck	2 trucks	76.42	78.76	78.57	78.87	74.33	76.30	76.25	76.89	61.75	62.75	62.85	63.34	46.64	47.03	47.16	47.23
	3 trucks	60.65	61.03	60.90	61.24	56.03	56.46	56.57	56.47	37.93	38.09	38.10	38.16	28.31	28.32	28.42	28.35
	4 trucks	49.95	48.43	48.51	48.55	40.52	40.63	40.70	40.69	26.42	26.40	26.35	26.43	19.78	19.79	19.77	19.81
2 trucks	2 trucks	96.96	99.22	99.29	99.58	87.79	94.75	94.81	96.65	61.35	64.04	64.04	65.15	46.62	47.67	47.53	47.98
	3 trucks	87.12	91.87	91.65	92.96	59.90	61.39	61.62	62.15	38.46	38.74	38.77	38.78	28.49	28.58	28.58	28.57
3 trucks	4 trucks	76.84	79.78	79.67	80.33	41.60	41.93	41.91	42.06	26.63	26.67	26.67	26.70	19.86	19.87	19.88	19.86
	2 trucks	99.75	99.87	99.86	99.90	85.66	95.24	95.20	97.51	61.06	64.01	64.28	65.27	46.70	47.89	47.72	48.27
	3 trucks	97.11	99.45	99.47	99.70	59.49	61.67	61.77	62.62	38.54	38.89	38.88	39.01	28.64	28.70	28.71	28.76
	4 trucks	87.62	93.76	93.77	96.05	41.65	41.97	42.05	42.10	26.71	26.74	26.74	26.75	19.89	19.91	19.91	19.91

Figure 33 Delivery Truck Utilization Results for the Two Hub Scenario

As shown in Table 22, the shortest distance dispatch rule does not yield the highest delivery truck utilizations. This is because high utilization rates can be due to the inefficiency of the system. As indicated previously, the other dispatch rules tend to yield higher travel distances and hence resulting in a higher utilization. The delivery truck utilization increases as the number of hub trucks are increased since orders can be brought to the pickup location for delivery faster. The delivery truck is a significant bottleneck at high demand patterns of every 2 hours.

TRUCK HUB	FLEET SIZE	DEMAND			
		E (2)	E (4)	E (6)	E (8)
1 truck	2 trucks	EDD / LTIS/ SST	EDD / LTIS/ SST	*	*
	3 trucks	*	*	*	*
	4 trucks	SD	*	*	*
2 trucks	2 trucks	SST	SST	EDD / LTIS/ SST	*
	3 trucks	SST	*	*	*
	4 trucks	EDD / LTIS/ SST	*	*	*
3 trucks	2 trucks	EDD / LTIS/ SST	SST	*	*
	3 trucks	SST	EDD / LTIS/ SST	*	*
	4 trucks	SST	*	*	*

Table 22 Statistical Comparison Delivery Truck Utilization Results for Two Hub Scenario



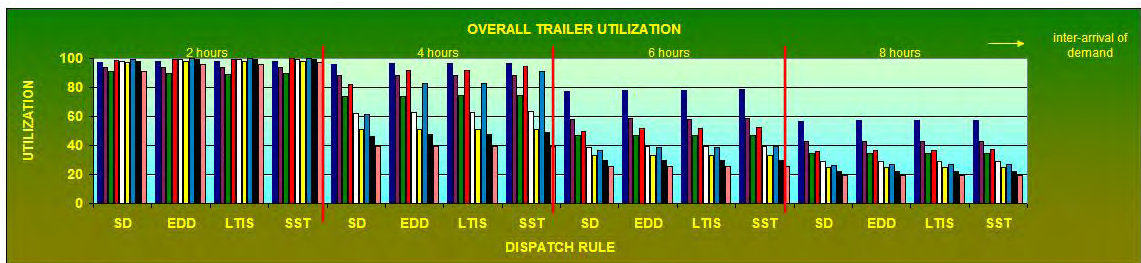
TRUCK HUB	FLEET SIZE	DEMAND															
		E (2)				E (4)				E (6)				E (8)			
		SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST
1 truck	2 trucks	61.04	65.64	65.62	65.27	63.29	64.13	64.35	63.84	52.60	52.56	52.37	52.57	38.38	38.44	38.42	38.51
	3 trucks	74.25	80.21	79.89	80.01	73.89	74.77	74.53	74.69	49.28	49.44	49.32	49.42	36.36	36.29	36.36	36.28
	4 trucks	84.28	89.34	89.33	89.30	73.47	73.82	73.96	73.97	46.93	47.10	46.99	47.14	35.09	35.05	35.07	35.05
2 trucks	2 trucks	47.26	43.10	43.34	40.21	40.24	40.58	40.61	39.29	23.35	23.56	23.75	23.67	16.99	17.04	17.01	17.05
	3 trucks	58.52	58.14	58.27	57.20	36.06	36.15	36.23	36.34	22.13	22.17	22.15	22.17	16.49	16.48	16.47	16.48
	4 trucks	68.50	68.62	68.92	68.56	34.01	34.02	34.02	34.02	21.65	21.67	21.65	21.66	16.18	16.18	16.18	16.18
3 trucks	2 trucks	37.76	29.12	29.20	25.14	22.83	25.32	25.38	24.84	13.64	13.68	13.68	13.81	10.09	10.10	10.10	10.11
	3 trucks	49.59	43.00	43.30	38.61	20.97	21.15	21.14	21.24	13.33	13.32	13.32	13.33	9.96	9.96	9.96	9.96
	4 trucks	53.09	52.48	52.51	50.98	20.47	20.47	20.47	20.47	13.17	13.17	13.17	13.16	9.91	9.91	9.90	9.91

Figure 34 Truck Hub Utilization Results for the Two Hub Scenario

Unlike the one hub scenario, the hub trucks are not a bottleneck for the two hub scenario, and sufficient hub truck capacity exists.

TRUCK HUB	FLEET SIZE	DEMAND			
		E (2)	E (4)	E (6)	E (8)
1 truck	2 trucks	EDD / LTIS/ SST	*	*	*
	3 trucks	EDD / LTIS/ SST	*	*	*
	4 trucks	EDD / LTIS/ SST	*	*	*
2 trucks	2 trucks	SD	*	*	*
	3 trucks	*	*	*	*
	4 trucks	*	*	*	*
3 trucks	2 trucks	SD	EDD / LTIS/ SST	*	*
	3 trucks	SD	*	*	*
	4 trucks	SD / EDD / LTIS	*	*	*

Table 23 Statistical Comparison Truck Hub Utilization Results for Two Hub Scenario



TRUCK HUB	FLEET SIZE	DEMAND															
		E (2)				E (4)				E (6)				E (8)			
		SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST
1 truck	2 trucks	97.24	97.66	97.61	97.67	96.06	96.51	96.48	96.53	77.50	78.08	78.03	78.41	56.83	57.05	57.11	57.19
	3 trucks	94.08	93.84	93.89	93.90	87.95	88.19	88.06	88.05	58.20	58.35	58.27	58.38	42.82	42.78	42.86	42.78
	4 trucks	91.26	89.40	89.31	89.45	74.06	74.09	74.14	74.20	46.67	46.77	46.67	46.79	34.56	34.54	34.55	34.55
2 trucks	2 trucks	98.80	99.60	99.64	99.71	82.30	91.56	91.42	94.23	49.64	51.64	51.73	52.69	36.13	36.73	36.63	36.93
	3 trucks	98.04	99.03	98.99	99.10	61.73	62.60	62.69	63.18	38.83	38.99	38.97	39.02	28.95	28.98	28.98	28.98
	4 trucks	97.57	98.03	98.08	98.16	50.76	50.90	50.88	50.95	32.76	32.78	32.78	32.79	24.61	24.61	24.61	24.61
3 trucks	2 trucks	99.01	99.81	99.83	99.85	61.51	83.01	83.09	91.10	36.35	38.34	38.39	39.59	26.52	27.03	26.96	27.24
	3 trucks	97.97	99.31	99.34	99.52	46.48	47.82	47.89	48.68	29.51	29.63	29.63	29.69	22.05	22.06	22.07	22.09
	4 trucks	91.32	95.58	95.57	97.13	39.41	39.55	39.57	39.61	25.62	25.63	25.63	25.63	19.29	19.29	19.29	19.29

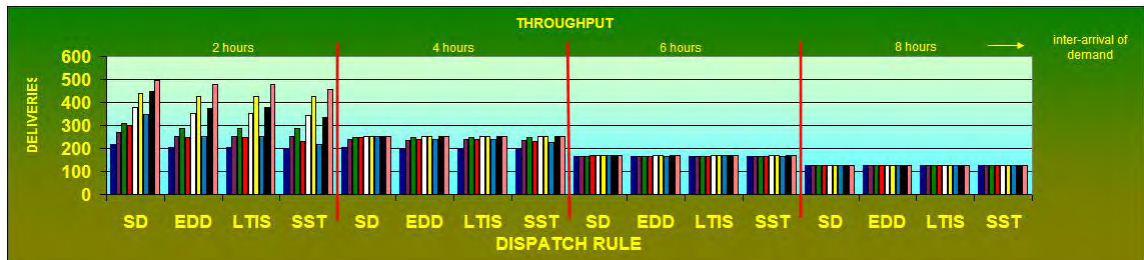
Figure 35 Trailer Utilization Results for the Two Hub Scenario

Trailers have very high utilization rates at peak demand of E(2). Note, the number trailers simulated is always three times the total number of trucks simulated. Hence, at high demand patterns, the trailer capacities should be increased to at least four times the total number of trucks simulated.

TRUCK HUB	FLEET SIZE	DEMAND			
		E (2)	E (4)	E (6)	E (8)
1 truck	2 trucks	EDD / LTIS/ SST	*	*	*
	3 trucks	*	*	*	*
	4 trucks	SD	*	*	*
2 trucks	2 trucks	EDD / LTIS/ SST	SST	*	*
	3 trucks	EDD / LTIS/ SST	*	*	*
	4 trucks	EDD / LTIS/ SST	*	*	*
3 trucks	2 trucks	EDD / LTIS/ SST	SST	EDD / LTIS/ SST	*
	3 trucks	EDD / LTIS/ SST	*	*	*
	4 trucks	EDD / LTIS/ SST	*	*	*

Table 24 Statistical Comparison Trailer Utilization Results for Two Hub Scenario

Throughput Results



TRUCK HUB	FLEET SIZE	DEMAND															
		E (2)				E (4)				E (6)				E (8)			
		SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST
1 truck	2 trucks	218.70	202.55	202.29	201.31	204.86	197.48	197.84	196.92	165.79	165.54	165.58	165.39	126.96	126.89	126.93	126.93
	3 trucks	269.16	253.15	251.69	252.67	238.19	236.42	236.99	236.71	167.18	167.16	167.18	167.11	127.23	127.23	127.18	127.21
	4 trucks	309.12	288.57	289.02	288.28	248.27	247.69	247.75	247.70	167.32	167.32	167.30	167.30	127.18	127.20	127.15	127.21
2 trucks	2 trucks	301.54	249.57	249.20	231.45	248.92	239.61	239.58	228.66	167.52	167.32	167.37	167.19	127.38	127.37	127.35	127.39
	3 trucks	377.05	351.15	350.55	343.89	250.86	250.82	250.81	250.76	167.52	167.57	167.53	167.58	127.35	127.35	127.34	127.35
	4 trucks	439.34	426.12	426.04	424.88	250.96	251.06	250.97	251.04	167.43	167.42	167.42	167.43	127.25	127.25	127.25	127.25
3 trucks	2 trucks	349.07	251.29	251.93	218.50	250.44	241.21	241.06	224.43	167.68	167.39	167.45	167.23	127.43	127.47	127.43	127.46
	3 trucks	447.75	375.84	377.03	336.85	251.13	251.17	251.13	251.05	167.55	167.57	167.58	167.59	127.33	127.33	127.34	127.34
	4 trucks	497.52	478.50	479.26	458.20	251.13	251.14	251.14	251.17	167.41	167.42	167.45	167.42	127.23	127.23	127.23	127.23

Figure 36 Throughput Results for the Two Hub Scenario

Compared with the one hub scenario, maximum throughput of 500 can be achieved for the demand patterns of every 2 hours for the SD dispatch rule. Table 26 provides the recommended fleet sizes for the various demand rates for the two hub simulation models.

TRUCK HUB	FLEET SIZE	DEMAND			
		E (2)	E (4)	E (6)	E (8)
1 truck	2 trucks	SD	SD	*	*
	3 trucks	SD	*	*	*
	4 trucks	SD	*	*	*
2 trucks	2 trucks	SD	SD	*	*
	3 trucks	SD	*	*	*
	4 trucks	SD	*	*	*
3 trucks	2 trucks	SD	SD	*	*
	3 trucks	SD	*	*	*
	4 trucks	SD	*	*	*

Table 25 Statistical Comparison Throughput Results for Two Hub Scenario

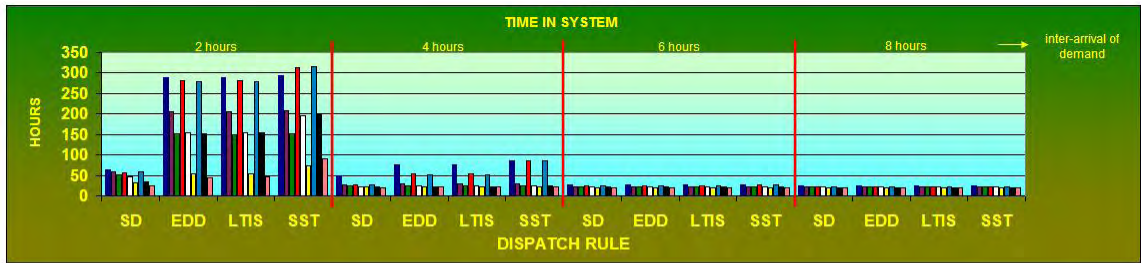
Inter-arrival of demand	Truck Hub	Delivery Truck
2 hours	3	4
4 hours	1	4
6 hours	1	2
8 hours	1	2

Table 26 Recommended Fleet Sizes for SCTV Model Two Hub Scenario

5.3 Experimentation and Results for the Three Hub Model Scenario

This section presents the experimentation and output results for the STCV simulation model for the three hub scenario. The hubs are located in Oakland, Los Angeles and Fresno. The truck hub column in the figures refers to the number of trucks simulated to delivery empty trailers to pickup and from delivery locations for each hub, and the fleet size column refers to the number of trucks simulated for the delivery task. The hub trucks are assigned to only one hub location, and hence if two trucks are allocated per hub then the system contains a total of six hub trucks.

Time in System Results



TRUCK HUB	FLEET SIZE	DEMAND															
		E (2)				E (4)				E (6)				E (8)			
		SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST
1 truck	2 trucks	64.82	288.96	289.80	294.24	47.98	76.59	76.56	84.44	26.34	27.47	27.28	27.83	23.74	24.05	24.08	24.18
	3 trucks	57.61	206.34	206.66	208.01	27.87	28.86	28.73	29.10	22.78	22.93	22.91	22.94	21.82	21.87	21.87	21.89
	4 trucks	50.51	150.99	150.52	150.94	24.06	24.36	24.43	24.50	21.71	21.79	21.75	21.79	21.11	21.14	21.13	21.14
2 trucks	2 trucks	56.08	281.09	280.46	314.48	27.41	53.05	53.00	84.99	23.58	25.23	25.03	26.04	22.58	23.04	23.03	23.20
	3 trucks	45.66	153.95	155.05	195.00	22.48	23.28	23.27	23.87	21.30	21.41	21.38	21.45	20.89	20.93	20.93	20.94
	4 trucks	32.33	53.78	53.58	72.51	21.04	21.14	21.13	21.17	20.44	20.45	20.45	20.46	20.24	20.24	20.25	20.25
3 trucks	2 trucks	59.80	279.55	278.34	315.00	26.47	52.55	52.45	85.79	23.30	24.93	24.81	25.82	22.34	22.81	22.77	22.99
	3 trucks	35.13	152.24	153.46	200.34	22.12	22.92	22.94	23.52	21.05	21.15	21.14	21.20	20.70	20.73	20.74	20.75
	4 trucks	24.26	45.16	46.48	90.34	20.73	20.83	20.82	20.86	20.22	20.24	20.23	20.24	20.08	20.08	20.08	20.08

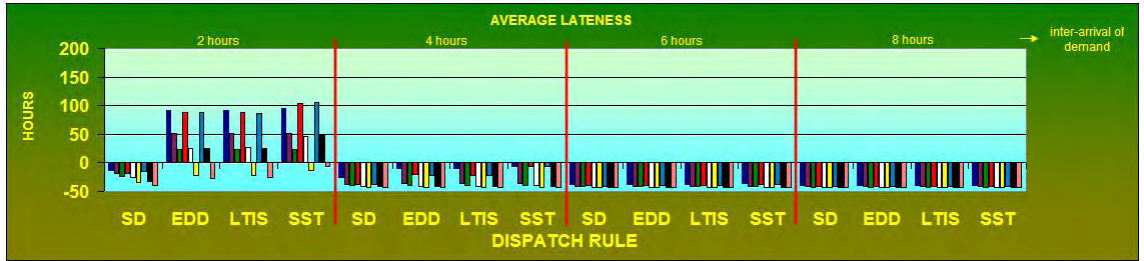
Figure 37 Average Time in System Results for the Three Hub Scenario

The three hub scenario resulted in a decrease of approximately 10 hours for the minimum cycle time for the demand pattern of every 2 hours as compared to the two hub scenario. This occurred for the 3 hub trucks and 4 delivery trucks simulation model for the SD dispatch rule. However, the reduction of the 10 hours in cycle time is offset by the expense of an additional 3 hub trucks due to the extra hub.

TRUCK HUB	FLEET SIZE	DEMAND			
		E (2)	E (4)	E (6)	E (8)
1 truck	2 trucks	SD	SD	SD	*
	3 trucks	SD	*	*	*
	4 trucks	SD	*	*	*
2 trucks	2 trucks	SD	SD	SD	SD
	3 trucks	SD	SD	*	*
	4 trucks	SD	*	*	*
3 trucks	2 trucks	SD	SD	SD	SD
	3 trucks	SD	SD	*	*
	4 trucks	SD	*	*	*

Table 27 Statistical Comparison Average Time in System Results for Three Hub Scenario

Average Lateness Results



TRUCK HUB	FLEET SIZE	DEMAND															
		E (2)				E (4)				E (6)				E (8)			
		SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST
1 truck	2 trucks	-13.72	92.44	92.33	95.87	-25.28	-9.93	-10.11	-5.72	-37.98	-36.91	-37.10	-36.58	-40.29	-39.98	-39.96	-39.83
	3 trucks	-18.75	50.72	50.65	52.26	-37.17	-36.14	-36.39	-36.04	-41.06	-40.86	-40.92	-40.85	-42.06	-42.01	-42.02	-41.98
	4 trucks	-23.51	23.73	22.84	23.70	-40.31	-39.96	-39.95	-39.90	-42.10	-42.01	-42.04	-42.01	-42.82	-42.80	-42.80	-42.79
2 trucks	2 trucks	-17.78	88.73	87.66	103.98	-36.99	-21.13	-21.58	-6.82	-40.20	-38.73	-38.94	-38.20	-41.29	-40.82	-40.82	-40.69
	3 trucks	-25.89	25.53	26.21	45.35	-41.39	-40.63	-40.71	-40.19	-42.33	-42.21	-42.26	-42.18	-42.85	-42.82	-42.81	-42.80
	4 trucks	-34.57	-22.60	-22.83	-13.88	-42.81	-42.72	-42.73	-42.69	-43.22	-43.20	-43.20	-43.20	-43.57	-43.57	-43.56	-43.56
3 trucks	2 trucks	-15.12	88.39	87.14	104.73	-37.70	-21.50	-21.73	-6.49	-40.41	-39.00	-39.10	-38.34	-41.44	-40.98	-40.99	-40.85
	3 trucks	-32.06	24.98	25.78	47.60	-41.69	-40.95	-40.96	-40.47	-42.52	-42.42	-42.45	-42.38	-42.97	-42.94	-42.93	-42.91
	4 trucks	-39.87	-26.87	-26.18	-6.67	-43.08	-42.96	-42.98	-42.92	-43.39	-43.37	-43.38	-43.37	-43.67	-43.67	-43.67	-43.67

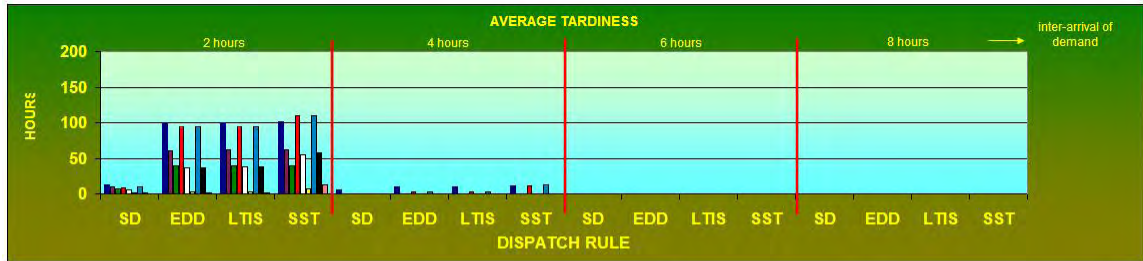
Figure 38 Average Lateness Results for the Three Hub Scenario

The results for average lateness for the three hub scenario are similar to the two hub scenario.

TRUCK HUB	FLEET SIZE	DEMAND			
		E (2)	E (4)	E (6)	E (8)
1 truck	2 trucks	SD	SD	*	*
	3 trucks	SD	*	*	*
	4 trucks	SD	*	*	*
2 trucks	2 trucks	SD	SD	SD	*
	3 trucks	SD	SD	*	*
	4 trucks	SD	*	*	*
3 trucks	2 trucks	SD	SD	SD	*
	3 trucks	SD	SD	*	*
	4 trucks	SD	*	*	*

Table 28 Statistical Comparison Average Lateness Results for Three Hub Scenario

Average Tardiness Results



TRUCK HUB	FLEET SIZE	DEMAND															
		E (2)				E (4)				E (6)				E (8)			
		SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST
1 truck	2 trucks	12.35	98.96	99.53	102.10	5.21	9.23	9.69	11.97	0.12	0.01	0.04	0.02	0.01	0.00	0.00	0.00
	3 trucks	9.66	60.94	61.64	62.34	0.49	0.08	0.14	0.11	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	4 trucks	7.18	38.87	38.75	38.85	0.09	0.01	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2 trucks	2 trucks	8.08	94.85	94.49	109.77	0.12	2.87	3.22	11.77	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00
	3 trucks	5.03	36.75	37.83	54.98	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	4 trucks	1.49	2.74	3.07	7.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3 trucks	2 trucks	9.33	94.41	93.97	110.43	0.11	2.73	3.19	11.99	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00
	3 trucks	1.54	36.21	37.34	57.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	4 trucks	0.03	1.35	1.85	12.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

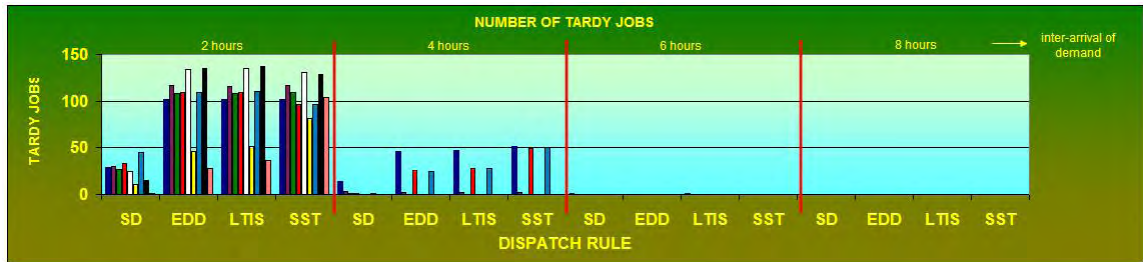
Figure 39 Average Tardiness Results for the Three Hub Scenario

Obviously, as the truck fleet size (delivery and hub trucks) increases tardiness decreases. Note, tardy orders still exist for the demand pattern of every 2 hours and when only 2 delivery trucks are simulated for the demand pattern of every 4 hours.

TRUCK HUB	FLEET SIZE	DEMAND			
		E (2)	E (4)	E (6)	E (8)
1 truck	2 trucks	SD	SD	EDD / LTIS / SST	*
	3 trucks	SD	EDD / LTIS / SST	*	*
	4 trucks	SD	EDD / LTIS / SST	*	*
2 trucks	2 trucks	SD	SD	*	*
	3 trucks	SD	*	*	*
	4 trucks	SD / EDD / LTIS	*	*	*
3 trucks	2 trucks	SD	SD	*	*
	3 trucks	SD	*	*	*
	4 trucks	SD	*	*	*

Table 29 Statistical Comparison Average Tardiness Results for Three Hub Scenario

Number of Tardy Orders Results



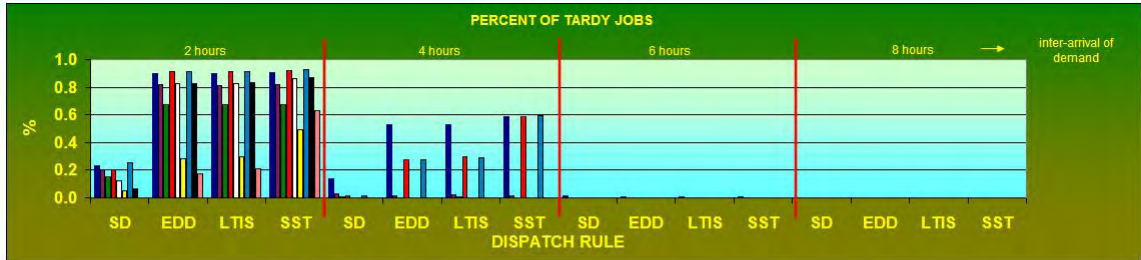
TRUCK HUB	FLEET SIZE	DEMAND															
		E (2)				E (4)				E (6)				E (8)			
		SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST
1 truck	2 trucks	28.91	102.14	102.10	101.35	14.21	45.92	47.08	51.59	0.89	0.28	0.66	0.51	0.09	0.02	0.07	0.01
	3 trucks	30.53	116.71	115.45	116.73	3.14	1.62	2.25	1.84	0.08	0.02	0.04	0.02	0.02	0.00	0.01	0.00
	4 trucks	26.46	108.67	108.72	109.25	0.83	0.20	0.49	0.23	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2 trucks	2 trucks	33.22	109.20	109.74	96.93	1.51	25.29	27.68	49.36	0.12	0.03	0.11	0.19	0.01	0.00	0.02	0.00
	3 trucks	24.76	134.40	135.17	130.28	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	4 trucks	10.70	45.77	50.91	81.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3 trucks	2 trucks	45.50	109.74	110.04	96.41	1.49	25.00	27.70	50.68	0.12	0.01	0.14	0.19	0.01	0.00	0.02	0.00
	3 trucks	15.38	134.84	136.74	128.49	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	4 trucks	0.65	28.20	36.59	103.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure 40 Number of Tardy Orders Results for the Three Hub Scenario

Tardy orders still occur for the three hub scenario for peak demand of every 2 hours.

TRUCK HUB	FLEET SIZE	DEMAND			
		E (2)	E (4)	E (6)	E (8)
1 truck	2 trucks	SD	SD	SD	*
	3 trucks	SD	*	*	EDD / SST
	4 trucks	SD	*	EDD / LTIS / SST	*
2 trucks	2 trucks	SD	SD	*	*
	3 trucks	SD	*	*	*
	4 trucks	SD	*	*	*
3 trucks	2 trucks	SD	SD	EDD	*
	3 trucks	SD	*	*	*
	4 trucks	SD	*	*	*

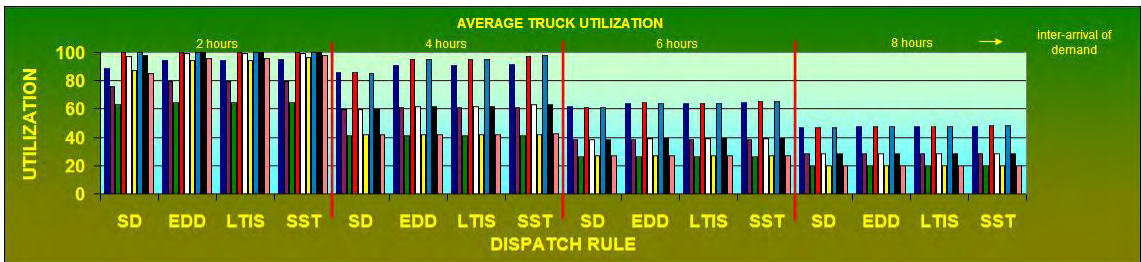
Table 30 Statistical Comparison Number of Tardy Orders Results for Three Hub Scenario



TRUCK HUB	FLEET SIZE	DEMAND															
		E (2)				E (4)				E (6)				E (8)			
		SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST
1 truck	2 trucks	0.23	0.90	0.90	0.91	0.14	0.53	0.53	0.59	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.00
	3 trucks	0.20	0.82	0.81	0.82	0.03	0.01	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	4 trucks	0.15	0.67	0.67	0.67	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2 trucks	2 trucks	0.20	0.91	0.92	0.92	0.01	0.28	0.30	0.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	3 trucks	0.12	0.83	0.83	0.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	4 trucks	0.05	0.28	0.30	0.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3 trucks	2 trucks	0.26	0.92	0.92	0.92	0.01	0.28	0.29	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	3 trucks	0.07	0.83	0.83	0.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	4 trucks	0.00	0.18	0.21	0.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure 41 Percent of Tardy Orders Results for the Three Hub Scenario

Utilization Results



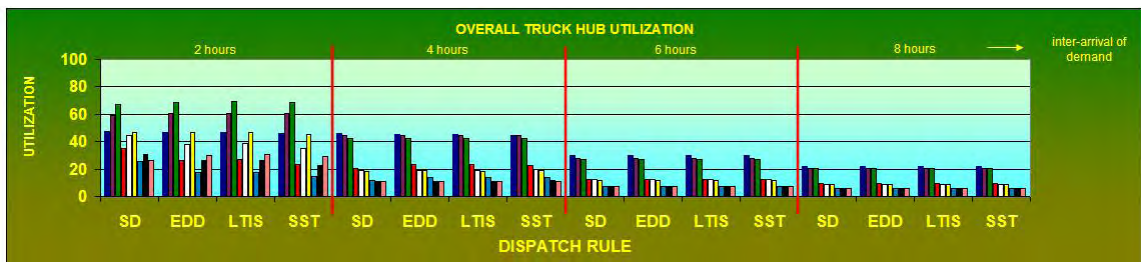
TRUCK HUB	FLEET SIZE	DEMAND															
		E (2)				E (4)				E (6)				E (8)			
		SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST
1 truck	2 trucks	88.92	94.07	94.41	95.02	86.14	90.54	90.44	91.26	61.98	63.91	63.74	64.34	46.66	47.40	47.46	47.71
	3 trucks	75.55	79.30	79.30	79.67	59.72	60.70	60.81	61.14	38.31	38.59	38.53	38.58	28.39	28.44	28.47	28.48
	4 trucks	63.22	64.75	64.77	64.87	41.18	41.37	41.37	41.46	26.50	26.55	26.52	26.55	19.83	19.83	19.84	19.83
2 trucks	2 trucks	99.70	99.87	99.85	99.90	85.60	95.38	95.32	97.44	61.01	64.26	64.11	65.27	46.65	47.77	47.80	48.10
	3 trucks	97.21	99.46	99.51	99.63	59.42	61.58	61.59	62.79	38.45	38.81	38.75	38.92	28.52	28.61	28.63	28.62
	4 trucks	87.31	94.02	94.00	96.12	41.66	42.03	42.04	42.14	26.63	26.66	26.66	26.66	19.86	19.88	19.88	19.89
3 trucks	2 trucks	99.88	99.90	99.91	99.91	85.05	95.26	95.36	97.52	61.04	64.18	64.13	65.33	46.60	47.80	47.77	48.13
	3 trucks	98.04	99.74	99.77	99.79	59.43	61.65	61.84	62.80	38.53	38.84	38.82	38.96	28.59	28.68	28.70	28.72
	4 trucks	85.44	95.57	95.93	98.18	41.79	42.19	42.19	42.33	26.64	26.72	26.69	26.72	19.92	19.93	19.94	19.94

Figure 42 Delivery Truck Utilization Results for the Three Hub Scenario

The delivery truck is a bottleneck for the demand pattern of every 2 hours and when only 2 delivery trucks are simulated for the demand pattern of every 4 hours.

TRUCK HUB	FLEET SIZE	DEMAND			
		E (2)	E (4)	E (6)	E (8)
1 truck	2 trucks	SST	EDD / LTIS / SST	*	*
	3 trucks	EDD / LTIS / SST	*	*	*
	4 trucks	EDD / LTIS / SST	*	*	*
2 trucks	2 trucks	EDD / LTIS / SST	SST	EDD / LTIS / SST	*
	3 trucks	EDD / LTIS / SST	EDD / LTIS / SST	*	*
	4 trucks	SST	*	*	*
3 trucks	2 trucks	*	SST	EDD / LTIS / SST	*
	3 trucks	EDD / LTIS / SST	EDD / LTIS / SST	*	*
	4 trucks	SST	*	*	*

Table 31 Statistical Comparison Delivery Truck Utilization Results for Three Hub Scenario



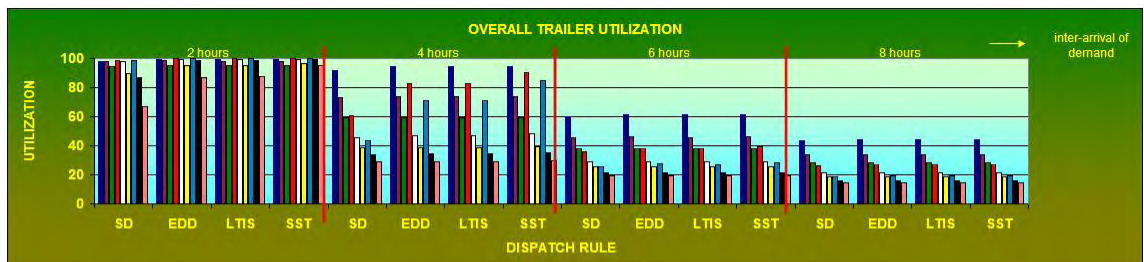
TRUCK HUB	FLEET SIZE	DEMAND															
		E (2)				E (4)				E (6)				E (8)			
		SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST
1 truck	2 trucks	47.25	47.01	46.77	46.21	46.27	45.15	45.40	44.63	29.83	29.92	29.87	30.01	21.64	21.64	21.67	21.64
	3 trucks	59.16	60.48	60.39	60.35	44.56	44.72	44.74	44.71	27.69	27.74	27.70	27.76	20.57	20.60	20.58	20.59
	4 trucks	66.83	68.91	69.01	68.90	41.98	42.01	42.09	42.13	26.86	26.85	26.80	26.85	20.11	20.11	20.11	20.11
2 trucks	2 trucks	34.70	26.48	26.65	23.18	20.73	23.26	23.08	22.71	12.52	12.61	12.63	12.72	9.27	9.28	9.27	9.28
	3 trucks	44.72	38.27	38.40	34.68	19.12	19.24	19.21	19.35	12.20	12.21	12.20	12.20	9.12	9.12	9.12	9.12
	4 trucks	46.74	46.48	46.49	45.09	18.61	18.63	18.61	18.63	12.03	12.03	12.03	12.03	9.02	9.02	9.02	9.02
3 trucks	2 trucks	25.78	17.44	17.45	14.96	11.63	13.54	13.51	14.11	7.41	7.42	7.42	7.45	5.55	5.54	5.54	5.54
	3 trucks	30.88	26.08	25.97	22.64	11.29	11.30	11.30	11.32	7.33	7.33	7.33	7.33	5.51	5.51	5.51	5.51
	4 trucks	25.99	30.19	30.30	29.12	11.17	11.15	11.15	11.16	7.27	7.27	7.27	7.27	5.49	5.49	5.50	5.49

Figure 43 Hub Truck Utilization Results for the Three Hub Scenario

As expected, the hub trucks are not a bottleneck for the three hub scenario.

TRUCK HUB	FLEET SIZE	DEMAND			
		E (2)	E (4)	E (6)	E (8)
1 truck	2 trucks	*	*	*	*
	3 trucks	EDD / LTIS / SST	*	*	*
	4 trucks	EDD / LTIS / SST	*	*	*
2 trucks	2 trucks	SD	EDD / LTIS / SST	*	*
	3 trucks	SD	*	*	*
	4 trucks	SD / EDD / LTIS	*	*	*
3 trucks	2 trucks	SD	EDD / LTIS / SST	*	*
	3 trucks	SD	*	*	*
	4 trucks	EDD / LTIS / SST	*	*	*

Table 32 Statistical Comparison Hub Truck Utilization Results for Three Hub Scenario



TRUCK HUB	FLEET SIZE	DEMAND															
		E (2)				E (4)				E (6)				E (8)			
		SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST
1 truck	2 trucks	97.63	99.07	99.08	99.11	91.84	94.27	94.25	94.78	59.94	61.31	61.06	61.69	43.46	43.86	43.88	44.03
	3 trucks	97.59	98.29	98.18	98.27	73.11	73.62	73.60	73.89	45.76	45.91	45.85	45.93	33.86	33.89	33.88	33.90
	4 trucks	94.66	95.06	95.03	95.01	59.16	59.34	59.31	59.43	37.78	37.76	37.72	37.77	28.21	28.22	28.21	28.23
2 trucks	2 trucks	98.89	99.79	99.80	99.82	60.70	82.89	82.72	90.64	35.83	38.14	37.86	39.20	26.15	26.63	26.63	26.81
	3 trucks	97.63	99.21	99.26	99.42	45.72	47.13	47.11	48.11	29.02	29.16	29.13	29.21	21.66	21.70	21.70	21.71
	4 trucks	89.83	95.04	95.05	96.65	38.78	38.93	38.92	38.98	25.18	25.19	25.19	25.20	18.95	18.95	18.95	18.95
3 trucks	2 trucks	98.61	99.72	99.71	99.77	43.30	70.92	70.76	84.51	25.57	27.27	27.14	28.20	18.68	19.03	19.01	19.17
	3 trucks	87.13	98.76	98.82	99.11	33.55	34.67	34.70	35.49	21.35	21.45	21.44	21.48	15.96	15.98	15.99	15.99
	4 trucks	67.03	86.66	87.52	94.89	29.19	29.31	29.30	29.36	19.00	19.01	19.01	19.02	14.33	14.33	14.33	14.33

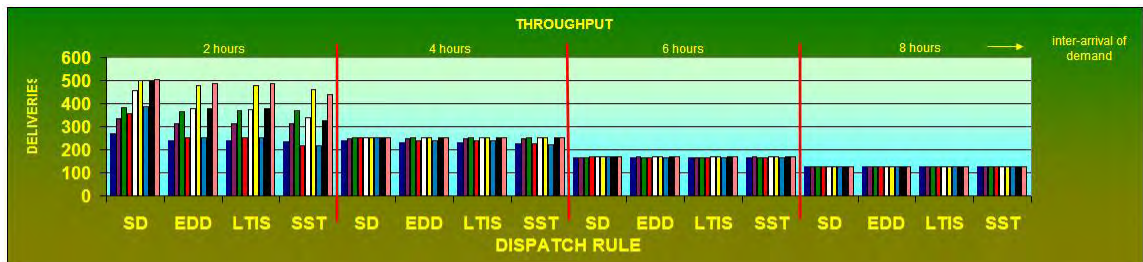
Figure 44 Trailer Utilization Results for the Three Hub Scenario

Similar to the two hub scenario, trailers also have very high utilization rates at peak demand of E(2) for the three hub scenario.

TRUCK HUB	FLEET SIZE	DEMAND			
		E (2)	E (4)	E (6)	E (8)
1 truck	2 trucks	EDD / LTIS / SST	EDD / LTIS / SST	*	*
	3 trucks	EDD / LTIS / SST	*	*	*
	4 trucks	*	*	*	*
2 trucks	2 trucks	EDD / LTIS / SST	SST	EDD / LTIS / SST	*
	3 trucks	EDD / LTIS / SST	*	*	*
	4 trucks	EDD / LTIS / SST	*	*	*
3 trucks	2 trucks	EDD / LTIS / SST	SST	EDD / LTIS / SST	*
	3 trucks	EDD / LTIS / SST	*	*	*
	4 trucks	SST	*	*	*

Table 33 Statistical Comparison Trailer Utilization Results for Three Hub Scenario

Throughput Results



TRUCK HUB	FLEET SIZE	DEMAND															
		E (2)				E (4)				E (6)				E (8)			
		SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST	SD	EDD	LTIS	SST
1 truck	2 trucks	267.52	237.99	238.02	234.08	238.14	229.36	229.28	226.01	167.16	167.02	166.97	166.86	127.08	127.12	127.11	127.09
	3 trucks	333.22	314.47	313.79	313.66	249.89	249.54	249.49	249.59	167.33	167.42	167.36	167.41	127.12	127.15	127.12	127.14
	4 trucks	380.81	367.10	367.44	367.43	250.51	250.41	250.37	250.43	167.35	167.38	167.37	167.37	127.14	127.15	127.15	127.16
2 trucks	2 trucks	355.31	251.48	251.84	219.19	250.41	241.26	240.88	224.18	167.52	167.27	167.26	167.03	127.21	127.26	127.28	127.25
	3 trucks	455.24	376.43	375.95	337.49	250.93	250.85	250.97	250.91	167.41	167.43	167.43	167.42	127.26	127.25	127.26	127.26
	4 trucks	498.24	479.36	479.92	459.15	251.03	251.06	251.04	251.04	167.42	167.40	167.40	167.40	127.22	127.21	127.22	127.21
3 trucks	2 trucks	386.66	251.49	252.57	217.11	250.72	240.92	241.24	223.77	167.55	167.33	167.35	167.06	127.28	127.32	127.31	127.30
	3 trucks	496.92	377.87	377.51	327.53	251.11	251.00	251.06	250.97	167.48	167.48	167.50	167.49	127.26	127.26	127.26	127.27
	4 trucks	503.61	487.70	486.90	438.22	251.11	251.17	251.13	251.13	167.43	167.43	167.42	167.43	127.20	127.20	127.20	127.20

Figure 45 Throughput Results for the Three Hub Scenario

Compared with the two hub scenario, maximum throughput of 500 can be achieved for the demand patterns of every 2 hours for the SD dispatch rule with 2 hub trucks at each hub instead of 3 hub trucks at each hub. Note, the total number of hub trucks, 6, are identical in both scenarios. The next section presents a detailed statistical comparison between all the scenarios simulated. Table 35 provides the recommended fleet sizes for the various demand rates for the three hub simulation models.

TRUCK HUB	FLEET SIZE	DEMAND			
		E (2)	E (4)	E (6)	E (8)
1 truck	2 trucks	SD	SD	*	*
	3 trucks	SD	*	*	*
	4 trucks	SD	*	*	*
2 trucks	2 trucks	SD	*	*	*
	3 trucks	SD	*	*	*
	4 trucks	SD	*	*	*
3 trucks	2 trucks	SD	*	*	*
	3 trucks	SD	*	*	*
	4 trucks	SD	*	*	*

Table 34 Statistical Comparison Throughput Results for Three Hub Scenario

Inter-arrival of demand	Truck Hub	Fleet Size
2 hours	2	4
4 hours	1	3
6 hours	1	2
8 hours	1	2

Table 35 Recommended Fleet Sizes for SCTV Model Three Hub Scenario

6 STATISTICAL COMPARISON BETWEEN THE CONVENTIONAL SYSTEM AND THE STCV HUB SYSTEMS

This section presents the statistical comparison between the conventional system and the proposed STCV system. The following four scenarios are compared:

- conventional system (no hub)
- one hub location model at Fresno
- two hub location model at Los Angeles and Oakland
- three hub location model at Los Angeles, Oakland, and Fresno.

The statistical analysis is only performed for the shortest distance dispatch rule since in general this rule yields the best results. The following performance measures were compared:

- average time customer order spends in the system (cycle time)
- average lateness of a customer order
- average tardiness of a customer order
- average number of tardy orders
- average throughput (number of completed orders)

A 95% confidence interval was used to test for statistical significance between different scenarios for the same total truck capacity. For example, a truck capacity of 5 yields the following scenarios for comparison:

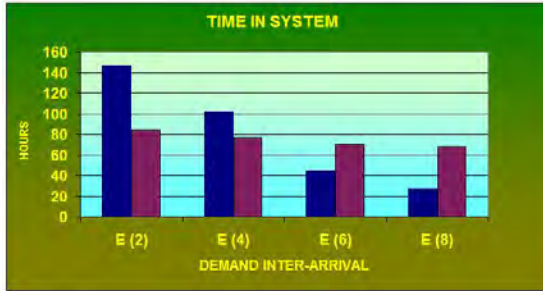
- conventional system with 5 trucks (no hub)
- one hub model with 1 hub truck and 4 delivery trucks
- one hub model with 2 hub trucks and 3 delivery trucks
- one hub model with 3 hub trucks and 2 delivery trucks
- two hub model and 1 hub truck per hub location and 3 delivery trucks
- three hub model and 1 hub truck per hub location and 2 delivery trucks

An asterisk symbol (*) indicates no significant difference exists between the different scenarios as shown on the figures displaying the statistical comparisons. The name of the scenario is given in the table if it is statistical significant at $\alpha = .05$. The different scenarios are represented by the following abbreviations:

- No hub
- 1 hub (# of hub trucks, # of delivery trucks)
- 2 hubs (# of hub trucks, # of delivery trucks)
- 3 hubs (# of hub trucks, # of delivery trucks)

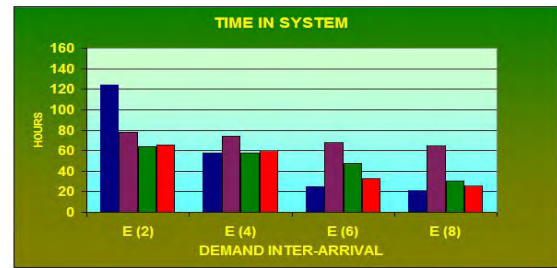
Note, the # of hub trucks indicates the number of hub trucks per hub location, and hence if 2 hubs are simulated and # of hub trucks equals 2 then a total of 4 hub trucks are available.

Time in System Results



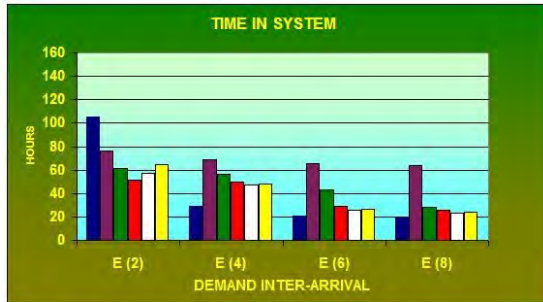
SYSTEM	TRUCK HUB	FLEET SIZE	DEMAND			
			E (2)	E (4)	E (6)	E (8)
NO HUB	-	3 trucks	146.69	101.97	44.51	27.22
1 HUB	1 truck	2 trucks	84.45	76.95	70.06	67.72

3 trucks



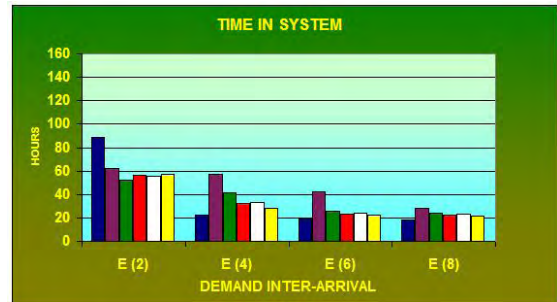
SYSTEM	TRUCK HUB	FLEET SIZE	DEMAND			
			E (2)	E (4)	E (6)	E (8)
NO HUB	-	4 trucks	124.26	58.03	24.90	21.01
1 HUB	1 truck	3 trucks	77.89	74.35	67.79	65.13
	2 trucks	2 trucks	64.02	57.81	47.47	30.74
2 HUBS	1 truck	2 trucks	65.74	60.33	33.04	25.90

4 trucks



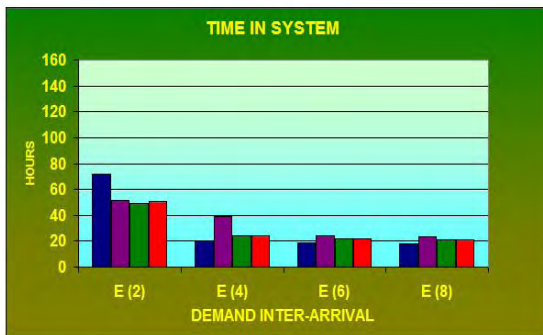
SYSTEM	TRUCK HUB	FLEET SIZE	DEMAND			
			E (2)	E (4)	E (6)	E (8)
NO HUB	-	5 trucks	104.96	29.13	20.71	19.19
1 HUB	1 truck	4 trucks	76.54	68.97	65.37	63.78
	2 trucks	3 trucks	61.55	56.40	43.01	28.53
	3 trucks	2 trucks	51.52	49.82	28.61	25.53
2 HUBS	1 truck	3 trucks	56.91	47.13	25.50	23.11
3 HUBS	1 truck	2 trucks	64.82	47.98	26.34	23.74

5 trucks



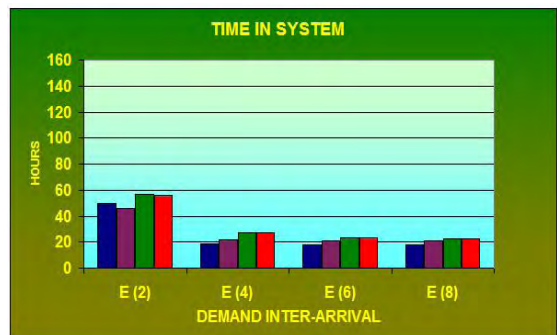
SYSTEM	TRUCK HUB	FLEET SIZE	DEMAND			
			E (2)	E (4)	E (6)	E (8)
NO HUB	-	6 trucks	88.64	22.54	19.10	18.39
1 HUB	2 trucks	4 trucks	61.81	56.99	42.32	27.91
	3 trucks	3 trucks	52.12	41.69	25.33	23.85
	1 truck	4 trucks	56.65	32.30	23.44	22.12
2 HUBS	2 trucks	2 trucks	55.76	33.01	24.35	23.03
3 HUBS	1 truck	3 trucks	57.61	27.67	22.78	21.82

6 trucks



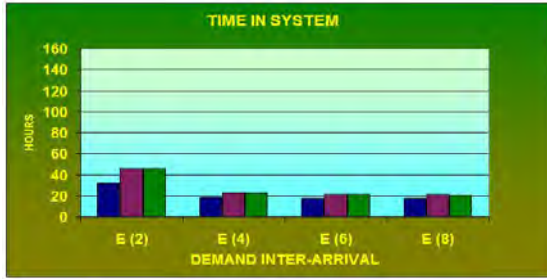
SYSTEM	TRUCK HUB	FLEET SIZE	DEMAND			
			E (2)	E (4)	E (6)	E (8)
NO HUB	-	7 trucks	72.14	20.10	18.34	18.01
1 HUB	3 trucks	4 trucks	51.27	38.81	24.45	23.26
2 HUBS	2 trucks	3 trucks	49.56	23.88	21.79	21.31
3 HUBS	1 truck	4 trucks	50.51	24.06	21.71	21.11

7 trucks



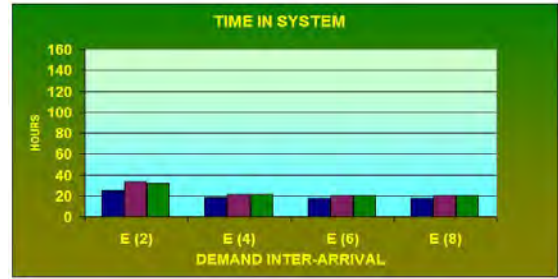
SYSTEM	TRUCK HUB	FLEET SIZE	DEMAND			
			E (2)	E (4)	E (6)	E (8)
NO HUB	-	8 trucks	49.79	18.91	17.96	17.80
2 HUBS	2 trucks	4 trucks	46.10	21.77	20.88	20.62
	3 trucks	3 trucks	56.75	27.50	23.67	22.67
	2 trucks	2 trucks	56.08	27.41	23.58	22.58
3 HUBS	2 trucks	2 trucks	56.08	27.41	23.58	22.58

8 trucks



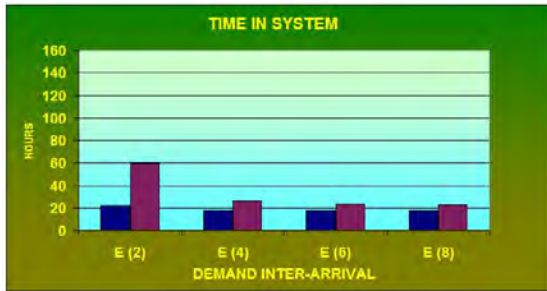
SYSTEM	TRUCK HUB	FLEET SIZE	DEMAND			
			E (2)	E (4)	E (6)	E (8)
NO HUB	-	9 trucks	32.14	18.27	17.75	17.67
2 HUBS	3 trucks	3 trucks	45.87	22.59	21.41	21.04
3 HUBS	2 trucks	3 trucks	45.66	22.48	21.30	20.89

9 trucks



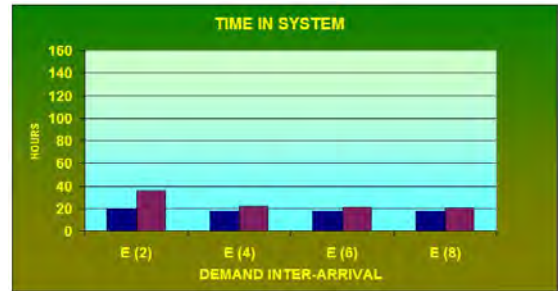
SYSTEM	TRUCK HUB	FLEET SIZE	DEMAND			
			E (2)	E (4)	E (6)	E (8)
NO HUB	-	10 trucks	25.00	17.91	17.64	17.60
2 HUBS	3 trucks	4 trucks	33.28	21.10	20.58	20.39
3 HUBS	2 trucks	4 trucks	32.33	21.04	20.44	20.24

10 trucks



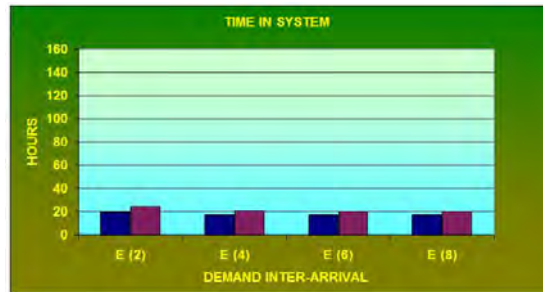
SYSTEM	TRUCK HUB	FLEET SIZE	DEMAND			
			E (2)	E (4)	E (6)	E (8)
NO HUB	-	11 trucks	21.87	17.71	17.57	17.57
3 HUBS	3 trucks	2 trucks	59.80	26.47	23.30	22.34

11 trucks



SYSTEM	TRUCK HUB	FLEET SIZE	DEMAND			
			E (2)	E (4)	E (6)	E (8)
NO HUB	-	12 trucks	20.12	17.58	17.54	17.56
3 HUBS	3 trucks	3 trucks	35.13	22.12	21.05	20.70

12 trucks



SYSTEM	TRUCK HUB	FLEET SIZE	DEMAND			
			E (2)	E (4)	E (6)	E (8)
NO HUB	-	13 trucks	19.08	17.51	17.53	17.56
3 HUBS	3 trucks	4 trucks	24.26	20.73	20.22	20.08

13 trucks

Figure 46 Average Time in System Results for Various Truck Capacities and Configurations

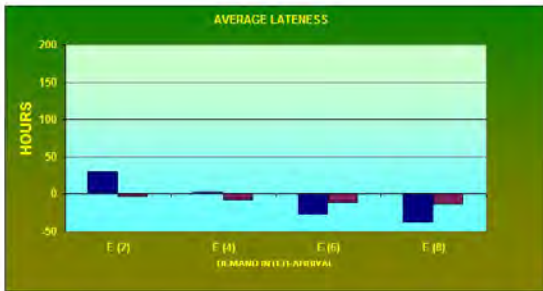
Figure 46 shows the output results for average time in system for various truck capacities and configurations, and Table 36 presents the statistical analysis results. As Table 36 indicates, the STCV system significantly reduces the cycle times of the orders at high demand patterns and limited truck capacities. This is because freeing the trucks from the loading and unloading time increases the systems capabilities. However, for cases which have high truck capacities and low demand the conventional system does yield lower values for average time in the system. Since the trucks are no longer bottlenecks, the extra travel time from the hub to the pickup location and the random waiting time for two different types of trucks (instead of one type) become a factor.

TIME IN SYSTEM				
TOTAL # OF TRUCKS	DEMAND			
	E (2)	E (4)	E (6)	E (8)
3 trucks	1 hub (1,2)	1 hub (1,2)	No Hub	No Hub
4 trucks	1 hub (2,2) or 2 hubs (1,2)	No hub, 1 hub (2,2) or 2 hubs (1,2)	No Hub	No Hub
5 trucks	1 hub (3,2)	No Hub	No Hub	No Hub
6 trucks	1 hub (3,3)	No Hub	No Hub	No Hub
7 trucks	1 hub (3,4), 2 hubs (2,3) or 3 hubs (1,4)	No Hub	No Hub	No Hub
8 trucks	2 hubs (2,4)	No Hub	No Hub	No Hub
9 trucks	No Hub	No Hub	No Hub	No Hub
10 trucks	No Hub	No Hub	No Hub	No Hub
11 trucks	No Hub	No Hub	No Hub	No Hub
12 trucks	No Hub	No Hub	No Hub	No Hub
13 trucks	No Hub	No Hub	No Hub	No Hub

* (# of hub trucks, # of delivery trucks)

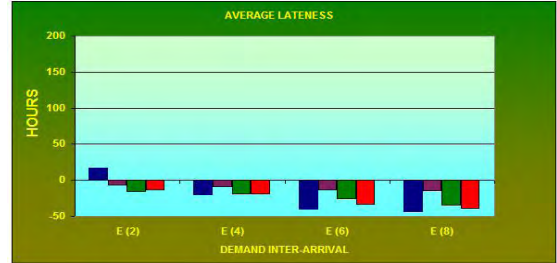
Table 36 Statistical Comparison Average Time in System Results for Various Trucks Capacities and Configurations

Average Lateness Results



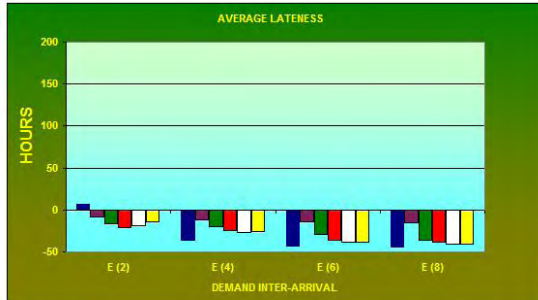
SYSTEM	TRUCK HUB	FLEET SIZE	E (2)	E (4)	E (6)	E (8)
NO HUB	-	3 trucks	29.60	2.99	-26.74	-37.99
1 HUB	1 truck	2 trucks	-2.86	-7.36	-11.02	-12.92

3 trucks



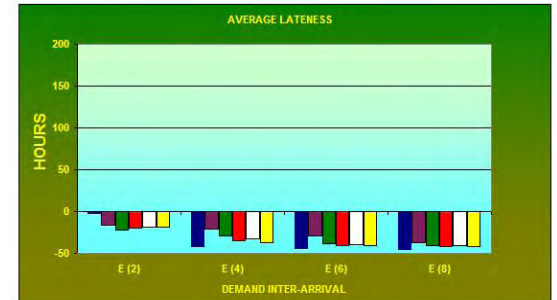
SYSTEM	TRUCK HUB	FLEET SIZE	E (2)	E (4)	E (6)	E (8)
NO HUB	-	4 trucks	17.08	-19.85	-39.75	-43.07
1 HUB	1 truck	3 trucks	-6.83	-9.25	-12.95	-14.82
		2 trucks	-15.43	-18.79	-25.47	-34.83
2 HUBS	1 truck	2 trucks	-13.12	-18.23	-33.16	-38.35

4 trucks



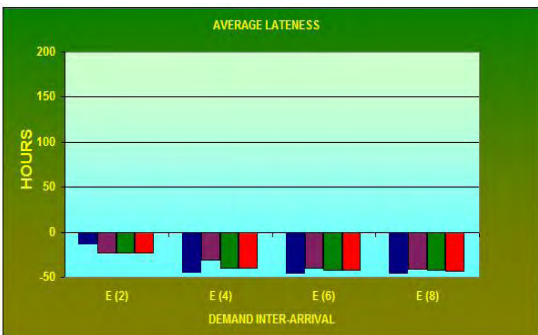
SYSTEM	TRUCK HUB	FLEET SIZE	E (2)	E (4)	E (6)	E (8)
NO HUB	-	5 trucks	6.65	-36.35	-43.27	-44.68
1 HUB	1 truck	4 trucks	-7.83	-11.57	-13.92	-15.49
		2 trucks	-16.75	-20.10	-28.63	-36.61
		3 trucks	-20.83	-24.33	-36.14	-38.78
2 HUBS	1 truck	3 trucks	-18.44	-26.44	-38.74	-40.83
3 HUBS	1 truck	2 trucks	-13.72	-25.28	-37.98	-40.29

5 trucks



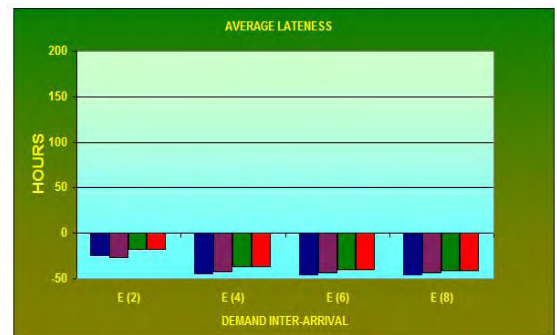
SYSTEM	TRUCK HUB	FLEET SIZE	E (2)	E (4)	E (6)	E (8)
NO HUB	-	6 trucks	-2.86	-41.76	-44.65	-45.38
1 HUB	2 trucks	4 trucks	-16.15	-20.44	-29.39	-37.34
		3 trucks	-21.94	-29.28	-38.90	-40.30
		3 trucks	-19.87	-34.46	-40.61	-41.84
2 HUBS	2 trucks	4 trucks	-18.11	-32.94	-39.44	-40.81
		2 trucks	-18.75	-37.17	-41.06	-42.06
3 HUBS	1 truck	3 trucks	-18.75	-37.17	-41.06	-42.06

6 trucks



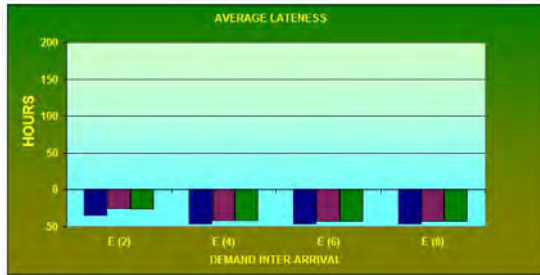
SYSTEM	TRUCK HUB	FLEET SIZE	E (2)	E (4)	E (6)	E (8)
NO HUB	-	7 trucks	-12.80	-43.90	-45.30	-45.69
1 HUB	3 trucks	4 trucks	-22.58	-31.21	-39.76	-40.99
2 HUBS	2 trucks	3 trucks	-23.31	-40.14	-41.82	-42.40
3 HUBS	1 truck	4 trucks	-23.51	-40.31	-42.10	-42.82

7 trucks



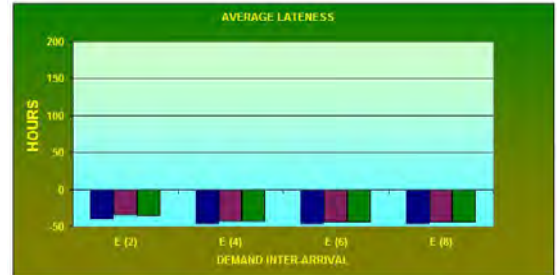
SYSTEM	TRUCK HUB	FLEET SIZE	E (2)	E (4)	E (6)	E (8)
NO HUB	-	8 trucks	-24.70	-44.96	-45.60	-45.86
2 HUBS	2 trucks	4 trucks	-26.59	-42.13	-42.77	-43.17
		3 trucks	-17.42	-36.85	-39.97	-41.11
		2 trucks	-17.78	-36.99	-40.20	-41.29
3 HUBS	2 trucks	2 trucks	-17.78	-36.99	-40.20	-41.29

8 trucks



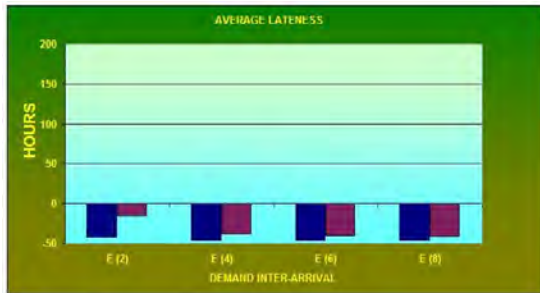
SYSTEM	TRUCK HUB	FLEET SIZE	DEMAND			
			E (2)	E (4)	E (6)	E (8)
NO HUB	-	9 trucks	-34.58	-45.51	-45.77	-45.94
2 HUBS	3 trucks	3 trucks	-25.55	-41.20	-42.12	-42.60
3 HUBS	2 trucks	3 trucks	-25.89	-41.39	-42.33	-42.85

9 trucks



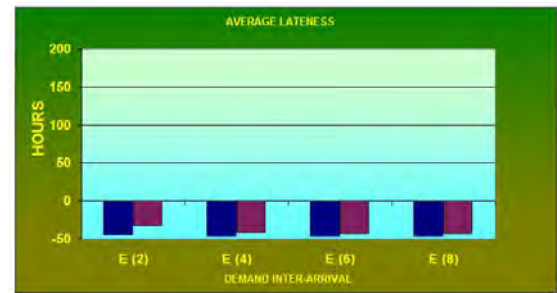
SYSTEM	TRUCK HUB	FLEET SIZE	DEMAND			
			E (2)	E (4)	E (6)	E (8)
NO HUB	-	10 trucks	-39.72	-45.81	-45.84	-45.98
2 HUBS	3 trucks	4 trucks	-33.90	-42.71	-43.01	-43.35
3 HUBS	2 trucks	4 trucks	-34.57	-42.81	-43.22	-43.57

10 trucks



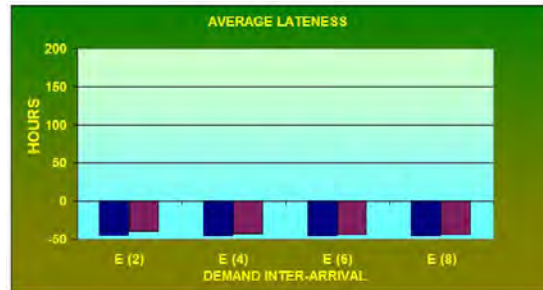
SYSTEM	TRUCK HUB	FLEET SIZE	DEMAND			
			E (2)	E (4)	E (6)	E (8)
NO HUB	-	11 trucks	-42.37	-45.97	-45.86	-45.99
3 HUBS	3 trucks	2 trucks	-15.12	-37.70	-40.41	-41.44

11 trucks



SYSTEM	TRUCK HUB	FLEET SIZE	DEMAND			
			E (2)	E (4)	E (6)	E (8)
NO HUB	-	12 trucks	-43.87	-46.04	-45.87	-45.99
3 HUBS	3 trucks	3 trucks	-32.06	-41.69	-42.52	-42.97

12 trucks



SYSTEM	TRUCK HUB	FLEET SIZE	DEMAND			
			E (2)	E (4)	E (6)	E (8)
NO HUB	-	13 trucks	-44.79	-46.08	-45.87	-45.98
3 HUBS	3 trucks	4 trucks	-39.87	-43.08	-43.39	-43.67

13 trucks

Figure 47 Average Lateness Results for Various Truck Capacities and Configurations

Figure 47 shows the output results for average lateness for various truck capacities and configurations, and Table 37 presents the statistical analysis results. The statistical analysis for average lateness is similar to the analysis for average time in system. It should be noted that average lateness yields a negative value except for the following cases:

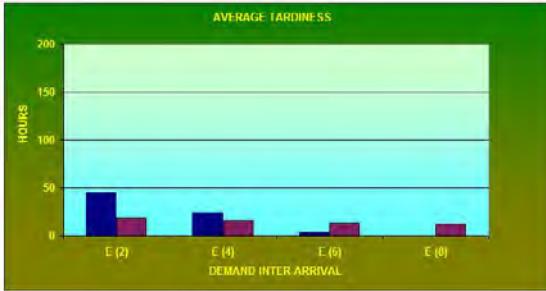
- conventional model demand on average every 2 hours and 3 trucks
- conventional model demand on average every 4 hours and 3 trucks
- conventional model demand on average every 2 hours and 4 trucks
- conventional model demand on average every 2 hours and 5 trucks

AVERAGE LATENESS				
TOTAL # OF TRUCKS	DEMAND			
	<u>E (2)</u>	<u>E (4)</u>	<u>E (6)</u>	<u>E (8)</u>
3 trucks	1 hub (1,2)	1 hub (1,2)	No Hub	No Hub
4 trucks	1 hub (2,2)	No hub, 1 hub (2,2) or 2 hubs (1,2)	No Hub	No Hub
5 trucks	1 hub (2,3) (3,2) or 2 hubs (1,3)	No Hub	No Hub	No Hub
6 trucks	1 hub (3,3)	No Hub	No Hub	No Hub
7 trucks	1 hub (3,4), 2 hubs (2,3) or 3 hubs (1,4)	No Hub	No Hub	No Hub
8 trucks	No Hub or 2 hubs (2,4)	No Hub	No Hub	No Hub
9 trucks	No Hub	No Hub	No Hub	No Hub
10 trucks	No Hub	No Hub	No Hub	No Hub
11 trucks	No Hub	No Hub	No Hub	No Hub
12 trucks	No Hub	No Hub	No Hub	No Hub
13 trucks	No Hub	No Hub	No Hub	No Hub

* (# of hub trucks, # of delivery trucks)

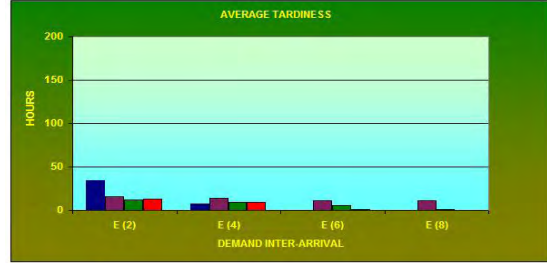
Table 37 Statistical Comparison Average Lateness Results for Various Trucks Capacities and Configurations

Average Tardiness Results



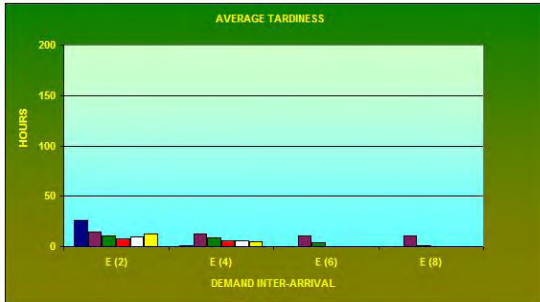
SYSTEM	TRUCK HUB	FLEET SIZE	DEMAND			
			E (2)	E (4)	E (6)	E (8)
NO HUB	-	3 trucks	44.58	23.31	3.83	0.41
1 HUB	1 truck	2 trucks	18.44	15.43	12.84	12.17

3 trucks



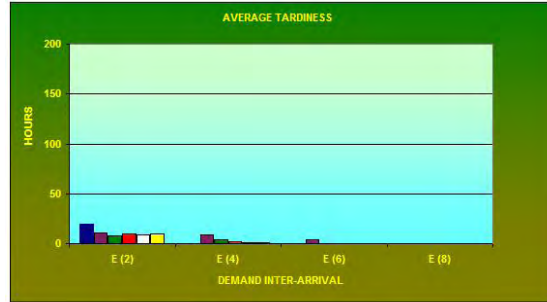
SYSTEM	TRUCK HUB	FLEET SIZE	DEMAND			
			E (2)	E (4)	E (6)	E (8)
NO HUB	-	4 trucks	34.21	7.85	0.15	0.01
1 HUB	1 truck	3 trucks	15.58	14.11	11.48	10.76
	2 trucks	2 trucks	11.83	9.39	5.25	0.83
2 HUBS	1 truck	2 trucks	12.85	9.71	1.33	0.15

4 trucks



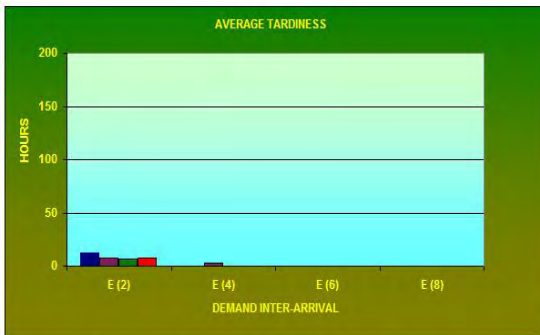
SYSTEM	TRUCK HUB	FLEET SIZE	DEMAND			
			E (2)	E (4)	E (6)	E (8)
NO HUB	-	5 trucks	26.08	0.64	0.01	0.00
1 HUB	1 truck	4 trucks	14.86	12.31	10.72	10.47
	2 trucks	3 trucks	10.66	8.58	3.78	0.51
	3 trucks	2 trucks	8.02	6.05	0.36	0.03
2 HUBS	1 truck	3 trucks	9.58	5.55	0.16	0.03
3 HUBS	1 truck	2 trucks	12.35	5.21	0.12	0.01

5 trucks



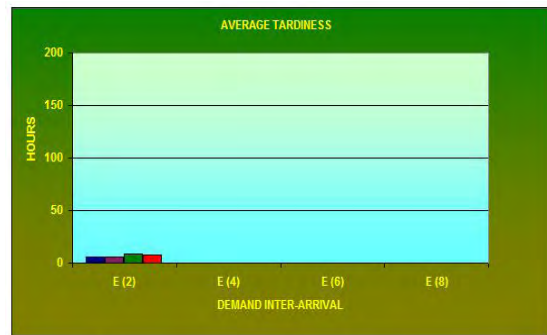
SYSTEM	TRUCK HUB	FLEET SIZE	DEMAND			
			E (2)	E (4)	E (6)	E (8)
NO HUB	-	6 trucks	19.25	0.04	0.00	0.00
1 HUB	2 trucks	4 trucks	10.71	8.32	3.46	0.38
	3 trucks	3 trucks	8.15	3.82	0.04	0.00
	1 truck	4 trucks	9.36	1.54	0.04	0.01
2 HUBS	2 trucks	2 trucks	8.79	1.10	0.01	0.00
3 HUBS	1 truck	3 trucks	9.66	0.49	0.01	0.00

6 trucks



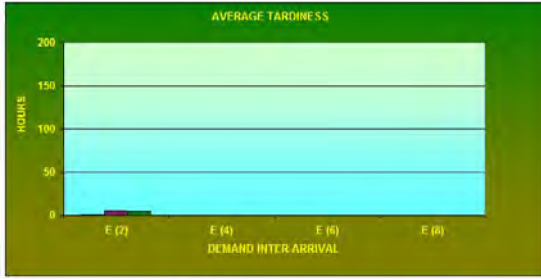
SYSTEM	TRUCK HUB	FLEET SIZE	DEMAND			
			E (2)	E (4)	E (6)	E (8)
NO HUB	-	7 trucks	12.61	0.00	0.00	0.00
1 HUB	3 trucks	4 trucks	7.71	3.05	0.02	0.00
2 HUBS	2 trucks	3 trucks	6.77	0.01	0.00	0.00
3 HUBS	1 truck	4 trucks	7.18	0.09	0.00	0.00

7 trucks



SYSTEM	TRUCK HUB	FLEET SIZE	DEMAND			
			E (2)	E (4)	E (6)	E (8)
NO HUB	-	8 trucks	5.42	0.00	0.00	0.00
2 HUBS	2 trucks	4 trucks	5.73	0.00	0.00	0.00
	3 trucks	2 trucks	8.39	0.11	0.01	0.00
3 HUBS	2 trucks	2 trucks	8.08	0.12	0.01	0.00

8 trucks



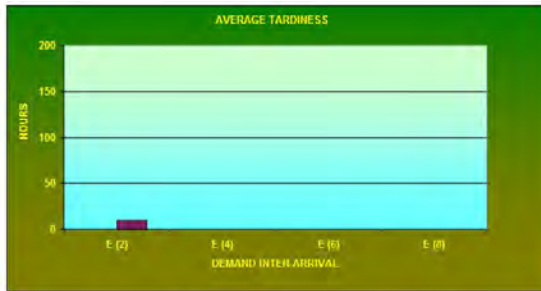
SYSTEM	TRUCK HUB	FLEET SIZE	DEMAND			
			E (2)	E (4)	E (6)	E (8)
NO HUB	-	9 trucks	1.21	0.00	0.00	0.00
2 HUBS	3 trucks	3 trucks	5.13	0.00	0.00	0.00
3 HUBS	2 trucks	3 trucks	5.03	0.00	0.00	0.00

9 trucks



SYSTEM	TRUCK HUB	FLEET SIZE	DEMAND			
			E (2)	E (4)	E (6)	E (8)
NO HUB	-	10 trucks	0.24	0.00	0.00	0.00
2 HUBS	3 trucks	4 trucks	1.71	0.00	0.00	0.00
3 HUBS	2 trucks	4 trucks	1.49	0.00	0.00	0.00

10 trucks



SYSTEM	TRUCK HUB	FLEET SIZE	DEMAND			
			E (2)	E (4)	E (6)	E (8)
NO HUB	-	11 trucks	0.05	0.00	0.00	0.00
3 HUBS	3 trucks	2 trucks	9.33	0.11	0.01	0.00

11 trucks



SYSTEM	TRUCK HUB	FLEET SIZE	DEMAND			
			E (2)	E (4)	E (6)	E (8)
NO HUB	-	12 trucks	0.01	0.00	0.00	0.00
3 HUBS	3 trucks	3 trucks	1.54	0.00	0.00	0.00

12 trucks



SYSTEM	TRUCK HUB	FLEET SIZE	DEMAND			
			E (2)	E (4)	E (6)	E (8)
NO HUB	-	12 trucks	0.01	0.00	0.00	0.00
3 HUBS	3 trucks	3 trucks	1.54	0.00	0.00	0.00

13 trucks

Figure 48 Average Tardiness Results for Various Truck Capacities and Configurations

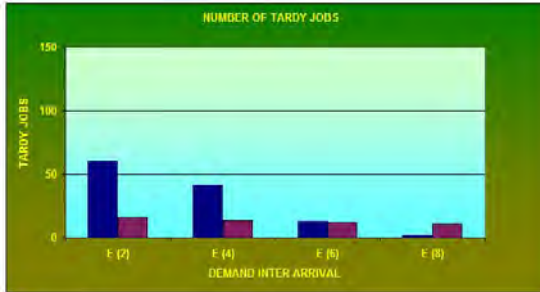
Figure 48 shows the output results for average tardiness for various truck capacities and configurations, and Table 38 presents the statistical analysis results. The conventional model can yield a system that on average has a zero average tardiness (see appendix for the actual confidence interval) for demand on average every 8 hours at a capacity of 3 trucks and for demand on average every 6 hours at a capacity of 4 trucks, and for demand on average every 4 at a capacity of 5 trucks. The STCV model can yield a system that on average has a zero average tardiness (see appendix for the actual confidence interval) for demand on average every 8 hours at a capacity of 4 trucks (2 hub model) and for demand on average every 6 hours at a capacity of 5 trucks (3 hub model), and for demand on average every 4 at a capacity of 6 trucks (3 hub model). The SCTV system cannot achieve an average tardiness of zero for the demand on average every 2 hours for the scenarios simulated, while the conventional system requires 10 trucks to achieve an average tardiness of zero.

AVERAGE TARDINESS				
TOTAL # OF TRUCKS	DEMAND			
	<u>E (2)</u>	<u>E (4)</u>	<u>E (6)</u>	<u>E (8)</u>
3 trucks	1 hub (1,2)	1 hub (1,2)	No Hub	No Hub
4 trucks	1 hub (2,2) or 2 hubs (1,2)	No hub, 1 hub (2,2) or 2 hubs (1,2)	No Hub	No Hub
5 trucks	1 hub (3,2)	No Hub	No Hub	No Hub
6 trucks	1 hub (2,4) (3,3), 2 hubs (1,4) (2,2) or 3 hubs (1,3)	No Hub	No Hub	No hub or 1 hub (3,3)
7 trucks	1 hub (3,4), 2 hubs (2,3) or 3 hubs (1,4)	No Hub	No hub or 2 hubs (2,3)	*
8 trucks	No Hub	No Hub or 2 hubs (2,4)	No Hub or 2 hubs (2,4)	*
9 trucks	No Hub	*	*	*
10 trucks	No Hub	*	*	*
11 trucks	No Hub	No Hub	*	*
12 trucks	No Hub	*	*	*
13 trucks	No Hub	*	*	*

* (# of hub trucks, # of delivery trucks)

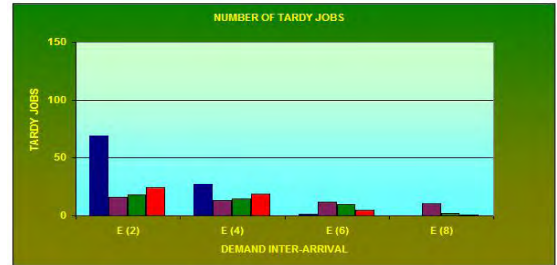
Table 38 Statistical Comparison Average Tardiness Results for Various Trucks Capacities and Configurations

Number of Tardy Jobs Results



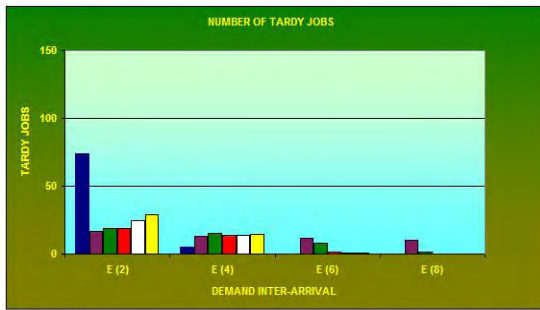
SYSTEM	TRUCK HUB	FLEET SIZE	DEMAND			
			E (2)	E (4)	E (6)	E (8)
NO HUB	-	3 trucks	59.82	41.37	12.70	1.97
1 HUB	1 truck	2 trucks	15.94	13.32	11.76	10.52

3 trucks



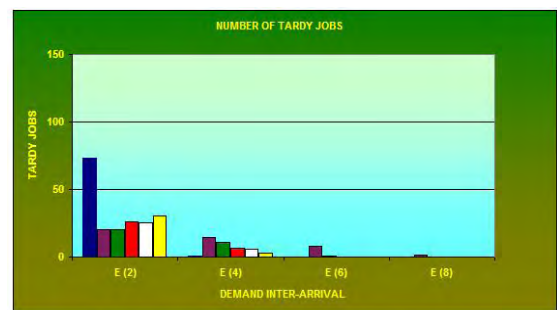
SYSTEM	TRUCK HUB	FLEET SIZE	DEMAND			
			E (2)	E (4)	E (6)	E (8)
NO HUB	-	4 trucks	69.03	27.19	1.39	0.16
1 HUB	1 truck	3 trucks	16.28	13.60	11.60	10.20
	2 trucks	2 trucks	18.44	14.99	9.61	2.32
2 HUBS	1 truck	2 trucks	24.25	18.64	4.56	0.68

4 trucks



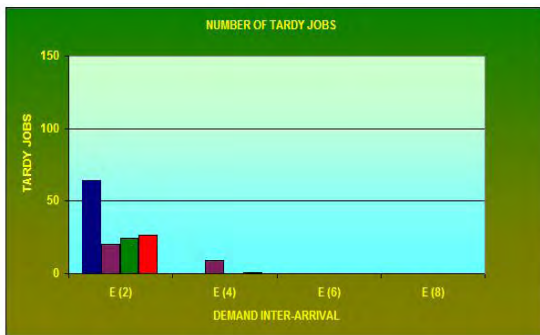
SYSTEM	TRUCK HUB	FLEET SIZE	DEMAND			
			E (2)	E (4)	E (6)	E (8)
NO HUB	-	5 trucks	74.11	5.38	0.10	0.00
1 HUB	1 truck	4 trucks	16.80	13.34	11.51	10.04
	2 trucks	3 trucks	18.89	14.99	7.72	1.53
	3 trucks	2 trucks	18.87	13.96	1.71	0.21
2 HUBS	1 truck	3 trucks	24.77	13.89	1.05	0.16
3 HUBS	1 truck	2 trucks	28.91	14.21	0.89	0.09

5 trucks



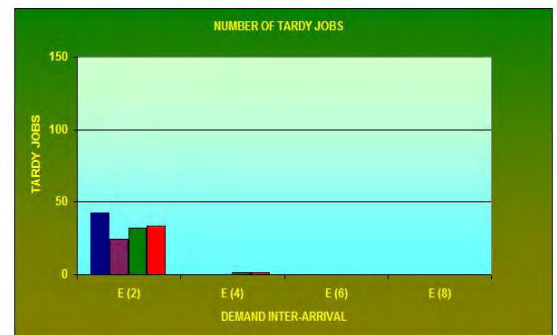
SYSTEM	TRUCK HUB	FLEET SIZE	DEMAND			
			E (2)	E (4)	E (6)	E (8)
NO HUB	-	6 trucks	73.03	0.72	0.01	0.01
1 HUB	2 trucks	4 trucks	19.94	14.72	7.62	1.36
	3 trucks	3 trucks	20.28	10.59	0.41	0.03
	4 trucks	2 trucks	26.20	6.58	0.35	0.05
2 HUBS	2 trucks	2 trucks	25.65	5.80	0.10	0.03
3 HUBS	1 truck	3 trucks	30.53	3.14	0.08	0.02

6 trucks



SYSTEM	TRUCK HUB	FLEET SIZE	DEMAND			
			E (2)	E (4)	E (6)	E (8)
NO HUB	-	7 trucks	63.91	0.11	0.00	0.00
1 HUB	3 trucks	4 trucks	20.22	8.94	0.21	0.02
2 HUBS	2 trucks	3 trucks	24.72	0.24	0.00	0.00
3 HUBS	1 truck	4 trucks	26.46	0.83	0.05	0.00

7 trucks



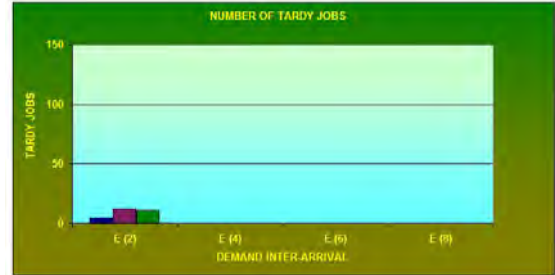
SYSTEM	TRUCK HUB	FLEET SIZE	DEMAND			
			E (2)	E (4)	E (6)	E (8)
NO HUB	-	8 trucks	42.63	0.02	0.00	0.00
2 HUBS	2 trucks	4 trucks	24.59	0.01	0.00	0.00
	3 trucks	3 trucks	31.99	1.61	0.08	0.02
3 HUBS	2 trucks	2 trucks	33.22	1.51	0.12	0.01

8 trucks



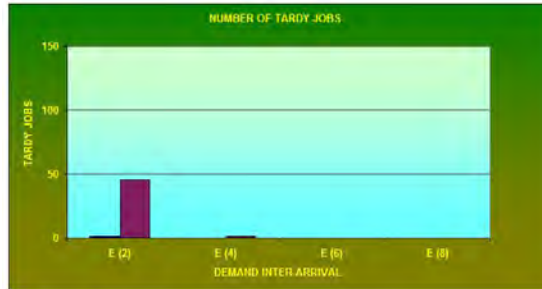
SYSTEM	TRUCK HUB	FLEET SIZE	DEMAND			
			E (2)	E (4)	E (6)	E (8)
NO HUB	-	9 trucks	16.62	0.00	0.00	0.00
2 HUBS	3 trucks	3 trucks	24.45	0.03	0.00	0.00
3 HUBS	2 trucks	3 trucks	24.76	0.00	0.01	0.00

9 trucks



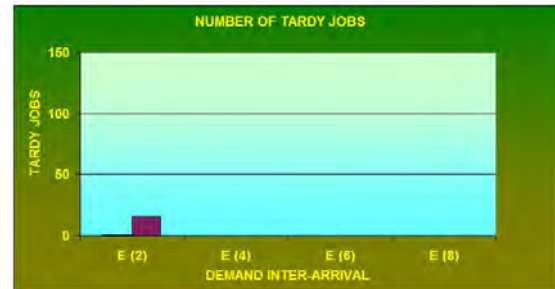
SYSTEM	TRUCK HUB	FLEET SIZE	DEMAND			
			E (2)	E (4)	E (6)	E (8)
NO HUB	-	10 trucks	4.71	0.00	0.00	0.00
2 HUBS	3 trucks	4 trucks	12.16	0.00	0.00	0.00
3 HUBS	2 trucks	4 trucks	10.70	0.00	0.00	0.00

10 trucks



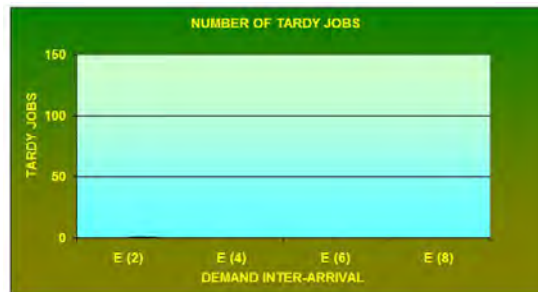
SYSTEM	TRUCK HUB	FLEET SIZE	DEMAND			
			E (2)	E (4)	E (6)	E (8)
NO HUB	-	11 trucks	1.29	0.00	0.00	0.00
3 HUBS	3 trucks	2 trucks	45.50	1.49	0.12	0.01

11 trucks



SYSTEM	TRUCK HUB	FLEET SIZE	DEMAND			
			E (2)	E (4)	E (6)	E (8)
NO HUB	-	12 trucks	0.33	0.00	0.00	0.00
3 HUBS	3 trucks	3 trucks	15.38	0.01	0.00	0.00

12 trucks



SYSTEM	TRUCK HUB	FLEET SIZE	DEMAND			
			E (2)	E (4)	E (6)	E (8)
NO HUB	-	13 trucks	0.11	0.00	0.00	0.00
3 HUBS	3 trucks	4 trucks	0.65	0.00	0.00	0.00

13 trucks

Figure 49 Number of Tardy Orders Results for Various Truck Capacities and Configurations

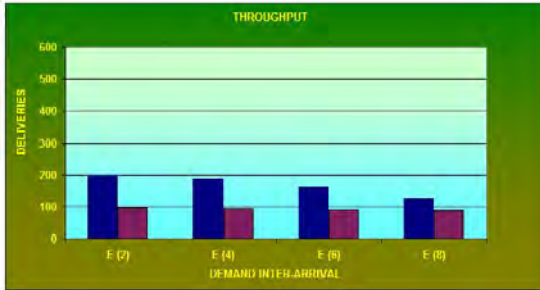
Figure 49 shows the output results for the number of tardy orders for various truck capacities and configurations, and Table 39 presents the statistical analysis results. The statistical analysis for number of tardy orders is similar to the analysis for average tardiness.

NUMBER OF TARDY JOBS				
TOTAL # OF TRUCKS	DEMAND			
	E (2)	E (4)	E (6)	E (8)
3 trucks	1 hub (1,2)	1 hub (1,2)	No hub or 1 hub (1,2)	No Hub
4 trucks	1 hub (1,3)	1 hub (1,3)	No Hub	No Hub
5 trucks	1 hub (1,4)	No Hub	No Hub	No Hub
6 trucks	1 hub (2,4) (3,3)	No Hub	No hub, 2 hubs (2,2) or 3 hubs (1,3)	No hub, 1 hub (3,3), 2 hubs (1,4) (2,2) or 3 hubs (1,3)
7 trucks	1 hub (3,4)	No hub or 2 hubs (2,3)	No hub or 2 hubs (2,3)	No hub, 2 hubs (2,3) or 3 hubs (1,4)
8 trucks	2 hubs (2,4)	No hub or 2 hubs (2,4)	No hub or 2 hubs (2,4)	No hub or 2 hubs (2,4)
9 trucks	No Hub	No hub or 3 hubs (2,3)	No hub or 2 hubs (3,3)	*
10 trucks	No Hub	*	*	*
11 trucks	No Hub	No Hub	No Hub	No Hub
12 trucks	No Hub	No Hub	*	*
13 trucks	No Hub	*	*	*

* (# of hub trucks, # of delivery trucks)

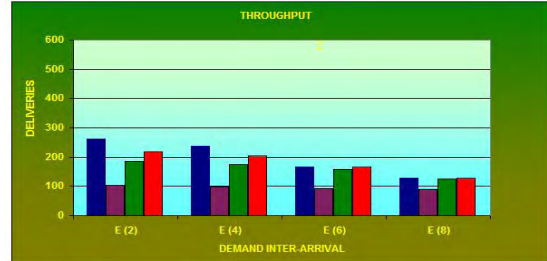
Table 39 Statistical Comparison Number of Tardy Orders Results for Various Trucks Capacities and Configurations

Throughput Results



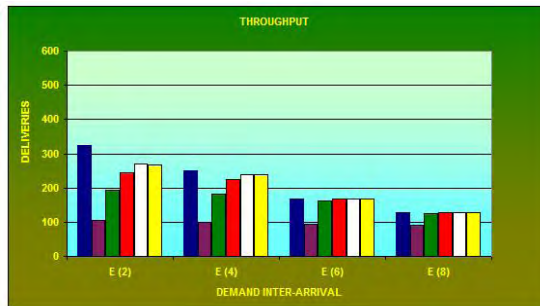
SYSTEM	TRUCK HUB	FLEET SIZE	DEMAND			
			E (2)	E (4)	E (6)	E (8)
NO HUB	-	3 trucks	199.09	189.21	162.83	126.32
1 HUB	1 truck	2 trucks	96.40	93.60	91.11	88.65

3 trucks



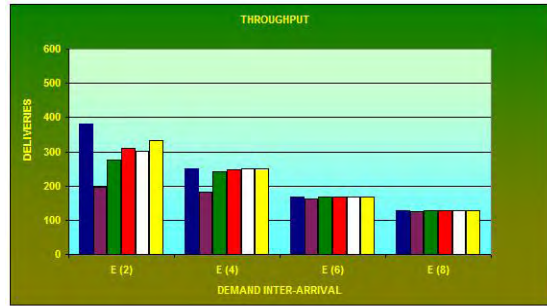
SYSTEM	TRUCK HUB	FLEET SIZE	DEMAND			
			E (2)	E (4)	E (6)	E (8)
NO HUB	-	4 trucks	261.10	236.48	167.04	126.98
1 HUB	1 truck	3 trucks	103.53	98.27	94.08	90.12
		2 trucks	184.57	174.35	158.02	126.14
2 HUBS	1 truck	2 trucks	218.70	204.86	165.79	126.96

4 trucks



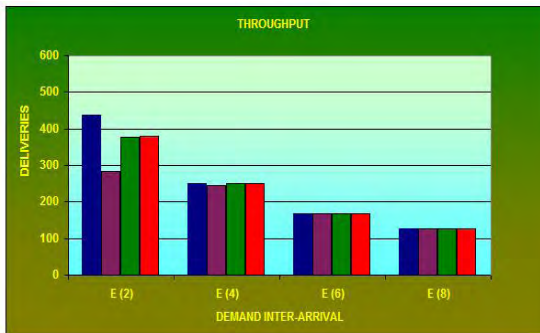
SYSTEM	TRUCK HUB	FLEET SIZE	DEMAND			
			E (2)	E (4)	E (6)	E (8)
NO HUB	-	5 trucks	323.01	249.01	167.30	127.10
1 HUB	1 truck	4 trucks	106.37	99.22	94.38	89.98
		2 trucks	192.21	181.02	161.30	126.34
		3 trucks	244.63	224.22	166.68	126.89
2 HUBS	1 truck	3 trucks	269.16	238.19	167.18	127.23
3 HUBS	1 truck	2 trucks	267.52	238.14	167.16	127.06

5 trucks



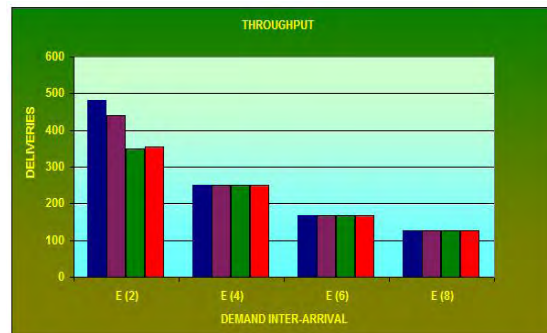
SYSTEM	TRUCK HUB	FLEET SIZE	DEMAND			
			E (2)	E (4)	E (6)	E (8)
NO HUB	-	6 trucks	382.39	250.39	167.38	127.12
1 HUB	2 trucks	4 trucks	196.56	183.40	161.53	126.39
		3 trucks	276.63	242.66	167.14	126.92
		4 trucks	309.12	248.27	167.32	127.18
2 HUBS	2 trucks	3 trucks	301.54	248.92	167.52	127.38
		2 trucks	333.22	249.89	167.33	127.12

6 trucks



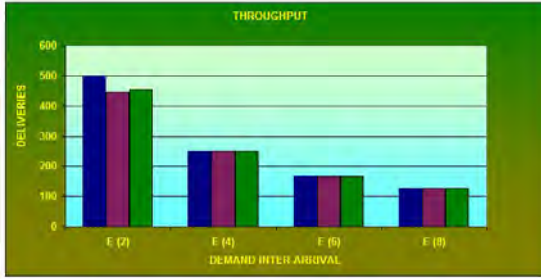
SYSTEM	TRUCK HUB	FLEET SIZE	DEMAND			
			E (2)	E (4)	E (6)	E (8)
NO HUB	-	7 trucks	437.53	250.55	167.31	127.13
1 HUB	3 trucks	4 trucks	283.40	244.70	167.11	126.96
2 HUBS	2 trucks	3 trucks	377.05	250.86	167.52	127.35
3 HUBS	1 truck	4 trucks	380.81	250.51	167.35	127.14

7 trucks



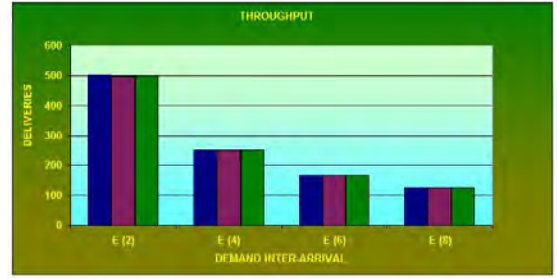
SYSTEM	TRUCK HUB	FLEET SIZE	DEMAND			
			E (2)	E (4)	E (6)	E (8)
NO HUB	-	8 trucks	480.81	250.66	167.29	127.14
2 HUBS	2 trucks	4 trucks	439.34	250.96	167.43	127.25
		3 trucks	349.07	250.44	167.68	127.43
3 HUBS	2 trucks	2 trucks	355.31	250.41	167.52	127.21

8 trucks



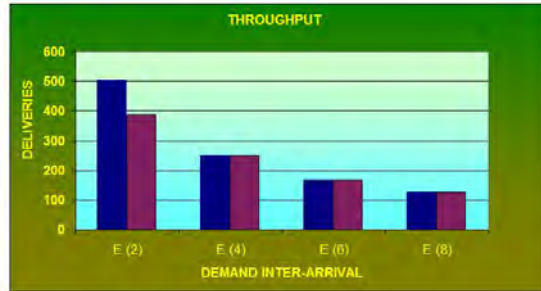
		DEMAND				
SYSTEM	TRUCK HUB	FLEET SIZE	E (2)	E (4)	E (6)	E (8)
NO HUB	-	9 trucks	498.49	250.76	167.32	127.16
2 HUBS	3 trucks	3 trucks	447.75	251.13	167.55	127.33
3 HUBS	2 trucks	3 trucks	455.24	250.93	167.41	127.26

9 trucks



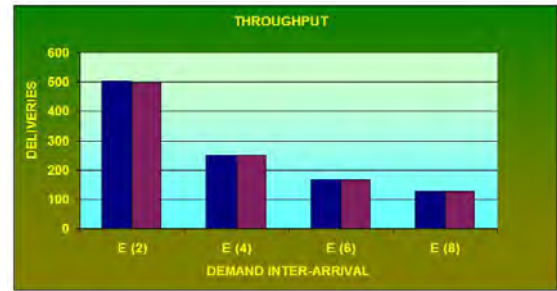
		DEMAND				
SYSTEM	TRUCK HUB	FLEET SIZE	E (2)	E (4)	E (6)	E (8)
NO HUB	-	10 trucks	501.97	250.73	167.31	127.19
2 HUBS	3 trucks	4 trucks	497.52	251.13	167.41	127.23
3 HUBS	2 trucks	4 trucks	498.24	251.03	167.42	127.22

10 trucks



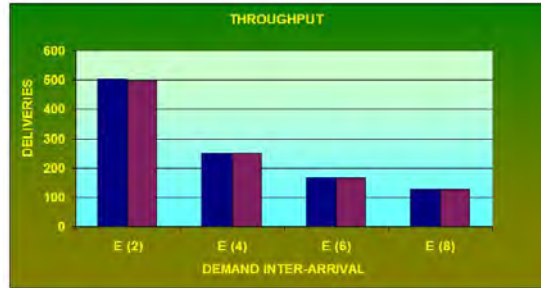
		DEMAND				
SYSTEM	TRUCK HUB	FLEET SIZE	E (2)	E (4)	E (6)	E (8)
NO HUB	-	11 trucks	503.06	250.75	167.32	127.18
3 HUBS	3 trucks	2 trucks	386.66	250.72	167.55	127.28

11 trucks



		DEMAND				
SYSTEM	TRUCK HUB	FLEET SIZE	E (2)	E (4)	E (6)	E (8)
NO HUB	-	12 trucks	503.57	250.76	167.34	127.19
3 HUBS	3 trucks	3 trucks	496.92	251.11	167.48	127.26

12 trucks



		DEMAND				
SYSTEM	TRUCK HUB	FLEET SIZE	E (2)	E (4)	E (6)	E (8)
NO HUB	-	13 trucks	503.57	250.76	167.34	127.19
3 HUBS	3 trucks	3 trucks	496.92	251.11	167.48	127.26

13 trucks

Figure 50 Throughput Results for Various Truck Capacities and Configurations

Figure 50 shows the output results for the throughput for various truck capacities and configurations, and Table 40 presents the statistical analysis results. The conventional system outperforms or is equal to the SCTV system at the same truck capacity for all scenarios when analyzing throughput. This could be due to the fact that in the conventional system all trucks can be used for the delivery task.

THROUGHPUT				
TOTAL # OF TRUCKS	DEMAND			
	<u>E (2)</u>	<u>E (4)</u>	<u>E (6)</u>	<u>E (8)</u>
3 trucks	No Hub	No Hub	No Hub	No Hub
4 trucks	No Hub	No Hub	No hub or 2 hubs (1,2)	No hub, 1 hub (2,2) or 2 hubs (1,2)
5 trucks	No Hub	No Hub	No hub, 1 hub (3,2), 2 hubs (1,3) or 3 hubs (1,2)	No hub, 1 hub (2,3) (3,2), 2 hubs (1,3) or 3 hubs (1,2)
6 trucks	No Hub	No hub, 2 hubs (1,4) (2,2) or 3 hubs (1,3)	No hub, 1 hub (3,3) 2 hubs (1,4) (2,2) or 3 hubs (1,3)	*
7 trucks	No Hub	No hub, 2 hubs (2,3) or 3 hubs (1,4)	*	*
8 trucks	No Hub	*	*	*
9 trucks	No Hub	*	*	*
10 trucks	*	*	*	*
11 trucks	No Hub	*	*	*
12 trucks	*	*	*	*
13 trucks	*	*	*	*

* (# of hub trucks, # of delivery trucks)

Table 40 Statistical Comparison Throughput Results for Various Trucks Capacities and Configurations

7 CONCLUSION

The productivity gains of the STCV mode of operation versus the conventional mode of operation is a function of the system capacity (number of available trucks in system) and the inter-arrival time of the orders (demand pattern). The STCV mode in general performs better when 1) random arrivals occur every 2 hours at a fleet size of 8 or less, and 2) random arrivals occur every 4 hours at a fleet size of 4 or less. These are scenarios where system truck capacity is limited, and hence freeing the trucks from the loading and unloading tasks will have a significant productivity gain. However, in scenarios where truck capacities are sufficient to meet the expected demand pattern, the conventional mode may outperform the SCTV mode of operation since the extra travel time from the hub to the pickup location and the random waiting time for two different types of trucks can off-set the productivity gained from freeing the truck from the loading and unloading task.

The shortest distance rule tends to yield the best results for most of the performance measures used in this simulation study. This is due to the efficient use of resources by avoiding unnecessary long trips. However, the shortest distance rule can yield non-practical results where some orders can wait indefinitely for a truck since the dispatch rule does not consider time or due date in the priority assignment of orders. This situation occurs at high demand levels where there are always several outstanding orders waiting for a truck. Hence, the shortest distance dispatch rule should be modified to include a maximum waiting time violation penalty.

Other issues and factors to consider in future studies are as follows:

- a. incorporate direct cost parameters (gas, trucks, trailers, drivers) in the simulation model
- b. incorporate direct revenue parameters (price for the service) in the simulation model
- c. vary the maximum truck weight limitation beyond the current 50,000 lbs to determine its effect on the performance measures
- d. vary the average order load of 25,000 lbs to determine its effect on the performance measures
- e. vary the variance of the order loads to determine its effect on the performance measures
- f. develop an optimization model to determine the hub locations and number of hubs
- g. add penalties for late deliveries
- h. vary the factor of number of trailers versus number of trucks (currently only modeled a factor of 3).
- i. implement a maximum wait time penalty for the shortest distance dispatch rule
- j. allow the hub trucks to transport empty trailers from/to any hub location in the simulation

- k. model intra-state hauling of goods
- l. perform simulation study for a fixed number of orders instead of only a steady-state study.

APPENDIX A: Program Listing for Simulation Model for Conventional Mode of Van Lines Operations

```
*****
*
*
*
*           Formatted Listing of Model:
*
* C:\Documents\RESEARCH\Path\Truck\trail0901_20loc_path - orig.MOD
*
*
*****
```

```
Time Units:           Hours
Distance Units:      Feet
Initialization Logic:  ACTIVATE calendar ()

                        int i=1
                        While(i<=fleet_size) do
                        {
                            truck_location[i]=1
                            truck_used[i]=0
                            inc i
                        }
```

```
Termination Logic:   pcnt_tardy = num_tardy / num
```

```
*****
*****
*
*           Locations
*
*****
*****
```

Name	Cap	Units	Stats	Rules
input	1	1	Time Series	Min(rule_att),
Min(rule_att), Redding	inf	1	Time Series	Min(rule_att),
Min(rule_att), Chico	inf	1	Time Series	Min(rule_att),
Min(rule_att), Sacramento	inf	1	Time Series	Min(rule_att),
Min(rule_att), Palm_Springs	inf	1	Time Series	Min(rule_att),
Min(rule_att), Stockton	inf	1	Time Series	Min(rule_att),
Min(rule_att), Santa_Rosa	inf	1	Time Series	Min(rule_att),
Min(rule_att), San_Fransisco	inf	1	Time Series	Min(rule_att),


```

Oakland      inf      1      Time Series Min(rule_att),
Min(rule_att),
San_Jose     inf      1      Time Series Min(rule_att),
Min(rule_att),
Fresno       inf      1      Time Series Min(rule_att),
Min(rule_att),
Bakersfield  inf      1      Time Series Min(rule_att),
Min(rule_att),
Los_Angeles  inf      1      Time Series Min(rule_att),
Min(rule_att),
Long_Beach   inf      1      Time Series Min(rule_att),
Min(rule_att),
Barstow      inf      1      Time Series Min(rule_att),
Min(rule_att),
San_Bernardino inf     1      Time Series Min(rule_att),
Min(rule_att),
San_Diego    inf      1      Time Series Min(rule_att),
Min(rule_att),
Santa_Barbara inf     1      Time Series Min(rule_att),
Min(rule_att),
San_Luis_Obispo inf    1      Time Series Min(rule_att),
Min(rule_att),
Irvine       inf      1      Time Series Min(rule_att),
Min(rule_att),
Monterey     inf      1      Time Series Min(rule_att),
Min(rule_att),
pickup_queue INFINITE 1      Time Series Min(rule_att),
Min(rule_att),
delivery_queue INFINITE 1      Time Series Min(rule_att),
Min(rule_att),
Waiting_queue inf     1      Time Series Min(rule_att),
Min(rule_att),
dummy        inf      1      Time Series Min(rule_att),
Min(rule_att),
dummy2       inf      1      Time Series Min(rule_att),
Min(rule_att),

```

```

*****
*****
*
*                               Entities
*
*****
*****

```

Name	Speed (fpm)	Stats	Cost
material1	150	Time Series	
material2	150	Time Series	

```

*****
*****
*
*                               Path Networks
*
*****
*****

```

Name Dist/Time	Type Speed	T/S Factor	From	To	BI	
Net1	Passing	Speed & Distance	N1	N2	Bi	378576
1			N1	N3	Bi	849552
1			N1	N4	Bi	3423024
1			N1	N5	Bi	1097184
1			N1	N6	Bi	1221792
1			N1	N7	Bi	1134144
1			N1	N8	Bi	1106160
1			N1	N9	Bi	1284096
1			N1	N10	Bi	1759824
1			N1	N11	Bi	2346960
1			N1	N12	Bi	2861232
1			N1	N13	Bi	2984784
1			N1	N14	Bi	3053424
1			N1	N15	Bi	3162192
1			N1	N16	Bi	3489024
1			N1	N17	Bi	2801568
1			N1	N18	Bi	2249808
1			N1	N19	Bi	3065040
1			N1	N20	Bi	1655808
1			N2	N3	Bi	467280
1			N2	N4	Bi	3045504
1			N2	N5	Bi	720192
1			N2	N6	Bi	779856
1			N2	N7	Bi	872784
1			N2	N8	Bi	844800
1			N2	N9	Bi	1022736

1	N2	N10	Bi	1382304
1	N2	N11	Bi	1969440
1	N2	N12	Bi	2483712
1	N2	N13	Bi	2607264
1	N2	N14	Bi	2662176
1	N2	N15	Bi	2784672
1	N2	N16	Bi	3111504
1	N2	N17	Bi	2540736
1	N2	N18	Bi	1988976
1	N2	N19	Bi	2688048
1	N2	N20	Bi	1394448
1	N3	N4	Bi	2583504
1	N3	N5	Bi	258192
1	N3	N6	Bi	538032
1	N3	N7	Bi	449856
1	N3	N8	Bi	421872
1	N3	N9	Bi	599808
1	N3	N10	Bi	920304
1	N3	N11	Bi	1507440
1	N3	N12	Bi	2021712
1	N3	N13	Bi	2145264
1	N3	N14	Bi	2200176
1	N3	N15	Bi	2322672
1	N3	N16	Bi	2649504
1	N3	N17	Bi	2117808
1	N3	N18	Bi	1566048
1	N3	N19	Bi	2226048
1	N3	N20	Bi	971520

1	N4	N5	Bi	2335872
1	N4	N6	Bi	2810016
1	N4	N7	Bi	2565024
1	N4	N8	Bi	2512224
1	N4	N9	Bi	2359632
1	N4	N10	Bi	1709664
1	N4	N11	Bi	1144176
1	N4	N12	Bi	569712
1	N4	N13	Bi	609312
1	N4	N14	Bi	656832
1	N4	N15	Bi	293568
1	N4	N16	Bi	742896
1	N4	N17	Bi	1066560
1	N4	N18	Bi	1617264
1	N4	N19	Bi	497376
1	N4	N20	Bi	2304720
1	N5	N6	Bi	675312
1	N5	N7	Bi	430320
1	N5	N8	Bi	377520
1	N5	N9	Bi	398640
1	N5	N10	Bi	663696
1	N5	N11	Bi	1259280
1	N5	N12	Bi	1773552
1	N5	N13	Bi	1897104
1	N5	N14	Bi	1952016
1	N5	N15	Bi	2073984
1	N5	N16	Bi	2400816
1	N5	N17	Bi	1916640

1	N5	N18	Bi	1364880
1	N5	N19	Bi	1977360
1	N5	N20	Bi	770352
1	N6	N7	Bi	284064
1	N6	N8	Bi	305184
1	N6	N9	Bi	510576
1	N6	N10	Bi	1224432
1	N6	N11	Bi	1732896
1	N6	N12	Bi	2247168
1	N6	N13	Bi	2370720
1	N6	N14	Bi	2425632
1	N6	N15	Bi	2547600
1	N6	N16	Bi	2874960
1	N6	N17	Bi	2031744
1	N6	N18	Bi	1479984
1	N6	N19	Bi	2450976
1	N6	N20	Bi	885456
1	N7	N8	Bi	60720
1	N7	N9	Bi	243936
1	N7	N10	Bi	979968
1	N7	N11	Bi	1488432
1	N7	N12	Bi	2002704
1	N7	N13	Bi	2126256
1	N7	N14	Bi	2181168
1	N7	N15	Bi	2303664
1	N7	N16	Bi	2630496
1	N7	N17	Bi	1765104
1	N7	N18	Bi	1213872

1	N7	N19	Bi	2206512
1	N7	N20	Bi	618816
1	N8	N9	Bi	204864
1	N8	N10	Bi	923472
1	N8	N11	Bi	1431936
1	N8	N12	Bi	1946208
1	N8	N13	Bi	2069760
1	N8	N14	Bi	2124672
1	N8	N15	Bi	2246640
1	N8	N16	Bi	2574000
1	N8	N17	Bi	1727088
1	N8	N18	Bi	1175328
1	N8	N19	Bi	2150016
1	N8	N20	Bi	580800
1	N9	N10	Bi	803088
1	N9	N11	Bi	1279872
1	N9	N12	Bi	1793616
1	N9	N13	Bi	1917168
1	N9	N14	Bi	1279872
1	N9	N15	Bi	2094576
1	N9	N16	Bi	2421408
1	N9	N17	Bi	1530144
1	N9	N18	Bi	978384
1	N9	N19	Bi	1997952
1	N9	N20	Bi	383856
1	N10	N11	Bi	578688
1	N10	N12	Bi	1145760
1	N10	N13	Bi	1269312

1	N10	N14	Bi	1259280
1	N10	N15	Bi	1446720
1	N10	N16	Bi	1773552
1	N10	N17	Bi	1335840
1	N10	N18	Bi	726528
1	N10	N19	Bi	1349568
1	N10	N20	Bi	804672
1	N11	N12	Bi	580800
1	N11	N13	Bi	704352
1	N11	N14	Bi	681648
1	N11	N15	Bi	881760
1	N11	N16	Bi	1208592
1	N11	N17	Bi	770880
1	N11	N18	Bi	636768
1	N11	N19	Bi	785136
1	N11	N20	Bi	1227600
1	N12	N13	Bi	127248
1	N12	N14	Bi	599280
1	N12	N15	Bi	308352
1	N12	N16	Bi	628320
1	N12	N17	Bi	497904
1	N12	N18	Bi	1048608
1	N12	N19	Bi	204336
1	N12	N20	Bi	1741872
1	N13	N14	Bi	664752
1	N13	N15	Bi	368016
1	N13	N16	Bi	586080
1	N13	N17	Bi	602976

1	N13	N18	Bi	1153152
1	N13	N19	Bi	159984
1	N13	N20	Bi	1964688
1	N14	N15	Bi	370128
1	N14	N16	Bi	924528
1	N14	N17	Bi	1064976
1	N14	N18	Bi	1615680
1	N14	N19	Bi	587136
1	N14	N20	Bi	1916640
1	N15	N16	Bi	561792
1	N15	N17	Bi	783552
1	N15	N18	Bi	1334256
1	N15	N19	Bi	260304
1	N15	N20	Bi	2018544
1	N16	N17	Bi	1121472
1	N16	N18	Bi	1672176
1	N16	N19	Bi	441936
1	N16	N20	Bi	2368080
1	N17	N18	Bi	554400
1	N17	N19	Bi	712800
1	N17	N20	Bi	1365408
1	N18	N19	Bi	1267200
1	N18	N20	Bi	792528
1	N19	N20	Bi	1943568

```

*****
*****
*
*
*
*****
*****

```

Interfaces

Net	Node	Location
Net1	N1	Redding
	N2	Chico
	N3	Sacramento
	N4	Palm_Springs
	N5	Stockton
	N6	Santa_Rosa
	N7	San_Fransisco
	N8	Oakland
	N9	San_Jose
	N10	Fresno
	N11	Bakersfield
	N12	Los_Angeles
	N13	Long_Beach
	N14	Barstow
	N15	San_Bernardino
	N16	San_Diego
	N17	Santa_Barbara
	N18	San_Luis_Obispo
	N19	Irvine
	N20	Monterey

```

*****
*****
*
*
*
*****
*****

```

Resources

Name	Units	Stats	Res Search	Ent Search	Path	Motion
truck1	1	By Unit	Closest	Min	Net1 Home: N1	Empty: 5720 fpm Full: 5720 fpm
truck2	1	By Unit	Closest	Min	Net1 Home: N2	Empty: 5720 fpm Full: 5720 fpm
truck3	1	By Unit	Closest	Min	Net1 Home: N3	Empty: 5720 fpm Full: 5720 fpm
truck4	1	By Unit	Least Used	Min	Net1 Home: N4	Empty: 5720 fpm Full: 5720 fpm
truck5	1	By Unit	Closest	Min	Net1 Home: N5	Empty: 5720 fpm Full: 5720 fpm
truck6	1	By Unit	Closest	Min	Net1 Home: N6	Empty: 5720 fpm Full: 5720 fpm
truck7	1	By Unit	Closest	Min	Net1 Home: N7	Empty: 5720 fpm Full: 5720 fpm

truck8	1	By Unit	Closest	Min	Net1 Home: N8	Empty: 5720 fpm Full: 5720 fpm
truck9	1	By Unit	Closest	Min	Net1 Home: N9	Empty: 5720 fpm Full: 5720 fpm
truck10	1	By Unit	Closest	Min	Net1 Home: N10	Empty: 5720 fpm Full: 5720 fpm
truck11	1	By Unit	Closest	Min	Net1 Home: N11	Empty: 5720 fpm Full: 5720 fpm
truck12	1	By Unit	Closest	Min	Net1 Home: N12	Empty: 5720 fpm Full: 5720 fpm
truck13	1	By Unit	Closest	Min	Net1 Home: N13	Empty: 5720 fpm Full: 5720 fpm
truck14	1	By Unit	Closest	Min	Net1 Home: N14	Empty: 5720 fpm Full: 5720 fpm
truck15	1	By Unit	Closest	Min	Net1 Home: N15	Empty: 5720 fpm Full: 5720 fpm
truck16	1	By Unit	Closest	Min	Net1 Home: N16	Empty: 5720 fpm Full: 5720 fpm
truck17	1	By Unit	Closest	Min	Net1 Home: N17	Empty: 5720 fpm Full: 5720 fpm
truck18	1	By Unit	Closest	Min	Net1 Home: N18	Empty: 5720 fpm Full: 5720 fpm
truck19	1	By Unit	Closest	Min	Net1 Home: N19	Empty: 5720 fpm Full: 5720 fpm
truck20	1	By Unit	Closest	Min	Net1 Home: N20	Empty: 5720 fpm Full: 5720 fpm

```

*****
*****
*
*                               Processing
*
*****
*****

```

```

                               Process
Routing

```

Entity	Location	Operation	Blk	Output
Destination	Rule			Move Logic

material1	dummy		1	material1 input
FIRST	1			

```

material1 input          //Display "Input:"$clock()$" task="$task$"
pickup="$pickup$" destination="$destination$" rule_att="$rule_att$"
weight="$weight$" arrival time="$arrival_hour

        if (task=1) and (trucknumber>0) then
        {
            if (freeunits(res(trucknumber)) > 0)
            then
                {
                    route 1
                }
            else
                route 3
        }

        else if (task=2) then
        {
            if (freeunits(res(trucknumber)) > 0) then
            {
                route 2
            }
            else
                route 3
        }
        else route 3

1      material1
pickup_queue  FIRST 1          //Display
"Pickup:"$clock()$" task="$task$" pickup="$pickup$"
destination="$destination$" rule_att="$rule_att$" weight="$weight$"
arrival time="$arrival_hour

//Display "truck",trucknumber

2      material1
delivery_queue  FIRST 1      //Display
"Delivery:"$clock()$" task="$task$" pickup="$pickup$"
destination="$destination$" rule_att="$rule_att$" weight="$weight$"
arrival time="$arrival_hour

//Display "truck",trucknumber

3      material1
Waiting_queue  FIRST 1      //Display
"Waiting:"$clock()$" task="$task$" pickup="$pickup$"
destination="$destination$" rule_att="$rule_att$" weight="$weight$"
arrival time="$arrival_hour

flag =0
material1 Waiting_queue
wait until flag=1
if task = 1 then
{
if rule = 1 then
trucknumber = shortest_distance()
if rule = 2 then
trucknumber = earliest_due_date()

```

```

        if rule = 3 then
        {
            trucknumber = longest_time_in_system()
            rule_att = arrival_hour - clock()
        }
        if rule = 4 then
        {
            trucknumber =
Smallest_Slack_Time_Pickup()
            if(trucknumber>0) then rule_att =
(due_date - clock()) - distance[truck_location[trucknumber],pickup]/65-
load_time-unload_time
                else rule_att=999999.0
            }
        }

        if task = 2 then
        {if rule = 1 then
            shortest_distance_after_pickup()
            if rule = 3 then
                rule_att = arrival_hour - clock()
            if rule = 4 then
                rule_att = (due_date - clock()) -
distance[truck_location[trucknumber],destination]/65-unload_time
                    1    material1 dummy2
FIRST 1
    material1 dummy2        inc counter

        if (task=1) and (trucknumber>0) then
            {if (freeunits(res(trucknumber)) > 0)
then
                {if rule_att < min_rule then min_rule =
rule_att}}

        if (task=2) then
            {if (freeunits(res(trucknumber)) > 0)
then
                {if rule_att < min_rule then min_rule =
rule_att}}

        Wait until counter = num_waiting

        //display "time",clock()
        //display "arriva_hr",arrival_hour
        //display "rule",rule_att
        //display "min_rule",min_rule

        if (trucknumber > 0) then
            {if (freeunits(res(trucknumber)) > 0) then
route 1
                else route 2}
            else route 2

```

```

//display "loc",truck_location[1]
//display "delivery",destination
//display "counter= ",counter
//display "num waiting= ",num_waiting
1 material1
Waiting_queue IF tie = 1, 1 flag = 0
material1 input
IF rule_att = min_rule tie = 1
Waiting_queue IF rule_att <> min_rule flag = 0
2 material1
Waiting_queue FIRST 1 flag = 0
material1 pickup_queue 1 material1 Redding
IF pickup=1, 1
material1 Chico
IF pickup=2
material1
Sacramento IF pickup=3
material1
Palm_Springs IF pickup=4
material1 Stockton
IF pickup = 5
material1
Santa_Rosa IF pickup = 6
material1
San_Fransisco IF pickup = 7
material1 Oakland
IF pickup = 8
material1 San_Jose
IF pickup = 9
material1 Fresno
IF pickup = 10
material1
Bakersfield IF pickup = 11
material1
Los_Angeles IF pickup = 12
material1
Long_Beach IF pickup = 13
material1 Barstow
IF pickup = 14
material1
San_Bernardino IF pickup = 15
material1
San_Diego IF pickup = 16
material1
Santa_Barbara IF pickup = 17
material1
San_Luis_Obispo IF pickup = 18
material1 Irvine
IF pickup = 19
material1 Monterey
IF pickup = 20

```

```

material1 Redding      if (task=1) then
                        {
                            truck_capacity[trucknumber]=truck_capacity[trucknumber]+weight
                                get (res(trucknumber))
                                wait load_time
                                truck_location[trucknumber]=1
                                free res(trucknumber)

                                if (trucknumber=1) then
cap1=truck_capacity[trucknumber]
                                else if (trucknumber=2) then
cap2=truck_capacity[trucknumber]
                                else if (trucknumber=3) then
cap3=truck_capacity[trucknumber]
                                else if (trucknumber=4) then
cap4=truck_capacity[trucknumber]
                                else if (trucknumber=5) then
cap5=truck_capacity[trucknumber]
                                else if (trucknumber=6) then
cap6=truck_capacity[trucknumber]
                                else if (trucknumber=7) then
cap7=truck_capacity[trucknumber]
                                else if (trucknumber=8) then
cap8=truck_capacity[trucknumber]
                                else if (trucknumber=9) then
cap9=truck_capacity[trucknumber]
                                else cap10=truck_capacity[trucknumber]

                                //display "truck load= ",cap1

                                flag = 1
                                min_rule = 9999999
                                num_waiting = contents(waiting_queue)+1
                                counter = 0
                                tie = 0
                                route 1}

                        else if (task=2) then
                        {
                                get (res(trucknumber))
                                route 2
                        }
                        else route 3

Waiting_queue    FIRST 1
IF destination=1, 1
IF destination=2
Sacramento      IF destination=3
res(trucknumber)

```

```

1    material1
    task=2
2    material2 Redding
    material2 Chico
    move with res(trucknumber)
    material2
    move with

```

```

material2
Palm_Springs IF destination=4 move with
res(trucknumber)

material2 Stockton
IF destination = 5 move with res(trucknumber)
material2
Santa_Rosa IF destination = 6 move with
res(trucknumber)
material2
San_Fransisco IF destination = 7 move with
res(trucknumber)
material2 Oakland
IF destination = 8 move with res(trucknumber)
material2 San_Jose
IF destination = 9 move with res(trucknumber)
material2 Fresno
IF destination = 10 move with res(trucknumber)
material2
Bakersfield IF destination = 11 move with
res(trucknumber)
material2
Los_Angeles IF destination = 12 move with
res(trucknumber)
material2
Long_Beach IF destination = 13 move with
res(trucknumber)
material2 Barstow
IF destination = 14 move with res(trucknumber)
material2
San_Bernardino IF destination = 15 move with
res(trucknumber)
material2
San_Diego IF destination = 16 move with
res(trucknumber)
material2
Santa_Barbara IF destination = 17 move with
res(trucknumber)
material2
San_Luis_Obispo IF destination = 18 move with
res(trucknumber)
material2 Irvine
IF destination = 19 move with res(trucknumber)
material2 Monterey
IF destination = 20 move with res(trucknumber)
3 material1
Waiting_queue FIRST 1
material1 Chico if (task=1) then
{
truck_capacity[trucknumber]=truck_capacity[trucknumber]+weight
get (res(trucknumber))
wait load_time
truck_location[trucknumber]=2
free res(trucknumber)

if (trucknumber=1) then
cap1=truck_capacity[trucknumber]

```

```

else if (trucknumber=2) then
cap2=truck_capacity[trucknumber]
else if (trucknumber=3) then
cap3=truck_capacity[trucknumber]
else if (trucknumber=4) then
cap4=truck_capacity[trucknumber]
else if (trucknumber=5) then
cap5=truck_capacity[trucknumber]
else if (trucknumber=6) then
cap6=truck_capacity[trucknumber]
else if (trucknumber=7) then
cap7=truck_capacity[trucknumber]
else if (trucknumber=8) then
cap8=truck_capacity[trucknumber]
else if (trucknumber=9) then
cap9=truck_capacity[trucknumber]
else cap10=truck_capacity[trucknumber]

//display "truck load= ",cap1

flag = 1
min_rule = 9999999
num_waiting = contents(waiting_queue)+1
counter = 0
tie = 0
route 1}

else if (task=2) then
{
get (res(trucknumber))
route 2
}
else route 3

Waiting_queue FIRST 1
1 material1
task=2
2 material2 Redding
IF destination=1, 1 move with res(trucknumber)
material2 Chico
IF destination=2 move with res(trucknumber)
material2
Sacramento IF destination=3
res(trucknumber) move with
material2
Palm_Springs IF destination=4
res(trucknumber) move with
material2 Stockton
IF destination = 5 move with res(trucknumber)
material2
Santa_Rosa IF destination = 6
res(trucknumber) move with
material2
San_Fransisco IF destination = 7
res(trucknumber) move with
material2 Oakland
IF destination = 8 move with res(trucknumber)

```



```

material2 San_Jose
IF destination = 9          move with res(trucknumber)
                             material2 Fresno
IF destination = 10        move with res(trucknumber)
                             material2
Bakersfield      IF destination = 11  move with
res(trucknumber)
                             material2
Los_Angeles      IF destination = 12  move with
res(trucknumber)
                             material2
Long_Beach       IF destination = 13  move with
res(trucknumber)
                             material2 Barstow
IF destination = 14        move with res(trucknumber)
                             material2
San_Bernardino   IF destination = 15  move with
res(trucknumber)
                             material2
San_Diego        IF destination = 16  move with
res(trucknumber)
                             material2
Santa_Barbara    IF destination = 17  move with
res(trucknumber)
                             material2
San_Luis_Obispo IF destination = 18  move with
res(trucknumber)
                             material2 Irvine
IF destination = 19        move with res(trucknumber)
                             material2 Monterey
IF destination = 20        move with res(trucknumber)
                             3      material1
Waiting_queue    FIRST 1
material1 Sacramento      if (task=1) then
                           {
                               truck_capacity[trucknumber]=truck_capacity[trucknumber]+weight
                               get (res(trucknumber))
                               wait load_time
                               truck_location[trucknumber]=3
                               free res(trucknumber)

                               if (trucknumber=1) then
cap1=truck_capacity[trucknumber]
                               else if (trucknumber=2) then
cap2=truck_capacity[trucknumber]
                               else if (trucknumber=3) then
cap3=truck_capacity[trucknumber]
                               else if (trucknumber=4) then
cap4=truck_capacity[trucknumber]
                               else if (trucknumber=5) then
cap5=truck_capacity[trucknumber]
                               else if (trucknumber=6) then
cap6=truck_capacity[trucknumber]
                               else if (trucknumber=7) then
cap7=truck_capacity[trucknumber]

```

```

else if (trucknumber=8) then
cap8=truck_capacity[trucknumber]
else if (trucknumber=9) then
cap9=truck_capacity[trucknumber]
else cap10=truck_capacity[trucknumber]

//display "truck load= ",cap1

flag = 1
min_rule = 9999999
num_waiting = contents(waiting_queue)+1
counter = 0
tie = 0
route 1}

else if (task=2) then
{
get (res(trucknumber))
route 2
}
else route 3

1 material1
Waiting_queue FIRST 1 task=2
2 material2 Redding
IF destination=1, 1 move with res(trucknumber)
material2 Chico
IF destination=2 move with res(trucknumber)
material2
Sacramento IF destination=3 move with
res(trucknumber)
material2
Palm_Springs IF destination=4 move with
res(trucknumber)
material2 Stockton
IF destination = 5 move with res(trucknumber)
material2
Santa_Rosa IF destination = 6 move with
res(trucknumber)
material2
San_Fransisco IF destination = 7 move with
res(trucknumber)
material2 Oakland
IF destination = 8 move with res(trucknumber)
material2 San_Jose
IF destination = 9 move with res(trucknumber)
material2 Fresno
IF destination = 10 move with res(trucknumber)
material2
Bakersfield IF destination = 11 move with
res(trucknumber)
material2
Los_Angeles IF destination = 12 move with
res(trucknumber)

```

```

Long_Beach      IF destination = 13      material2
res(trucknumber)      move with

IF destination = 14      material2 Barstow
                        move with res(trucknumber)
                        material2
San_Bernardino  IF destination = 15      move with
res(trucknumber)      material2

San_Diego       IF destination = 16      move with
res(trucknumber)      material2

Santa_Barbara  IF destination = 17      move with
res(trucknumber)      material2

San_Luis_Obispo IF destination = 18      move with
res(trucknumber)      material2

IF destination = 19      material2 Irvine
                        move with res(trucknumber)
                        material2 Monterey
IF destination = 20      move with res(trucknumber)
                        3      material1

Waiting_queue  FIRST 1
material1 Palm_Springs  if (task=1) then
                        {
                            truck_capacity[trucknumber]=truck_capacity[trucknumber]+weight
                            get (res(trucknumber))
                            wait load_time
                            truck_location[trucknumber]=4
                            free res(trucknumber)

                            if (trucknumber=1) then
cap1=truck_capacity[trucknumber]
                            else if (trucknumber=2) then
cap2=truck_capacity[trucknumber]
                            else if (trucknumber=3) then
cap3=truck_capacity[trucknumber]
                            else if (trucknumber=4) then
cap4=truck_capacity[trucknumber]
                            else if (trucknumber=5) then
cap5=truck_capacity[trucknumber]
                            else if (trucknumber=6) then
cap6=truck_capacity[trucknumber]
                            else if (trucknumber=7) then
cap7=truck_capacity[trucknumber]
                            else if (trucknumber=8) then
cap8=truck_capacity[trucknumber]
                            else if (trucknumber=9) then
cap9=truck_capacity[trucknumber]
                            else cap10=truck_capacity[trucknumber]

//display "truck load= ",cap1

                            flag = 1
                            min_rule = 9999999

```

```

        num_waiting = contents(waiting_queue)+1
        counter = 0
        tie = 0
        route 1}

else if (task=2) then
{
    get (res(trucknumber))
    route 2
}
else route 3

Waiting_queue    FIRST 1
1    material1
    task=2
2    material2 Redding
IF destination=1, 1    move with res(trucknumber)
    material2 Chico
IF destination=2    move with res(trucknumber)
    material2
Sacramento    IF destination=3
res(trucknumber)    move with
    material2
Palm_Springs    IF destination=4
res(trucknumber)    move with
    material2 Stockton
IF destination = 5    move with res(trucknumber)
    material2
Santa_Rosa    IF destination = 6
res(trucknumber)    move with
    material2
San_Franisisco    IF destination = 7
res(trucknumber)    move with
    material2 Oakland
IF destination = 8    move with res(trucknumber)
    material2 San_Jose
IF destination = 9    move with res(trucknumber)
    material2 Fresno
IF destination = 10    move with res(trucknumber)
    material2
Bakersfield    IF destination = 11
res(trucknumber)    move with
    material2
Los_Angeles    IF destination = 12
res(trucknumber)    move with
    material2
Long_Beach    IF destination = 13
res(trucknumber)    move with
    material2 Barstow
IF destination = 14    move with res(trucknumber)
    material2
San_Bernardino    IF destination = 15
res(trucknumber)    move with
    material2
San_Diego    IF destination = 16
res(trucknumber)    move with

```

```

                                material2
Santa_Barbara IF destination = 17 move with
res(trucknumber)

                                material2
San_Luis_Obispo IF destination = 18 move with
res(trucknumber)

                                material2 Irvine
IF destination = 19 move with res(trucknumber)
                                material2 Monterey
IF destination = 20 move with res(trucknumber)
                                3 material1

Waiting_queue FIRST 1
material1 Stockton if (task=1) then
{

    truck_capacity[trucknumber]=truck_capacity[trucknumber]+weight
                                get (res(trucknumber))
                                wait load_time
                                truck_location[trucknumber]=5
                                free res(trucknumber)

                                if (trucknumber=1) then
cap1=truck_capacity[trucknumber]
                                else if (trucknumber=2) then
cap2=truck_capacity[trucknumber]
                                else if (trucknumber=3) then
cap3=truck_capacity[trucknumber]
                                else if (trucknumber=4) then
cap4=truck_capacity[trucknumber]
                                else if (trucknumber=5) then
cap5=truck_capacity[trucknumber]
                                else if (trucknumber=6) then
cap6=truck_capacity[trucknumber]
                                else if (trucknumber=7) then
cap7=truck_capacity[trucknumber]
                                else if (trucknumber=8) then
cap8=truck_capacity[trucknumber]
                                else if (trucknumber=9) then
cap9=truck_capacity[trucknumber]
                                else cap10=truck_capacity[trucknumber]

                                //display "truck load= ",cap1

                                flag = 1
                                min_rule = 9999999
                                num_waiting = contents(waiting_queue)+1
                                counter = 0
                                tie = 0
                                route 1}

else if (task=2) then
{
    get (res(trucknumber))
    route 2
}
else route 3

```

```

Waiting_queue  FIRST 1
1  material1
   task=2
IF destination = 1, 1 2  material2 Redding
   move with res(trucknumber)
   material2 Chico
IF destination = 2 2  material2
   move with res(trucknumber)
   material2
Sacramento IF destination = 3
res(trucknumber)   move with
   material2
Palm_Springs IF destination = 4
res(trucknumber)   move with
   material2 Stockton
IF destination = 5 2  material2
   move with res(trucknumber)
   material2
Santa_Rosa IF destination = 6
res(trucknumber)   move with
   material2
San_Fransisco IF destination = 7
res(trucknumber)   move with
   material2
IF destination = 8 2  material2 Oakland
   move with res(trucknumber)
   material2 San_Jose
IF destination = 9 2  material2 Fresno
   move with res(trucknumber)
   material2
IF destination = 10 2  material2
   move with res(trucknumber)
   material2
Bakersfield IF destination = 11
res(trucknumber)   move with
   material2
Los_Angeles IF destination = 12
res(trucknumber)   move with
   material2
Long_Beach IF destination = 13
res(trucknumber)   move with
   material2 Barstow
IF destination = 14 2  material2
   move with res(trucknumber)
   material2
San_Bernardino IF destination = 15
res(trucknumber)   move with
   material2
San_Diego IF destination = 16
res(trucknumber)   move with
   material2
Santa_Barbara IF destination = 17
res(trucknumber)   move with
   material2
San_Luis_Obispo IF destination = 18
res(trucknumber)   move with
   material2
IF destination = 19 2  material2 Irvine
   move with res(trucknumber)
   material2 Monterey
IF destination = 20 2  material2
   move with res(trucknumber)
   material2
Waiting_queue  FIRST 1
3  material1

```

```

material1 Santa_Rosa      if (task=1) then
                          {
                              truck_capacity[trucknumber]=truck_capacity[trucknumber]+weight
                              get (res(trucknumber))
                              wait load_time
                              truck_location[trucknumber]=6
                              free res(trucknumber)

                              if (trucknumber=1) then
cap1=truck_capacity[trucknumber]
                              else if (trucknumber=2) then
cap2=truck_capacity[trucknumber]
                              else if (trucknumber=3) then
cap3=truck_capacity[trucknumber]
                              else if (trucknumber=4) then
cap4=truck_capacity[trucknumber]
                              else if (trucknumber=5) then
cap5=truck_capacity[trucknumber]
                              else if (trucknumber=6) then
cap6=truck_capacity[trucknumber]
                              else if (trucknumber=7) then
cap7=truck_capacity[trucknumber]
                              else if (trucknumber=8) then
cap8=truck_capacity[trucknumber]
                              else if (trucknumber=9) then
cap9=truck_capacity[trucknumber]
                              else cap10=truck_capacity[trucknumber]

                              //display "truck load= ",cap1

                              flag = 1
                              min_rule = 9999999
                              num_waiting = contents(waiting_queue)+1
                              counter = 0
                              tie = 0
                              route 1}

                          else if (task=2) then
                              {
                                  get (res(trucknumber))
                                  route 2
                              }
                          else route 3

Waiting_queue    FIRST 1
IF destination = 1, 1
IF destination = 2
Sacramento      IF destination = 3
res(trucknumber)

1    material1
    task=2
2    material2 Redding
    move with res(trucknumber)
    material2 Chico
    move with res(trucknumber)
    material2
    move with

```

```

material2
Palm_Springs    IF destination = 4    move with
res(trucknumber)

IF destination = 5    move with res(trucknumber)
material2 Stockton
material2
Santa_Rosa      IF destination = 6    move with
res(trucknumber)

IF destination = 7    move with
material2
San_Fransisco   IF destination = 7    move with
res(trucknumber)

IF destination = 8    move with res(trucknumber)
material2 Oakland
IF destination = 9    move with res(trucknumber)
material2 San_Jose
IF destination = 10   move with res(trucknumber)
material2 Fresno
Bakersfield     IF destination = 11   move with
res(trucknumber)

IF destination = 11   move with
material2
Los_Angeles     IF destination = 12   move with
res(trucknumber)

IF destination = 12   move with
material2
Long_Beach      IF destination = 13   move with
res(trucknumber)

IF destination = 13   move with
material2 Barstow
IF destination = 14   move with res(trucknumber)
material2
San_Bernardino  IF destination = 15   move with
res(trucknumber)

IF destination = 15   move with
material2
San_Diego       IF destination = 16   move with
res(trucknumber)

IF destination = 16   move with
material2
Santa_Barbara   IF destination = 17   move with
res(trucknumber)

IF destination = 17   move with
material2
San_Luis_Obispo IF destination = 18   move with
res(trucknumber)

IF destination = 18   move with
material2 Irvine
IF destination = 19   move with res(trucknumber)
material2 Monterey
IF destination = 20   move with res(trucknumber)
3    material1

Waiting_queue    FIRST 1
material1 San_Fransisco  if (task=1) then
                        {
                            truck_capacity[trucknumber]=truck_capacity[trucknumber]+weight
                                get (res(trucknumber))
                                wait load_time
                                truck_location[trucknumber]=7
                                free res(trucknumber)

                                if (trucknumber=1) then
cap1=truck_capacity[trucknumber]

```



```

else if (trucknumber=2) then
cap2=truck_capacity[trucknumber]
else if (trucknumber=3) then
cap3=truck_capacity[trucknumber]
else if (trucknumber=4) then
cap4=truck_capacity[trucknumber]
else if (trucknumber=5) then
cap5=truck_capacity[trucknumber]
else if (trucknumber=6) then
cap6=truck_capacity[trucknumber]
else if (trucknumber=7) then
cap7=truck_capacity[trucknumber]
else if (trucknumber=8) then
cap8=truck_capacity[trucknumber]
else if (trucknumber=9) then
cap9=truck_capacity[trucknumber]
else cap10=truck_capacity[trucknumber]

//display "truck load= ",cap1

flag = 1
min_rule = 9999999
num_waiting = contents(waiting_queue)+1
counter = 0
tie = 0
route 1}

else if (task=2) then
{
get (res(trucknumber))
route 2
}
else route 3

Waiting_queue FIRST 1
1 material1
task=2
2 material2 Redding
IF destination = 1, 1 move with res(trucknumber)
material2 Chico
IF destination = 2 move with res(trucknumber)
material2
Sacramento IF destination = 3
res(trucknumber) move with
material2
Palm_Springs IF destination = 4
res(trucknumber) move with
material2 Stockton
IF destination = 5 move with res(trucknumber)
material2
Santa_Rosa IF destination = 6
res(trucknumber) move with
material2
San_Fransisco IF destination = 7
res(trucknumber) move with
material2 Oakland
IF destination = 8 move with res(trucknumber)

```

```

material2 San_Jose
IF destination = 9          move with res(trucknumber)
                             material2 Fresno
IF destination = 10        move with res(trucknumber)
                             material2
Bakersfield      IF destination = 11  move with
res(trucknumber)
                             material2
Los_Angeles      IF destination = 12  move with
res(trucknumber)
                             material2
Long_Beach       IF destination = 13  move with
res(trucknumber)
                             material2 Barstow
IF destination = 14        move with res(trucknumber)
                             material2
San_Bernardino   IF destination = 15  move with
res(trucknumber)
                             material2
San_Diego        IF destination = 16  move with
res(trucknumber)
                             material2
Santa_Barbara    IF destination = 17  move with
res(trucknumber)
                             material2
San_Luis_Obispo IF destination = 18  move with
res(trucknumber)
                             material2 Irvine
IF destination = 19        move with res(trucknumber)
                             material2 Monterey
IF destination = 20        move with res(trucknumber)
                             3      material1
Waiting_queue    FIRST 1
material1 Oakland          if (task=1) then
                           {
                               truck_capacity[trucknumber]=truck_capacity[trucknumber]+weight
                               get (res(trucknumber))
                               wait load_time
                               truck_location[trucknumber]=8
                               free res(trucknumber)

                               if (trucknumber=1) then
cap1=truck_capacity[trucknumber]
                               else if (trucknumber=2) then
cap2=truck_capacity[trucknumber]
                               else if (trucknumber=3) then
cap3=truck_capacity[trucknumber]
                               else if (trucknumber=4) then
cap4=truck_capacity[trucknumber]
                               else if (trucknumber=5) then
cap5=truck_capacity[trucknumber]
                               else if (trucknumber=6) then
cap6=truck_capacity[trucknumber]
                               else if (trucknumber=7) then
cap7=truck_capacity[trucknumber]

```

```

else if (trucknumber=8) then
cap8=truck_capacity[trucknumber]
else if (trucknumber=9) then
cap9=truck_capacity[trucknumber]
else cap10=truck_capacity[trucknumber]

//display "truck load= ",cap1

flag = 1
min_rule = 9999999
num_waiting = contents(waiting_queue)+1
counter = 0
tie = 0

route 1}

else if (task=2) then
{
get (res(trucknumber))
route 2
}
else route 3

1 material1
Waiting_queue FIRST 1 task=2
2 material2 Redding
IF destination = 1, 1 move with res(trucknumber)
material2 Chico
IF destination = 2 move with res(trucknumber)
material2
Sacramento IF destination = 3 move with
res(trucknumber)
material2
Palm_Springs IF destination = 4 move with
res(trucknumber)
material2 Stockton
IF destination = 5 move with res(trucknumber)
material2
Santa_Rosa IF destination = 6 move with
res(trucknumber)
material2
San_Fransisco IF destination = 7 move with
res(trucknumber)
material2 Oakland
IF destination = 8 move with res(trucknumber)
material2 San_Jose
IF destination = 9 move with res(trucknumber)
material2 Fresno
IF destination = 10 move with res(trucknumber)
material2
Bakersfield IF destination = 11 move with
res(trucknumber)
material2
Los_Angeles IF destination = 12 move with
res(trucknumber)

```

```

material2
Long_Beach      IF destination = 13      move with
res(trucknumber)

material2 Barstow
IF destination = 14      move with res(trucknumber)
material2
San_Bernardino  IF destination = 15      move with
res(trucknumber)

material2
San_Diego       IF destination = 16      move with
res(trucknumber)

material2
Santa_Barbara   IF destination = 17      move with
res(trucknumber)

material2
San_Luis_Obispo IF destination = 18      move with
res(trucknumber)

material2 Irvine
IF destination = 19      move with res(trucknumber)
material2 Monterey
IF destination = 20      move with res(trucknumber)
3      material1

Waiting_queue   FIRST 1
material1 San_Jose      if (task=1) then
                        {
                            truck_capacity[trucknumber]=truck_capacity[trucknumber]+weight
                                get (res(trucknumber))
                                wait load_time
                                truck_location[trucknumber]=9
                                free res(trucknumber)

                                if (trucknumber=1) then
cap1=truck_capacity[trucknumber]
                                else if (trucknumber=2) then
cap2=truck_capacity[trucknumber]
                                else if (trucknumber=3) then
cap3=truck_capacity[trucknumber]
                                else if (trucknumber=4) then
cap4=truck_capacity[trucknumber]
                                else if (trucknumber=5) then
cap5=truck_capacity[trucknumber]
                                else if (trucknumber=6) then
cap6=truck_capacity[trucknumber]
                                else if (trucknumber=7) then
cap7=truck_capacity[trucknumber]
                                else if (trucknumber=8) then
cap8=truck_capacity[trucknumber]
                                else if (trucknumber=9) then
cap9=truck_capacity[trucknumber]
                                else cap10=truck_capacity[trucknumber]

                                //display "truck load= ",cap1

                                flag = 1
                                min_rule = 9999999

```

```

        num_waiting = contents(waiting_queue)+1
        counter = 0
        tie = 0
        route 1}

else if (task=2) then
{
    get (res(trucknumber))
    route 2
}
else route 3

```

```

Waiting_queue    FIRST 1
1    material1
    task=2
2    material2 Redding
IF destination = 1, 1    move with res(trucknumber)
                        material2 Chico
IF destination = 2    move with res(trucknumber)
                        material2
Sacramento        IF destination = 3
res(trucknumber)    move with
                        material2
Palm_Springs      IF destination = 4
res(trucknumber)    move with
                        material2 Stockton
IF destination = 5    move with res(trucknumber)
                        material2
Santa_Rosa         IF destination = 6
res(trucknumber)    move with
                        material2
San_Fransisco     IF destination = 7
res(trucknumber)    move with
                        material2 Oakland
IF destination = 8    move with res(trucknumber)
                        material2 San_Jose
IF destination = 9    move with res(trucknumber)
                        material2 Fresno
IF destination = 10   move with res(trucknumber)
                        material2
Bakersfield       IF destination = 11
res(trucknumber)    move with
                        material2
Los_Angeles        IF destination = 12
res(trucknumber)    move with
                        material2
Long_Beach         IF destination = 13
res(trucknumber)    move with
                        material2 Barstow
IF destination = 14   move with res(trucknumber)
                        material2
San_Bernardino    IF destination = 15
res(trucknumber)    move with
                        material2
San_Diego          IF destination = 16
res(trucknumber)    move with

```

```

                                material2
Santa_Barbara IF destination = 17 move with
res(trucknumber)

                                material2
San_Luis_Obispo IF destination = 18 move with
res(trucknumber)

                                material2 Irvine
IF destination = 19 move with res(trucknumber)
                                material2 Monterey
IF destination = 20 move with res(trucknumber)
                                3 material1

Waiting_queue FIRST 1
material1 Fresno if (task=1) then
{

    truck_capacity[trucknumber]=truck_capacity[trucknumber]+weight
                                get (res(trucknumber))
                                wait load_time
                                truck_location[trucknumber]=10
                                free res(trucknumber)

                                if (trucknumber=1) then
cap1=truck_capacity[trucknumber]
                                else if (trucknumber=2) then
cap2=truck_capacity[trucknumber]
                                else if (trucknumber=3) then
cap3=truck_capacity[trucknumber]
                                else if (trucknumber=4) then
cap4=truck_capacity[trucknumber]
                                else if (trucknumber=5) then
cap5=truck_capacity[trucknumber]
                                else if (trucknumber=6) then
cap6=truck_capacity[trucknumber]
                                else if (trucknumber=7) then
cap7=truck_capacity[trucknumber]
                                else if (trucknumber=8) then
cap8=truck_capacity[trucknumber]
                                else if (trucknumber=9) then
cap9=truck_capacity[trucknumber]
                                else cap10=truck_capacity[trucknumber]

                                //display "truck load= ",cap1

                                flag = 1
                                min_rule = 9999999
                                num_waiting = contents(waiting_queue)+1
                                counter = 0
                                tie = 0
                                route 1}

else if (task=2) then
{
    get (res(trucknumber))
    route 2
}
else route 3

```

```

Waiting_queue  FIRST 1
1 material1
task=2
2 material2 Redding
IF destination = 1, 1 move with res(trucknumber)
material2 Chico
IF destination = 2 move with res(trucknumber)
material2
Sacramento IF destination = 3 move with
res(trucknumber)
material2
Palm_Springs IF destination = 4 move with
res(trucknumber)
material2 Stockton
IF destination = 5 move with res(trucknumber)
material2
Santa_Rosa IF destination = 6 move with
res(trucknumber)
material2
San_Fransisco IF destination = 7 move with
res(trucknumber)
material2 Oakland
IF destination = 8 move with res(trucknumber)
material2 San_Jose
IF destination = 9 move with res(trucknumber)
material2 Fresno
IF destination = 10 move with res(trucknumber)
material2
Bakersfield IF destination = 11 move with
res(trucknumber)
material2
Los_Angeles IF destination = 12 move with
res(trucknumber)
material2
Long_Beach IF destination = 13 move with
res(trucknumber)
material2 Barstow
IF destination = 14 move with res(trucknumber)
material2
San_Bernardino IF destination = 15 move with
res(trucknumber)
material2
San_Diego IF destination = 16 move with
res(trucknumber)
material2
Santa_Barbara IF destination = 17 move with
res(trucknumber)
material2
San_Luis_Obispo IF destination = 18 move with
res(trucknumber)
material2 Irvine
IF destination = 19 move with res(trucknumber)
material2 Monterey
IF destination = 20 move with res(trucknumber)
3 material1
Waiting_queue  FIRST 1

```

```

material1 Bakersfield      if (task=1) then
                            {
                                truck_capacity[trucknumber]=truck_capacity[trucknumber]+weight
                                get (res(trucknumber))
                                wait load_time
                                truck_location[trucknumber]=11
                                free res(trucknumber)

                                if (trucknumber=1) then
cap1=truck_capacity[trucknumber]
                                else if (trucknumber=2) then
cap2=truck_capacity[trucknumber]
                                else if (trucknumber=3) then
cap3=truck_capacity[trucknumber]
                                else if (trucknumber=4) then
cap4=truck_capacity[trucknumber]
                                else if (trucknumber=5) then
cap5=truck_capacity[trucknumber]
                                else if (trucknumber=6) then
cap6=truck_capacity[trucknumber]
                                else if (trucknumber=7) then
cap7=truck_capacity[trucknumber]
                                else if (trucknumber=8) then
cap8=truck_capacity[trucknumber]
                                else if (trucknumber=9) then
cap9=truck_capacity[trucknumber]
                                else cap10=truck_capacity[trucknumber]

                                //display "truck load= ",cap1

                                flag = 1
                                min_rule = 9999999
                                num_waiting = contents(waiting_queue)+1
                                counter = 0
                                tie = 0
                                route 1}

                            else if (task=2) then
                                {
                                    get (res(trucknumber))
                                    route 2
                                }
                            else route 3

Waiting_queue      FIRST 1
IF destination = 1, 1
IF destination = 2
Sacramento      IF destination = 3
res(trucknumber)

1      material1
      task=2
2      material2 Redding
      move with res(trucknumber)
      material2 Chico
      move with res(trucknumber)
      material2
      move with

```



```

material2
Palm_Springs    IF destination = 4    move with
res(trucknumber)

material2 Stockton
IF destination = 5    move with res(trucknumber)
material2
Santa_Rosa      IF destination = 6    move with
res(trucknumber)

material2
San_Fransisco  IF destination = 7    move with
res(trucknumber)

material2 Oakland
IF destination = 8    move with res(trucknumber)
material2 San_Jose
IF destination = 9    move with res(trucknumber)
material2 Fresno
IF destination = 10   move with res(trucknumber)
material2
Bakersfield    IF destination = 11   move with
res(trucknumber)

material2
Los_Angeles    IF destination = 12   move with
res(trucknumber)

material2
Long_Beach     IF destination = 13   move with
res(trucknumber)

material2 Barstow
IF destination = 14   move with res(trucknumber)
material2
San_Bernardino IF destination = 15   move with
res(trucknumber)

material2
San_Diego      IF destination = 16   move with
res(trucknumber)

material2
Santa_Barbara  IF destination = 17   move with
res(trucknumber)

material2
San_Luis_Obispo IF destination = 18   move with
res(trucknumber)

material2 Irvine
IF destination = 19   move with res(trucknumber)
material2 Monterey
IF destination = 20   move with res(trucknumber)
3    material1

Waiting_queue  FIRST 1
material1 Los_Angeles    if (task=1) then
                        {
                            truck_capacity[trucknumber]=truck_capacity[trucknumber]+weight
                                get (res(trucknumber))
                                wait load_time
                                truck_location[trucknumber]=12
                                free res(trucknumber)

                                if (trucknumber=1) then
cap1=truck_capacity[trucknumber]

```

```

else if (trucknumber=2) then
cap2=truck_capacity[trucknumber]
else if (trucknumber=3) then
cap3=truck_capacity[trucknumber]
else if (trucknumber=4) then
cap4=truck_capacity[trucknumber]
else if (trucknumber=5) then
cap5=truck_capacity[trucknumber]
else if (trucknumber=6) then
cap6=truck_capacity[trucknumber]
else if (trucknumber=7) then
cap7=truck_capacity[trucknumber]
else if (trucknumber=8) then
cap8=truck_capacity[trucknumber]
else if (trucknumber=9) then
cap9=truck_capacity[trucknumber]
else cap10=truck_capacity[trucknumber]

//display "truck load= ",cap1

flag = 1
min_rule = 9999999
num_waiting = contents(waiting_queue)+1
counter = 0
tie = 0
route 1}

else if (task=2) then
{
get (res(trucknumber))
route 2
}
else route 3

1 material1
Waiting_queue FIRST 1 task=2
2 material2 Redding
IF destination = 1, 1 move with res(trucknumber)
material2 Chico
IF destination = 2 move with res(trucknumber)
material2
Sacramento IF destination = 3
res(trucknumber) move with
material2
Palm_Springs IF destination = 4
res(trucknumber) move with
material2 Stockton
IF destination = 5 move with res(trucknumber)
material2
Santa_Rosa IF destination = 6
res(trucknumber) move with
material2
San_Fransisco IF destination = 7
res(trucknumber) move with
material2 Oakland
IF destination = 8 move with res(trucknumber)

```

```

IF destination = 9
    material2 San_Jose
    move with res(trucknumber)
IF destination = 10
    material2 Fresno
    move with res(trucknumber)
Bakersfield IF destination = 11
res(trucknumber)
    material2
    move with
Los_Angeles IF destination = 12
res(trucknumber)
    material2
    move with
Long_Beach IF destination = 13
res(trucknumber)
    material2
    move with
IF destination = 14
    material2 Barstow
    move with res(trucknumber)
San_Bernardino IF destination = 15
res(trucknumber)
    material2
    move with
San_Diego IF destination = 16
res(trucknumber)
    material2
    move with
Santa_Barbara IF destination = 17
res(trucknumber)
    material2
    move with
San_Luis_Obispo IF destination = 18
res(trucknumber)
    material2
    move with
IF destination = 19
    material2 Irvine
    move with res(trucknumber)
IF destination = 20
    material2 Monterey
    move with res(trucknumber)
    3 material1
Waiting_queue FIRST 1
material1 Long_Beach
    if (task=1) then
    {
        truck_capacity[trucknumber]=truck_capacity[trucknumber]+weight
        get (res(trucknumber))
        wait load_time
        truck_location[trucknumber]=13
        free res(trucknumber)
        if (trucknumber=1) then
cap1=truck_capacity[trucknumber]
        else if (trucknumber=2) then
cap2=truck_capacity[trucknumber]
        else if (trucknumber=3) then
cap3=truck_capacity[trucknumber]
        else if (trucknumber=4) then
cap4=truck_capacity[trucknumber]
        else if (trucknumber=5) then
cap5=truck_capacity[trucknumber]
        else if (trucknumber=6) then
cap6=truck_capacity[trucknumber]
        else if (trucknumber=7) then
cap7=truck_capacity[trucknumber]
    }

```

```

else if (trucknumber=8) then
cap8=truck_capacity[trucknumber]
else if (trucknumber=9) then
cap9=truck_capacity[trucknumber]
else cap10=truck_capacity[trucknumber]

//display "truck load= ",cap1

flag = 1
min_rule = 9999999
num_waiting = contents(waiting_queue)+1
counter = 0
tie = 0
route 1}

else if (task=2) then
{
get (res(trucknumber))
route 2
}
else route 3

1 material1
task=2
2 material2 Redding
material2 Chico
material2
move with
material2
move with
material2 Stockton
material2
move with
material2 Oakland
material2 San_Jose
material2 Fresno
material2
move with
material2
move with

```

Waiting_queue FIRST 1

IF destination = 1, 1

IF destination = 2

Sacramento IF destination = 3
res(trucknumber)

Palm_Springs IF destination = 4
res(trucknumber)

IF destination = 5

Santa_Rosa IF destination = 6
res(trucknumber)

San_Fransisco IF destination = 7
res(trucknumber)

IF destination = 8

IF destination = 9

IF destination = 10

Bakersfield IF destination = 11
res(trucknumber)

Los_Angeles IF destination = 12
res(trucknumber)

```

material2
Long_Beach      IF destination = 13      move with
res(trucknumber)

material2 Barstow
IF destination = 14      move with res(trucknumber)
material2
San_Bernardino  IF destination = 15      move with
res(trucknumber)

material2
San_Diego       IF destination = 16      move with
res(trucknumber)

material2
Santa_Barbara   IF destination = 17      move with
res(trucknumber)

material2
San_Luis_Obispo IF destination = 18      move with
res(trucknumber)

material2 Irvine
IF destination = 19      move with res(trucknumber)
material2 Monterey
IF destination = 20      move with res(trucknumber)
3      material1

Waiting_queue   FIRST 1
material1 Barstow      if (task=1) then
                        {
                            truck_capacity[trucknumber]=truck_capacity[trucknumber]+weight
                            get (res(trucknumber))
                            wait load_time
                            truck_location[trucknumber]=14
                            free res(trucknumber)

                                if (trucknumber=1) then
cap1=truck_capacity[trucknumber]
                                else if (trucknumber=2) then
cap2=truck_capacity[trucknumber]
                                else if (trucknumber=3) then
cap3=truck_capacity[trucknumber]
                                else if (trucknumber=4) then
cap4=truck_capacity[trucknumber]
                                else if (trucknumber=5) then
cap5=truck_capacity[trucknumber]
                                else if (trucknumber=6) then
cap6=truck_capacity[trucknumber]
                                else if (trucknumber=7) then
cap7=truck_capacity[trucknumber]
                                else if (trucknumber=8) then
cap8=truck_capacity[trucknumber]
                                else if (trucknumber=9) then
cap9=truck_capacity[trucknumber]
                                else cap10=truck_capacity[trucknumber]

                                //display "truck load= ",cap1

                                flag = 1
                                min_rule = 9999999

```

```

        num_waiting = contents(waiting_queue)+1
        counter = 0
        tie = 0
        route 1}

else if (task=2) then
{
    get (res(trucknumber))
    route 2
}
else route 3

Waiting_queue    FIRST 1
1    material1
    task=2
2    material2 Redding
IF destination = 1, 1    move with res(trucknumber)
                        material2 Chico
IF destination = 2    move with res(trucknumber)
                        material2
Sacramento    IF destination = 3
res(trucknumber)    move with
                        material2
Palm_Springs    IF destination = 4
res(trucknumber)    move with
                        material2 Stockton
IF destination = 5    move with res(trucknumber)
                        material2
Santa_Rosa    IF destination = 6
res(trucknumber)    move with
                        material2
San_Franisisco    IF destination = 7
res(trucknumber)    move with
                        material2 Oakland
IF destination = 8    move with res(trucknumber)
                        material2 San_Jose
IF destination = 9    move with res(trucknumber)
                        material2 Fresno
IF destination = 10    move with res(trucknumber)
                        material2
Bakersfield    IF destination = 11
res(trucknumber)    move with
                        material2
Los_Angeles    IF destination = 12
res(trucknumber)    move with
                        material2
Long_Beach    IF destination = 13
res(trucknumber)    move with
                        material2 Barstow
IF destination = 14    move with res(trucknumber)
                        material2
San_Bernardino    IF destination = 15
res(trucknumber)    move with
                        material2
San_Diego    IF destination = 16
res(trucknumber)    move with

```

```

material2
Santa_Barbara IF destination = 17      move with
res(trucknumber)                       material2

San_Luis_Obispo IF destination = 18    move with
res(trucknumber)                       material2

IF destination = 19                     move with res(trucknumber)      material2 Irvine
material2 Monterey
IF destination = 20                     move with res(trucknumber)      material2 Monterey
3 material1
Waiting_queue FIRST 1
material1 San_Bernardino if (task=1) then
{
truck_capacity[trucknumber]=truck_capacity[trucknumber]+weight
get (res(trucknumber))
wait load_time
truck_location[trucknumber]=15
free res(trucknumber)

if (trucknumber=1) then
cap1=truck_capacity[trucknumber]
else if (trucknumber=2) then
cap2=truck_capacity[trucknumber]
else if (trucknumber=3) then
cap3=truck_capacity[trucknumber]
else if (trucknumber=4) then
cap4=truck_capacity[trucknumber]
else if (trucknumber=5) then
cap5=truck_capacity[trucknumber]
else if (trucknumber=6) then
cap6=truck_capacity[trucknumber]
else if (trucknumber=7) then
cap7=truck_capacity[trucknumber]
else if (trucknumber=8) then
cap8=truck_capacity[trucknumber]
else if (trucknumber=9) then
cap9=truck_capacity[trucknumber]
else cap10=truck_capacity[trucknumber]

//display "truck load= ",cap1

flag = 1
min_rule = 9999999
num_waiting = contents(waiting_queue)+1
counter = 0
tie = 0
route 1}

else if (task=2) then
{
get (res(trucknumber))
route 2
}
else route 3

```

```

Waiting_queue  FIRST 1
IF destination = 1, 1
IF destination = 2
Sacramento    IF destination = 3
res(trucknumber)
Palm_Springs  IF destination = 4
res(trucknumber)
IF destination = 5
Santa_Rosa     IF destination = 6
res(trucknumber)
San_Fransisco IF destination = 7
res(trucknumber)
IF destination = 8
IF destination = 9
IF destination = 10
Bakersfield   IF destination = 11
res(trucknumber)
Los_Angeles   IF destination = 12
res(trucknumber)
Long_Beach    IF destination = 13
res(trucknumber)
IF destination = 14
San_Bernardino IF destination = 15
res(trucknumber)
San_Diego     IF destination = 16
res(trucknumber)
Santa_Barbara IF destination = 17
res(trucknumber)
San_Luis_Obispo IF destination = 18
res(trucknumber)
IF destination = 19
IF destination = 20
Waiting_queue  FIRST 1
material1 San_Diego    if (task=1) then

```

```

1  material1
   task=2
2  material2 Redding
   material2 Chico
   material2
   move with
   material2
   move with
   material2 Stockton
   material2
   move with
   material2
   move with
   material2
   move with
   material2 Oakland
   material2 San_Jose
   material2 Fresno
   material2
   move with
   material2 Barstow
   material2
   move with
   material2
   move with
   material2
   move with
   material2 Irvine
   material2 Monterey
3  material1

```



```

{
truck_capacity[trucknumber]=truck_capacity[trucknumber]+weight
get (res(trucknumber))
wait load_time
truck_location[trucknumber]=16
free res(trucknumber)

if (trucknumber=1) then
cap1=truck_capacity[trucknumber]
else if (trucknumber=2) then
cap2=truck_capacity[trucknumber]
else if (trucknumber=3) then
cap3=truck_capacity[trucknumber]
else if (trucknumber=4) then
cap4=truck_capacity[trucknumber]
else if (trucknumber=5) then
cap5=truck_capacity[trucknumber]
else if (trucknumber=6) then
cap6=truck_capacity[trucknumber]
else if (trucknumber=7) then
cap7=truck_capacity[trucknumber]
else if (trucknumber=8) then
cap8=truck_capacity[trucknumber]
else if (trucknumber=9) then
cap9=truck_capacity[trucknumber]
else cap10=truck_capacity[trucknumber]

//display "truck load= ",cap1

flag = 1
min_rule = 9999999
num_waiting = contents(waiting_queue)+1
counter = 0
tie = 0
route 1}

else if (task=2) then
{
get (res(trucknumber))
route 2
}
else route 3

Waiting_queue FIRST 1
IF destination = 1, 1
IF destination = 2
Sacramento IF destination = 3
res(trucknumber)

1 material1
task=2
2 material2 Redding
move with res(trucknumber)
material2 Chico
move with res(trucknumber)
material2
move with

```

```

material2
Palm_Springs    IF destination = 4    move with
res(trucknumber)

material2 Stockton
IF destination = 5    move with res(trucknumber)
material2
Santa_Rosa      IF destination = 6    move with
res(trucknumber)

material2
San_Fransisco  IF destination = 7    move with
res(trucknumber)

material2 Oakland
IF destination = 8    move with res(trucknumber)
material2 San_Jose
IF destination = 9    move with res(trucknumber)
material2 Fresno
IF destination = 10   move with res(trucknumber)
material2
Bakersfield    IF destination = 11   move with
res(trucknumber)

material2
Los_Angeles    IF destination = 12   move with
res(trucknumber)

material2
Long_Beach     IF destination = 13   move with
res(trucknumber)

material2 Barstow
IF destination = 14   move with res(trucknumber)
material2
San_Bernardino IF destination = 15   move with
res(trucknumber)

material2
San_Diego      IF destination = 16   move with
res(trucknumber)

material2
Santa_Barbara  IF destination = 17   move with
res(trucknumber)

material2
San_Luis_Obispo IF destination = 18   move with
res(trucknumber)

material2 Irvine
IF destination = 19   move with res(trucknumber)
material2 Monterey
IF destination = 20   move with res(trucknumber)
3    material1

Waiting_queue  FIRST 1
material1 Santa_Barbara  if (task=1) then
{

truck_capacity[trucknumber]=truck_capacity[trucknumber]+weight
get (res(trucknumber))
wait load_time
truck_location[trucknumber]=17
free res(trucknumber)

if (trucknumber=1) then
cap1=truck_capacity[trucknumber]

```

```

else if (trucknumber=2) then
cap2=truck_capacity[trucknumber]
else if (trucknumber=3) then
cap3=truck_capacity[trucknumber]
else if (trucknumber=4) then
cap4=truck_capacity[trucknumber]
else if (trucknumber=5) then
cap5=truck_capacity[trucknumber]
else if (trucknumber=6) then
cap6=truck_capacity[trucknumber]
else if (trucknumber=7) then
cap7=truck_capacity[trucknumber]
else if (trucknumber=8) then
cap8=truck_capacity[trucknumber]
else if (trucknumber=9) then
cap9=truck_capacity[trucknumber]
else cap10=truck_capacity[trucknumber]

//display "truck load= ",cap1

flag = 1
min_rule = 9999999
num_waiting = contents(waiting_queue)+1
counter = 0
tie = 0
route 1}

else if (task=2) then
{
get (res(trucknumber))
route 2
}
else route 3

Waiting_queue FIRST 1
1 material1
task=2
2 material2 Redding
IF destination = 1, 1 move with res(trucknumber)
material2 Chico
IF destination = 2 move with res(trucknumber)
material2
Sacramento IF destination = 3
res(trucknumber) move with
material2
Palm_Springs IF destination = 4
res(trucknumber) move with
material2 Stockton
IF destination = 5 move with res(trucknumber)
material2
Santa_Rosa IF destination = 6
res(trucknumber) move with
material2
San_Fransisco IF destination = 7
res(trucknumber) move with
material2 Oakland
IF destination = 8 move with res(trucknumber)

```

```

IF destination = 9
    material2 San_Jose
    move with res(trucknumber)
IF destination = 10
    material2 Fresno
    move with res(trucknumber)
Bakersfield IF destination = 11
res(trucknumber)
    material2
    move with
Los_Angeles IF destination = 12
res(trucknumber)
    material2
    move with
Long_Beach IF destination = 13
res(trucknumber)
    material2
    move with
IF destination = 14
    material2 Barstow
    move with res(trucknumber)
San_Bernardino IF destination = 15
res(trucknumber)
    material2
    move with
San_Diego IF destination = 16
res(trucknumber)
    material2
    move with
Santa_Barbara IF destination = 17
res(trucknumber)
    material2
    move with
San_Luis_Obispo IF destination = 18
res(trucknumber)
    material2
    move with
IF destination = 19
    material2 Irvine
    move with res(trucknumber)
IF destination = 20
    material2 Monterey
    move with res(trucknumber)
    3 material1
Waiting_queue FIRST 1
    material1 San_Luis_Obispo if (task=1) then
        {
            truck_capacity[trucknumber]=truck_capacity[trucknumber]+weight
            get (res(trucknumber))
            wait load_time
            truck_location[trucknumber]=18
            free res(trucknumber)
            if (trucknumber=1) then
cap1=truck_capacity[trucknumber]
            else if (trucknumber=2) then
cap2=truck_capacity[trucknumber]
            else if (trucknumber=3) then
cap3=truck_capacity[trucknumber]
            else if (trucknumber=4) then
cap4=truck_capacity[trucknumber]
            else if (trucknumber=5) then
cap5=truck_capacity[trucknumber]
            else if (trucknumber=6) then
cap6=truck_capacity[trucknumber]
            else if (trucknumber=7) then
cap7=truck_capacity[trucknumber]

```

```

else if (trucknumber=8) then
cap8=truck_capacity[trucknumber]
else if (trucknumber=9) then
cap9=truck_capacity[trucknumber]
else cap10=truck_capacity[trucknumber]

//display "truck load= ",cap1

flag = 1
min_rule = 9999999
num_waiting = contents(waiting_queue)+1
counter = 0
tie = 0
route 1}

else if (task=2) then
{
get (res(trucknumber))
route 2
}
else route 3

1 material1
task=2
2 material2 Redding
material2 Chico
material2
move with
material2
move with
material2 Stockton
material2
move with
material2 Oakland
material2 San_Jose
material2 Fresno
material2
move with
material2
move with

```

Waiting_queue FIRST 1

IF destination = 1, 1

IF destination = 2

Sacramento IF destination = 3
res(trucknumber)

Palm_Springs IF destination = 4
res(trucknumber)

IF destination = 5

Santa_Rosa IF destination = 6
res(trucknumber)

San_Fransisco IF destination = 7
res(trucknumber)

IF destination = 8

IF destination = 9

IF destination = 10

Bakersfield IF destination = 11
res(trucknumber)

Los_Angeles IF destination = 12
res(trucknumber)

```

material2
Long_Beach      IF destination = 13      move with
res(trucknumber)

material2 Barstow
IF destination = 14      move with res(trucknumber)
material2
San_Bernardino  IF destination = 15      move with
res(trucknumber)

material2
San_Diego       IF destination = 16      move with
res(trucknumber)

material2
Santa_Barbara   IF destination = 17      move with
res(trucknumber)

material2
San_Luis_Obispo IF destination = 18      move with
res(trucknumber)

material2 Irvine
IF destination = 19      move with res(trucknumber)
material2 Monterey
IF destination = 20      move with res(trucknumber)
3      material1

Waiting_queue  FIRST 1
material1 Irvine      if (task=1) then
                      {
                        truck_capacity[trucknumber]=truck_capacity[trucknumber]+weight
                        get (res(trucknumber))
                        wait load_time
                        truck_location[trucknumber]=19
                        free res(trucknumber)

                        if (trucknumber=1) then
cap1=truck_capacity[trucknumber]
                        else if (trucknumber=2) then
cap2=truck_capacity[trucknumber]
                        else if (trucknumber=3) then
cap3=truck_capacity[trucknumber]
                        else if (trucknumber=4) then
cap4=truck_capacity[trucknumber]
                        else if (trucknumber=5) then
cap5=truck_capacity[trucknumber]
                        else if (trucknumber=6) then
cap6=truck_capacity[trucknumber]
                        else if (trucknumber=7) then
cap7=truck_capacity[trucknumber]
                        else if (trucknumber=8) then
cap8=truck_capacity[trucknumber]
                        else if (trucknumber=9) then
cap9=truck_capacity[trucknumber]
                        else cap10=truck_capacity[trucknumber]

//display "truck load= ",cap1

flag = 1
min_rule = 9999999

```

```

        num_waiting = contents(waiting_queue)+1
        counter = 0
        tie = 0
        route 1}

else if (task=2) then
{
    get (res(trucknumber))
    route 2
}
else route 3

Waiting_queue    FIRST 1
1    material1
    task=2
2    material2 Redding
IF destination = 1, 1    move with res(trucknumber)
                        material2 Chico
IF destination = 2    move with res(trucknumber)
                        material2
Sacramento    IF destination = 3
res(trucknumber)    move with
                        material2
Palm_Springs    IF destination = 4
res(trucknumber)    move with
                        material2 Stockton
IF destination = 5    move with res(trucknumber)
                        material2
Santa_Rosa    IF destination = 6
res(trucknumber)    move with
                        material2
San_Franisisco    IF destination = 7
res(trucknumber)    move with
                        material2 Oakland
IF destination = 8    move with res(trucknumber)
                        material2 San_Jose
IF destination = 9    move with res(trucknumber)
                        material2 Fresno
IF destination = 10    move with res(trucknumber)
                        material2
Bakersfield    IF destination = 11
res(trucknumber)    move with
                        material2
Los_Angeles    IF destination = 12
res(trucknumber)    move with
                        material2
Long_Beach    IF destination = 13
res(trucknumber)    move with
                        material2 Barstow
IF destination = 14    move with res(trucknumber)
                        material2
San_Bernardino    IF destination = 15
res(trucknumber)    move with
                        material2
San_Diego    IF destination = 16
res(trucknumber)    move with

```

```

                                material2
Santa_Barbara  IF destination = 17  move with
res(trucknumber)

                                material2
San_Luis_Obispo IF destination = 18  move with

                                material2 Irvine
IF destination = 19                move with res(trucknumber)
                                material2 Monterey
IF destination = 20                move with res(trucknumber)
                                3      material1
Waiting_queue  FIRST 1
material1 Monterey      if (task=1) then
                        {

                                truck_capacity[trucknumber]=truck_capacity[trucknumber]+weight
                                get (res(trucknumber))
                                wait load_time
                                truck_location[trucknumber]=20
                                free res(trucknumber)

                                if (trucknumber=1) then
cap1=truck_capacity[trucknumber]
                                else if (trucknumber=2) then
cap2=truck_capacity[trucknumber]
                                else if (trucknumber=3) then
cap3=truck_capacity[trucknumber]
                                else if (trucknumber=4) then
cap4=truck_capacity[trucknumber]
                                else if (trucknumber=5) then
cap5=truck_capacity[trucknumber]
                                else if (trucknumber=6) then
cap6=truck_capacity[trucknumber]
                                else if (trucknumber=7) then
cap7=truck_capacity[trucknumber]
                                else if (trucknumber=8) then
cap8=truck_capacity[trucknumber]
                                else if (trucknumber=9) then
cap9=truck_capacity[trucknumber]
                                else cap10=truck_capacity[trucknumber]

                                //display "truck load= ",cap1

                                flag = 1
                                min_rule = 9999999
                                num_waiting = contents(waiting_queue)+1
                                counter = 0
                                tie = 0
                                route 1}

                        else if (task=2) then
                        {
                                get (res(trucknumber))
                                route 2
                        }
else route 3

```



```

Waiting_queue  FIRST 1
IF destination = 1, 1
IF destination = 2
Sacramento    IF destination = 3
res(trucknumber)
Palm_Springs  IF destination = 4
res(trucknumber)
IF destination = 5
Santa_Rosa     IF destination = 6
res(trucknumber)
San_Fransisco IF destination = 7
res(trucknumber)
IF destination = 8
IF destination = 9
IF destination = 10
Bakersfield   IF destination = 11
res(trucknumber)
Los_Angeles   IF destination = 12
res(trucknumber)
Long_Beach    IF destination = 13
res(trucknumber)
IF destination = 14
San_Bernardino IF destination = 15
res(trucknumber)
San_Diego     IF destination = 16
res(trucknumber)
Santa_Barbara IF destination = 17
res(trucknumber)
San_Luis_Obispo IF destination = 18
res(trucknumber)
IF destination = 19
IF destination = 20
Waiting_queue  FIRST 1

```

1 material1
task=2
2 material2 Redding
material2 Chico
material2
move with
material2
move with
material2 Stockton
material2
move with
material2
move with
material2
move with
material2 Oakland
material2 San_Jose
material2 Fresno
material2
move with
material2
move with
material2 Barstow
material2
move with
material2
move with
material2 Irvine
material2 Monterey
3 material1

```

material1 delivery_queue          1    material1 Redding
IF truck_location[trucknumber]=1, 1
                                   material1 Chico
IF truck_location[trucknumber]=2
                                   material1
Sacramento      IF truck_location[trucknumber]=3
                                   material1
Palm_Springs   IF truck_location[trucknumber]=4
                                   material1 Stockton
IF truck_location[trucknumber] = 5
                                   material1
Santa_Rosa      IF truck_location[trucknumber] = 6
                                   material1
San_Fransisco  IF truck_location[trucknumber] = 7
                                   material1 Oakland
IF truck_location[trucknumber] = 8
                                   material1 San_Jose
IF truck_location[trucknumber] = 9
                                   material1 Fresno
IF truck_location[trucknumber]= 10
                                   material1
Bakersfield    IF truck_location[trucknumber] = 11
                                   material1
Los_Angeles    IF truck_location[trucknumber] = 12
                                   material1
Long_Beach     IF truck_location[trucknumber] = 13
                                   material1 Barstow
IF truck_location[trucknumber] = 14
                                   material1
San_Bernardino IF truck_location[trucknumber] = 15
                                   material1
San_Diego      IF truck_location[trucknumber] = 16
                                   material1
Santa_Barbara  IF truck_location[trucknumber] = 17
                                   material1
San_Luis_Obispo IF truck_location[trucknumber] = 18
                                   material1 Irvine
IF truck_location[trucknumber] = 19
                                   material1 Monterey
IF truck_location[trucknumber] = 20
material2 Redding      wait unload_time

                                   //display "delivery hour=",clock()
                                   //display "delivery @ ",destination
                                   //display "weight=",weight

truck_capacity[trucknumber]=truck_capacity[trucknumber]-weight
truck_location[trucknumber]=1
free res(trucknumber)
flag = 1
num_waiting = contents(waiting_queue)
min_rule = 9999999
counter = 0
tie = 0

```

```

        if (trucknumber=1) then
cap1=truck_capacity[trucknumber]
        else if (trucknumber=2) then
cap2=truck_capacity[trucknumber]
        else if (trucknumber=3) then
cap3=truck_capacity[trucknumber]
        else if (trucknumber=4) then
cap4=truck_capacity[trucknumber]
        else if (trucknumber=5) then
cap5=truck_capacity[trucknumber]
        else if (trucknumber=6) then
cap6=truck_capacity[trucknumber]
        else if (trucknumber=7) then
cap7=truck_capacity[trucknumber]
        else if (trucknumber=8) then
cap8=truck_capacity[trucknumber]
        else if (trucknumber=9) then
cap9=truck_capacity[trucknumber]
        else cap10=truck_capacity[trucknumber]

        Lateness = clock() - due_date
        Total_square_lateness =
Total_square_lateness+Lateness*Lateness
        Total_lateness = Total_lateness + Lateness
        if (Lateness > 0) then Tardiness = Lateness
        else Tardiness = 0
        if tardiness > 0
        then inc num_tardy
        Total_tardiness = Total_tardiness +
Tardiness

        inc NUM
        Avg_Lateness = Total_lateness/NUM
        if( NUM>1) then Var_Lateness = (
Total_square_lateness - Total_lateness*Total_lateness/NUM)/(NUM-1)
        Avg_Tardiness = Total_tardiness/NUM

        //display "truck load= ",cap1
        1 material2 EXIT

FIRST 1
material2 Chico        wait unload_time

        //display "delivery hour=",clock()
        //display "delivery @ ",destination
        //display "weight=",weight

truck_capacity[trucknumber]=truck_capacity[trucknumber]-weight
truck_location[trucknumber]=2
free res(trucknumber)
flag = 1
num_waiting = contents(waiting_queue)
min_rule = 9999999
counter = 0
tie = 0
        if (trucknumber=1) then
cap1=truck_capacity[trucknumber]

```

```

else if (trucknumber=2) then
cap2=truck_capacity[trucknumber]
else if (trucknumber=3) then
cap3=truck_capacity[trucknumber]
else if (trucknumber=4) then
cap4=truck_capacity[trucknumber]
else if (trucknumber=5) then
cap5=truck_capacity[trucknumber]
else if (trucknumber=6) then
cap6=truck_capacity[trucknumber]
else if (trucknumber=7) then
cap7=truck_capacity[trucknumber]
else if (trucknumber=8) then
cap8=truck_capacity[trucknumber]
else if (trucknumber=9) then
cap9=truck_capacity[trucknumber]
else cap10=truck_capacity[trucknumber]

Lateness = clock() - due_date
Total_square_lateness =
Total_square_lateness+Lateness*Lateness
Total_lateness = Total_lateness + Lateness
if (Lateness > 0) then Tardiness = Lateness
else Tardiness = 0
if tardiness > 0
then inc num_tardy
Total_tardiness = Total_tardiness +
Tardiness

inc NUM
Avg_Lateness = Total_lateness/NUM
if( NUM>1) then Var_Lateness = (
Total_square_lateness - Total_lateness*Total_lateness/NUM)/(NUM-1)
Avg_Tardiness = Total_tardiness/NUM

//display "truck load= ",cap1
1 material2 EXIT

FIRST 1
material2 Sacramento wait unload_time

//display "delivery hour=",clock()
//display "delivery @ ",destination
//display "weight=",weight

truck_capacity[trucknumber]=truck_capacity[trucknumber]-weight
truck_location[trucknumber]=3
free res(trucknumber)
flag = 1
num_waiting = contents(waiting_queue)
min_rule = 9999999
counter = 0
tie = 0
if (trucknumber=1) then
cap1=truck_capacity[trucknumber]
else if (trucknumber=2) then
cap2=truck_capacity[trucknumber]

```

```

else if (trucknumber=3) then
cap3=truck_capacity[trucknumber]
else if (trucknumber=4) then
cap4=truck_capacity[trucknumber]
else if (trucknumber=5) then
cap5=truck_capacity[trucknumber]
else if (trucknumber=6) then
cap6=truck_capacity[trucknumber]
else if (trucknumber=7) then
cap7=truck_capacity[trucknumber]
else if (trucknumber=8) then
cap8=truck_capacity[trucknumber]
else if (trucknumber=9) then
cap9=truck_capacity[trucknumber]
else cap10=truck_capacity[trucknumber]

Lateness = clock() - due_date
Total_square_lateness =
Total_square_lateness+Lateness*Lateness
Total_lateness = Total_lateness + Lateness
if (Lateness > 0) then Tardiness = Lateness
else Tardiness = 0
if tardiness > 0
then inc num_tardy
Total_tardiness = Total_tardiness +
Tardiness

inc NUM
Avg_Lateness = Total_lateness/NUM
if( NUM>1) then Var_Lateness = (
Total_square_lateness - Total_lateness*Total_lateness/NUM)/(NUM-1)
Avg_Tardiness = Total_tardiness/NUM

//display "truck load= ",cap1
1 material2 EXIT

FIRST 1
material2 Palm_Springs wait unload_time

//display "delivery hour=",clock()
//display "delivery @ ",destination
//display "weight=",weight

truck_capacity[trucknumber]=truck_capacity[trucknumber]-weight
truck_location[trucknumber]=4
free res(trucknumber)
flag = 1
num_waiting = contents(waiting_queue)
min_rule = 9999999
counter = 0
tie = 0
if (trucknumber=1) then
cap1=truck_capacity[trucknumber]
else if (trucknumber=2) then
cap2=truck_capacity[trucknumber]
else if (trucknumber=3) then
cap3=truck_capacity[trucknumber]

```

```

                                else if (trucknumber=4) then
cap4=truck_capacity[trucknumber]
                                else if (trucknumber=5) then
cap5=truck_capacity[trucknumber]
                                else if (trucknumber=6) then
cap6=truck_capacity[trucknumber]
                                else if (trucknumber=7) then
cap7=truck_capacity[trucknumber]
                                else if (trucknumber=8) then
cap8=truck_capacity[trucknumber]
                                else if (trucknumber=9) then
cap9=truck_capacity[trucknumber]
                                else cap10=truck_capacity[trucknumber]

                                Lateness = clock() - due_date
                                Total_square_lateness =
Total_square_lateness+Lateness*Lateness
                                Total_lateness = Total_lateness + Lateness
                                if (Lateness > 0) then Tardiness = Lateness
                                else Tardiness = 0
                                if tardiness > 0
                                then inc num_tardy
                                Total_tardiness = Total_tardiness +
Tardiness

                                inc NUM
                                Avg_Lateness = Total_lateness/NUM
                                if( NUM>1) then Var_Lateness = (
Total_square_lateness - Total_lateness*Total_lateness/NUM)/(NUM-1)
                                Avg_Tardiness = Total_tardiness/NUM

                                //display "truck load= ",cap1
                                                1      material2 EXIT

FIRST 1
material2 Stockton      wait unload_time

                                //display "delivery hour=",clock()
                                //display "delivery @ ",destination
                                //display "weight=",weight

truck_capacity[trucknumber]=truck_capacity[trucknumber]-weight
truck_location[trucknumber]=5
free res(trucknumber)
flag = 1
num_waiting = contents(waiting_queue)
min_rule = 9999999
counter = 0
tie = 0
if (trucknumber=1) then
cap1=truck_capacity[trucknumber]
                                else if (trucknumber=2) then
cap2=truck_capacity[trucknumber]
                                else if (trucknumber=3) then
cap3=truck_capacity[trucknumber]
                                else if (trucknumber=4) then
cap4=truck_capacity[trucknumber]

```

```

else if (trucknumber=5) then
cap5=truck_capacity[trucknumber]
else if (trucknumber=6) then
cap6=truck_capacity[trucknumber]
else if (trucknumber=7) then
cap7=truck_capacity[trucknumber]
else if (trucknumber=8) then
cap8=truck_capacity[trucknumber]
else if (trucknumber=9) then
cap9=truck_capacity[trucknumber]
else cap10=truck_capacity[trucknumber]

Lateness = clock() - due_date
Total_square_lateness =
Total_square_lateness+Lateness*Lateness
Total_lateness = Total_lateness + Lateness
if (Lateness > 0) then Tardiness = Lateness
else Tardiness = 0
if tardiness > 0
then inc num_tardy
Total_tardiness = Total_tardiness +
Tardiness

inc NUM
Avg_Lateness = Total_lateness/NUM
if( NUM>1) then Var_Lateness = (
Total_square_lateness - Total_lateness*Total_lateness/NUM)/(NUM-1)
Avg_Tardiness = Total_tardiness/NUM

//display "truck load= ",cap1
1 material2 EXIT

FIRST 1
material2 Santa_Rosa wait unload_time

//display "delivery hour=",clock()
//display "delivery @ ",destination
//display "weight=",weight

truck_capacity[trucknumber]=truck_capacity[trucknumber]-weight
truck_location[trucknumber]=6
free res(trucknumber)
flag = 1
num_waiting = contents(waiting_queue)
min_rule = 9999999
counter = 0
tie = 0
if (trucknumber=1) then
cap1=truck_capacity[trucknumber]
else if (trucknumber=2) then
cap2=truck_capacity[trucknumber]
else if (trucknumber=3) then
cap3=truck_capacity[trucknumber]
else if (trucknumber=4) then
cap4=truck_capacity[trucknumber]
else if (trucknumber=5) then
cap5=truck_capacity[trucknumber]

```

```

else if (trucknumber=6) then
cap6=truck_capacity[trucknumber]
else if (trucknumber=7) then
cap7=truck_capacity[trucknumber]
else if (trucknumber=8) then
cap8=truck_capacity[trucknumber]
else if (trucknumber=9) then
cap9=truck_capacity[trucknumber]
else cap10=truck_capacity[trucknumber]

Lateness = clock() - due_date
Total_square_lateness =
Total_square_lateness+Lateness*Lateness
Total_lateness = Total_lateness + Lateness
if (Lateness > 0) then Tardiness = Lateness
else Tardiness = 0
if tardiness > 0
then inc num_tardy
Total_tardiness = Total_tardiness +
Tardiness

inc NUM
Avg_Lateness = Total_lateness/NUM
if( NUM>1) then Var_Lateness = (
Total_square_lateness - Total_lateness*Total_lateness/NUM)/(NUM-1)
Avg_Tardiness = Total_tardiness/NUM

//display "truck load= ",cap1
1 material2 EXIT

FIRST 1
material2 San_Fransisco wait unload_time

//display "delivery hour=",clock()
//display "delivery @ ",destination
//display "weight=",weight

truck_capacity[trucknumber]=truck_capacity[trucknumber]-weight
truck_location[trucknumber]=7
free res(trucknumber)
flag = 1
num_waiting = contents(waiting_queue)
min_rule = 9999999
counter = 0
tie = 0
if (trucknumber=1) then
cap1=truck_capacity[trucknumber]
else if (trucknumber=2) then
cap2=truck_capacity[trucknumber]
else if (trucknumber=3) then
cap3=truck_capacity[trucknumber]
else if (trucknumber=4) then
cap4=truck_capacity[trucknumber]
else if (trucknumber=5) then
cap5=truck_capacity[trucknumber]
else if (trucknumber=6) then
cap6=truck_capacity[trucknumber]

```



```

else if (trucknumber=7) then
cap7=truck_capacity[trucknumber]
else if (trucknumber=8) then
cap8=truck_capacity[trucknumber]
else if (trucknumber=9) then
cap9=truck_capacity[trucknumber]
else cap10=truck_capacity[trucknumber]

Lateness = clock() - due_date
Total_square_lateness =
Total_square_lateness+Lateness*Lateness
Total_lateness = Total_lateness + Lateness
if (Lateness > 0) then Tardiness = Lateness
else Tardiness = 0
if tardiness > 0
then inc num_tardy
Total_tardiness = Total_tardiness +
Tardiness

inc NUM
Avg_Lateness = Total_lateness/NUM
if( NUM>1) then Var_Lateness = (
Total_square_lateness - Total_lateness*Total_lateness/NUM)/(NUM-1)
Avg_Tardiness = Total_tardiness/NUM

//display "truck load= ",cap1
1 material2 EXIT

FIRST 1
material2 Oakland wait unload_time

//display "delivery hour=",clock()
//display "delivery @ ",destination
//display "weight=",weight

truck_capacity[trucknumber]=truck_capacity[trucknumber]-weight
truck_location[trucknumber]=8
free res(trucknumber)
flag = 1
num_waiting = contents(waiting_queue)
min_rule = 9999999
counter = 0
tie = 0
if (trucknumber=1) then
cap1=truck_capacity[trucknumber]
else if (trucknumber=2) then
cap2=truck_capacity[trucknumber]
else if (trucknumber=3) then
cap3=truck_capacity[trucknumber]
else if (trucknumber=4) then
cap4=truck_capacity[trucknumber]
else if (trucknumber=5) then
cap5=truck_capacity[trucknumber]
else if (trucknumber=6) then
cap6=truck_capacity[trucknumber]
else if (trucknumber=7) then
cap7=truck_capacity[trucknumber]

```

```

else if (trucknumber=8) then
cap8=truck_capacity[trucknumber]
else if (trucknumber=9) then
cap9=truck_capacity[trucknumber]
else cap10=truck_capacity[trucknumber]

Lateness = clock() - due_date
Total_square_lateness =
Total_square_lateness+Lateness*Lateness
Total_lateness = Total_lateness + Lateness
if (Lateness > 0) then Tardiness = Lateness
else Tardiness = 0
if tardiness > 0
then inc num_tardy
Total_tardiness = Total_tardiness +
Tardiness

inc NUM
Avg_Lateness = Total_lateness/NUM
if( NUM>1) then Var_Lateness = (
Total_square_lateness - Total_lateness*Total_lateness/NUM)/(NUM-1)
Avg_Tardiness = Total_tardiness/NUM

//display "truck load= ",cap1
1 material2 EXIT

FIRST 1
material2 San_Jose wait unload_time

//display "delivery hour=",clock()
//display "delivery @ ",destination
//display "weight=",weight

truck_capacity[trucknumber]=truck_capacity[trucknumber]-weight
truck_location[trucknumber]=9
free res(trucknumber)
flag = 1
num_waiting = contents(waiting_queue)
min_rule = 9999999
counter = 0
tie = 0
if (trucknumber=1) then
cap1=truck_capacity[trucknumber]
else if (trucknumber=2) then
cap2=truck_capacity[trucknumber]
else if (trucknumber=3) then
cap3=truck_capacity[trucknumber]
else if (trucknumber=4) then
cap4=truck_capacity[trucknumber]
else if (trucknumber=5) then
cap5=truck_capacity[trucknumber]
else if (trucknumber=6) then
cap6=truck_capacity[trucknumber]
else if (trucknumber=7) then
cap7=truck_capacity[trucknumber]
else if (trucknumber=8) then
cap8=truck_capacity[trucknumber]

```

```

else if (trucknumber=9) then
cap9=truck_capacity[trucknumber]
else cap10=truck_capacity[trucknumber]

Lateness = clock() - due_date
Total_square_lateness =
Total_square_lateness+Lateness*Lateness
Total_lateness = Total_lateness + Lateness
if (Lateness > 0) then Tardiness = Lateness
else Tardiness = 0
if tardiness > 0
then inc num_tardy
Total_tardiness = Total_tardiness +
Tardiness

inc NUM
Avg_Lateness = Total_lateness/NUM
if( NUM>1) then Var_Lateness = (
Total_square_lateness - Total_lateness*Total_lateness/NUM)/(NUM-1)
Avg_Tardiness = Total_tardiness/NUM

//display "truck load= ",cap1
1 material2 EXIT

FIRST 1
material2 Fresno wait unload_time

//display "delivery hour=",clock()
//display "delivery @ ",destination
//display "weight=",weight

truck_capacity[trucknumber]=truck_capacity[trucknumber]-weight
truck_location[trucknumber]=10
free res(trucknumber)
flag = 1
num_waiting = contents(waiting_queue)
min_rule = 9999999
counter = 0
tie = 0
if (trucknumber=1) then
cap1=truck_capacity[trucknumber]
else if (trucknumber=2) then
cap2=truck_capacity[trucknumber]
else if (trucknumber=3) then
cap3=truck_capacity[trucknumber]
else if (trucknumber=4) then
cap4=truck_capacity[trucknumber]
else if (trucknumber=5) then
cap5=truck_capacity[trucknumber]
else if (trucknumber=6) then
cap6=truck_capacity[trucknumber]
else if (trucknumber=7) then
cap7=truck_capacity[trucknumber]
else if (trucknumber=8) then
cap8=truck_capacity[trucknumber]
else if (trucknumber=9) then
cap9=truck_capacity[trucknumber]
else cap10=truck_capacity[trucknumber]

```

```

        Lateness = clock() - due_date
        Total_square_lateness =
Total_square_lateness+Lateness*Lateness
        Total_lateness = Total_lateness + Lateness
        if (Lateness > 0) then Tardiness = Lateness
        else Tardiness = 0
        if tardiness > 0
        then inc num_tardy
        Total_tardiness = Total_tardiness +
Tardiness

        inc NUM
        Avg_Lateness = Total_lateness/NUM
        if( NUM>1) then Var_Lateness = (
Total_square_lateness - Total_lateness*Total_lateness/NUM)/(NUM-1)
        Avg_Tardiness = Total_tardiness/NUM

        //display "truck load= ",cap1
                                1      material2 EXIT

FIRST 1
  material2 Bakersfield      wait unload_time

        //display "delivery hour=",clock()
        //display "delivery @ ",destination
        //display "weight=",weight

truck_capacity[trucknumber]=truck_capacity[trucknumber]-weight
truck_location[trucknumber]=11
free res(trucknumber)
flag = 1
num_waiting = contents(waiting_queue)
min_rule = 9999999
counter = 0
tie = 0
if (trucknumber=1) then
cap1=truck_capacity[trucknumber]
        else if (trucknumber=2) then
cap2=truck_capacity[trucknumber]
        else if (trucknumber=3) then
cap3=truck_capacity[trucknumber]
        else if (trucknumber=4) then
cap4=truck_capacity[trucknumber]
        else if (trucknumber=5) then
cap5=truck_capacity[trucknumber]
        else if (trucknumber=6) then
cap6=truck_capacity[trucknumber]
        else if (trucknumber=7) then
cap7=truck_capacity[trucknumber]
        else if (trucknumber=8) then
cap8=truck_capacity[trucknumber]
        else if (trucknumber=9) then
cap9=truck_capacity[trucknumber]
        else cap10=truck_capacity[trucknumber]

        Lateness = clock() - due_date

```

```

Total_square_lateness =
Total_square_lateness+Lateness*Lateness
Total_lateness = Total_lateness + Lateness
if (Lateness > 0) then Tardiness = Lateness
else Tardiness = 0
if tardiness > 0
then inc num_tardy
Total_tardiness = Total_tardiness +
Tardiness

inc NUM
Avg_Lateness = Total_lateness/NUM
if( NUM>1) then Var_Lateness = (
Total_square_lateness - Total_lateness*Total_lateness/NUM)/(NUM-1)
Avg_Tardiness = Total_tardiness/NUM

//display "truck load= ",cap1
1 material2 EXIT

FIRST 1
material2 Los_Angeles wait unload_time

//display "delivery hour=",clock()
//display "delivery @ ",destination
//display "weight=",weight

truck_capacity[trucknumber]=truck_capacity[trucknumber]-weight
truck_location[trucknumber]=12
free res(trucknumber)
flag = 1
num_waiting = contents(waiting_queue)
min_rule = 9999999
counter = 0
tie = 0
if (trucknumber=1) then
cap1=truck_capacity[trucknumber]
else if (trucknumber=2) then
cap2=truck_capacity[trucknumber]
else if (trucknumber=3) then
cap3=truck_capacity[trucknumber]
else if (trucknumber=4) then
cap4=truck_capacity[trucknumber]
else if (trucknumber=5) then
cap5=truck_capacity[trucknumber]
else if (trucknumber=6) then
cap6=truck_capacity[trucknumber]
else if (trucknumber=7) then
cap7=truck_capacity[trucknumber]
else if (trucknumber=8) then
cap8=truck_capacity[trucknumber]
else if (trucknumber=9) then
cap9=truck_capacity[trucknumber]
else cap10=truck_capacity[trucknumber]

Lateness = clock() - due_date
Total_square_lateness =
Total_square_lateness+Lateness*Lateness
Total_lateness = Total_lateness + Lateness

```

```

        if (Lateness > 0) then Tardiness = Lateness
        else Tardiness = 0
        if tardiness > 0
        then inc num_tardy
        Total_tardiness = Total_tardiness +
Tardiness
        inc NUM
        Avg_Lateness = Total_lateness/NUM
        if( NUM>1) then Var_Lateness = (
Total_square_lateness - Total_lateness*Total_lateness/NUM)/(NUM-1)
        Avg_Tardiness = Total_tardiness/NUM

        //display "truck load= ",cap1
        1 material2 EXIT

FIRST 1
material2 Long_Beach wait unload_time

        //display "delivery hour=",clock()
        //display "delivery @ ",destination
        //display "weight=",weight

truck_capacity[trucknumber]=truck_capacity[trucknumber]-weight
truck_location[trucknumber]=13
free res(trucknumber)
flag = 1
num_waiting = contents(waiting_queue)
min_rule = 9999999
counter = 0
tie = 0
if (trucknumber=1) then
cap1=truck_capacity[trucknumber]
else if (trucknumber=2) then
cap2=truck_capacity[trucknumber]
else if (trucknumber=3) then
cap3=truck_capacity[trucknumber]
else if (trucknumber=4) then
cap4=truck_capacity[trucknumber]
else if (trucknumber=5) then
cap5=truck_capacity[trucknumber]
else if (trucknumber=6) then
cap6=truck_capacity[trucknumber]
else if (trucknumber=7) then
cap7=truck_capacity[trucknumber]
else if (trucknumber=8) then
cap8=truck_capacity[trucknumber]
else if (trucknumber=9) then
cap9=truck_capacity[trucknumber]
else cap10=truck_capacity[trucknumber]

Lateness = clock() - due_date
Total_square_lateness =
Total_square_lateness+Lateness*Lateness
Total_lateness = Total_lateness + Lateness
if (Lateness > 0) then Tardiness = Lateness
else Tardiness = 0
if tardiness > 0

```

```

        then inc num_tardy
        Total_tardiness = Total_tardiness +
Tardiness
        inc NUM
        Avg_Lateness = Total_lateness/NUM
        if( NUM>1) then Var_Lateness = (
Total_square_lateness - Total_lateness*Total_lateness/NUM)/(NUM-1)
        Avg_Tardiness = Total_tardiness/NUM

        //display "truck load= ",cap1
        1 material2 EXIT

FIRST 1
material2 Barstow wait unload_time

        //display "delivery hour=",clock()
        //display "delivery @ ",destination
        //display "weight=",weight

truck_capacity[trucknumber]=truck_capacity[trucknumber]-weight
truck_location[trucknumber]=14
free res(trucknumber)
flag = 1
num_waiting = contents(waiting_queue)
min_rule = 9999999
counter = 0
tie = 0
if (trucknumber=1) then
cap1=truck_capacity[trucknumber]
else if (trucknumber=2) then
cap2=truck_capacity[trucknumber]
else if (trucknumber=3) then
cap3=truck_capacity[trucknumber]
else if (trucknumber=4) then
cap4=truck_capacity[trucknumber]
else if (trucknumber=5) then
cap5=truck_capacity[trucknumber]
else if (trucknumber=6) then
cap6=truck_capacity[trucknumber]
else if (trucknumber=7) then
cap7=truck_capacity[trucknumber]
else if (trucknumber=8) then
cap8=truck_capacity[trucknumber]
else if (trucknumber=9) then
cap9=truck_capacity[trucknumber]
else cap10=truck_capacity[trucknumber]

        Lateness = clock() - due_date
        Total_square_lateness =
Total_square_lateness+Lateness*Lateness
        Total_lateness = Total_lateness + Lateness
        if (Lateness > 0) then Tardiness = Lateness
        else Tardiness = 0
        if tardiness > 0
        then inc num_tardy
        Total_tardiness = Total_tardiness +
Tardiness

```

```

        inc NUM
        Avg_Lateness = Total_lateness/NUM
        if( NUM>1) then Var_Lateness = (
Total_square_lateness - Total_lateness*Total_lateness/NUM)/(NUM-1)
        Avg_Tardiness = Total_tardiness/NUM

        //display "truck load= ",cap1
                                1      material2 EXIT

FIRST 1
  material2 San_Bernardino wait unload_time

        //display "delivery hour=",clock()
        //display "delivery @ ",destination
        //display "weight=",weight

truck_capacity[trucknumber]=truck_capacity[trucknumber]-weight
truck_location[trucknumber]=15
free res(trucknumber)
flag = 1
num_waiting = contents(waiting_queue)
min_rule = 9999999
counter = 0
tie = 0
if (trucknumber=1) then
cap1=truck_capacity[trucknumber]
    else if (trucknumber=2) then
cap2=truck_capacity[trucknumber]
    else if (trucknumber=3) then
cap3=truck_capacity[trucknumber]
    else if (trucknumber=4) then
cap4=truck_capacity[trucknumber]
    else if (trucknumber=5) then
cap5=truck_capacity[trucknumber]
    else if (trucknumber=6) then
cap6=truck_capacity[trucknumber]
    else if (trucknumber=7) then
cap7=truck_capacity[trucknumber]
    else if (trucknumber=8) then
cap8=truck_capacity[trucknumber]
    else if (trucknumber=9) then
cap9=truck_capacity[trucknumber]
    else cap10=truck_capacity[trucknumber]

        Lateness = clock() - due_date
        Total_square_lateness =
Total_square_lateness+Lateness*Lateness
        Total_lateness = Total_lateness + Lateness
        if (Lateness > 0) then Tardiness = Lateness
        else Tardiness = 0
        if tardiness > 0
        then inc num_tardy
        Total_tardiness = Total_tardiness +

Tardiness

        inc NUM
        Avg_Lateness = Total_lateness/NUM

```



```

        if( NUM>1) then Var_Lateness = (
Total_square_lateness - Total_lateness*Total_lateness/NUM)/(NUM-1)
        Avg_Tardiness = Total_tardiness/NUM

        //display "truck load= ",cap1
                                1      material2 EXIT

FIRST 1
  material2 San_Diego      wait unload_time

        //display "delivery hour=",clock()
        //display "delivery @ ",destination
        //display "weight=",weight

truck_capacity[trucknumber]=truck_capacity[trucknumber]-weight
truck_location[trucknumber]=16
free res(trucknumber)
flag = 1
num_waiting = contents(waiting_queue)
min_rule = 9999999
counter = 0
tie = 0
if (trucknumber=1) then
cap1=truck_capacity[trucknumber]
        else if (trucknumber=2) then
cap2=truck_capacity[trucknumber]
        else if (trucknumber=3) then
cap3=truck_capacity[trucknumber]
        else if (trucknumber=4) then
cap4=truck_capacity[trucknumber]
        else if (trucknumber=5) then
cap5=truck_capacity[trucknumber]
        else if (trucknumber=6) then
cap6=truck_capacity[trucknumber]
        else if (trucknumber=7) then
cap7=truck_capacity[trucknumber]
        else if (trucknumber=8) then
cap8=truck_capacity[trucknumber]
        else if (trucknumber=9) then
cap9=truck_capacity[trucknumber]
        else cap10=truck_capacity[trucknumber]

        Lateness = clock() - due_date
Total_square_lateness+Lateness*Lateness
Total_lateness = Total_lateness + Lateness
if (Lateness > 0) then Tardiness = Lateness
else Tardiness = 0
if tardiness > 0
then inc num_tardy
Total_tardiness = Total_tardiness +

Tardiness

inc NUM
Avg_Lateness = Total_lateness/NUM
if( NUM>1) then Var_Lateness = (
Total_square_lateness - Total_lateness*Total_lateness/NUM)/(NUM-1)
Avg_Tardiness = Total_tardiness/NUM

```

```

//display "truck load= ",cap1
1 material2 EXIT
FIRST 1
material2 Santa_Barbara wait unload_time

//display "delivery hour=",clock()
//display "delivery @ ",destination
//display "weight=",weight

truck_capacity[trucknumber]=truck_capacity[trucknumber]-weight
truck_location[trucknumber]=17
free res(trucknumber)
flag = 1
num_waiting = contents(waiting_queue)
min_rule = 9999999
counter = 0
tie = 0
if (trucknumber=1) then
cap1=truck_capacity[trucknumber]
else if (trucknumber=2) then
cap2=truck_capacity[trucknumber]
else if (trucknumber=3) then
cap3=truck_capacity[trucknumber]
else if (trucknumber=4) then
cap4=truck_capacity[trucknumber]
else if (trucknumber=5) then
cap5=truck_capacity[trucknumber]
else if (trucknumber=6) then
cap6=truck_capacity[trucknumber]
else if (trucknumber=7) then
cap7=truck_capacity[trucknumber]
else if (trucknumber=8) then
cap8=truck_capacity[trucknumber]
else if (trucknumber=9) then
cap9=truck_capacity[trucknumber]
else cap10=truck_capacity[trucknumber]

Lateness = clock() - due_date
Total_square_lateness =
Total_square_lateness+Lateness*Lateness
Total_lateness = Total_lateness + Lateness
if (Lateness > 0) then Tardiness = Lateness
else Tardiness = 0
if tardiness > 0
then inc num_tardy
Total_tardiness = Total_tardiness +
Tardiness

inc NUM
Avg_Lateness = Total_lateness/NUM
if( NUM>1) then Var_Lateness = (
Total_square_lateness - Total_lateness*Total_lateness/NUM)/(NUM-1)
Avg_Tardiness = Total_tardiness/NUM

//display "truck load= ",cap1

```

```

1 material2 EXIT

FIRST 1
material2 San_Luis_Obispo wait unload_time

//display "delivery hour=",clock()
//display "delivery @ ",destination
//display "weight=",weight

truck_capacity[trucknumber]=truck_capacity[trucknumber]-weight
truck_location[trucknumber]=18
free res(trucknumber)
flag = 1
num_waiting = contents(waiting_queue)
min_rule = 9999999
counter = 0
tie = 0
if (trucknumber=1) then
cap1=truck_capacity[trucknumber]
else if (trucknumber=2) then
cap2=truck_capacity[trucknumber]
else if (trucknumber=3) then
cap3=truck_capacity[trucknumber]
else if (trucknumber=4) then
cap4=truck_capacity[trucknumber]
else if (trucknumber=5) then
cap5=truck_capacity[trucknumber]
else if (trucknumber=6) then
cap6=truck_capacity[trucknumber]
else if (trucknumber=7) then
cap7=truck_capacity[trucknumber]
else if (trucknumber=8) then
cap8=truck_capacity[trucknumber]
else if (trucknumber=9) then
cap9=truck_capacity[trucknumber]
else cap10=truck_capacity[trucknumber]

Lateness = clock() - due_date
Total_square_lateness =
Total_square_lateness+Lateness*Lateness
Total_lateness = Total_lateness + Lateness
if (Lateness > 0) then Tardiness = Lateness
else Tardiness = 0
if tardiness > 0
then inc num_tardy
Total_tardiness = Total_tardiness +
Tardiness

inc NUM
Avg_Lateness = Total_lateness/NUM
if( NUM>1) then Var_Lateness = (
Total_square_lateness - Total_lateness*Total_lateness/NUM)/(NUM-1)
Avg_Tardiness = Total_tardiness/NUM

//display "truck load= ",cap1
1 material2 EXIT

FIRST 1
material2 Irvine wait unload_time

```

```

//display "delivery hour=",clock()
//display "delivery @ ",destination
//display "weight=",weight

truck_capacity[trucknumber]=truck_capacity[trucknumber]-weight
truck_location[trucknumber]=19
free res(trucknumber)
flag = 1
num_waiting = contents(waiting_queue)
min_rule = 9999999
counter = 0
tie = 0
if (trucknumber=1) then
cap1=truck_capacity[trucknumber]
else if (trucknumber=2) then
cap2=truck_capacity[trucknumber]
else if (trucknumber=3) then
cap3=truck_capacity[trucknumber]
else if (trucknumber=4) then
cap4=truck_capacity[trucknumber]
else if (trucknumber=5) then
cap5=truck_capacity[trucknumber]
else if (trucknumber=6) then
cap6=truck_capacity[trucknumber]
else if (trucknumber=7) then
cap7=truck_capacity[trucknumber]
else if (trucknumber=8) then
cap8=truck_capacity[trucknumber]
else if (trucknumber=9) then
cap9=truck_capacity[trucknumber]
else cap10=truck_capacity[trucknumber]

Lateness = clock() - due_date
Total_square_lateness =
Total_square_lateness+Lateness*Lateness
Total_lateness = Total_lateness + Lateness
if (Lateness > 0) then Tardiness = Lateness
else Tardiness = 0
if tardiness > 0
then inc num_tardy
Total_tardiness = Total_tardiness +
Tardiness

inc NUM
Avg_Lateness = Total_lateness/NUM
if( NUM>1) then Var_Lateness = (
Total_square_lateness - Total_lateness*Total_lateness/NUM)/(NUM-1)
Avg_Tardiness = Total_tardiness/NUM

//display "truck load= ",cap1
1 material2 EXIT

FIRST 1
material2 Monterey wait unload_time

//display "delivery hour=",clock()
//display "delivery @ ",destination

```

```

//display "weight=",weight

truck_capacity[trucknumber]=truck_capacity[trucknumber]-weight
truck_location[trucknumber]=20
free res(trucknumber)
flag = 1
num_waiting = contents(waiting_queue)
min_rule = 9999999
counter = 0
tie = 0
if (trucknumber=1) then
cap1=truck_capacity[trucknumber]
else if (trucknumber=2) then
cap2=truck_capacity[trucknumber]
else if (trucknumber=3) then
cap3=truck_capacity[trucknumber]
else if (trucknumber=4) then
cap4=truck_capacity[trucknumber]
else if (trucknumber=5) then
cap5=truck_capacity[trucknumber]
else if (trucknumber=6) then
cap6=truck_capacity[trucknumber]
else if (trucknumber=7) then
cap7=truck_capacity[trucknumber]
else if (trucknumber=8) then
cap8=truck_capacity[trucknumber]
else if (trucknumber=9) then
cap9=truck_capacity[trucknumber]
else cap10=truck_capacity[trucknumber]

Lateness = clock() - due_date
Total_square_lateness =
Total_square_lateness+Lateness*Lateness
Total_lateness = Total_lateness + Lateness
if (Lateness > 0) then Tardiness = Lateness
else Tardiness = 0
if tardiness > 0
then inc num_tardy
Total_tardiness = Total_tardiness +
Tardiness

inc NUM
Avg_Lateness = Total_lateness/NUM
if( NUM>1) then Var_Lateness = (
Total_square_lateness - Total_lateness*Total_lateness/NUM)/(NUM-1)
Avg_Tardiness = Total_tardiness/NUM

//display "truck load= ",cap1
1 material2 EXIT

FIRST 1

*****
*****
*
* Arrivals
*

```

```

*****
*****

Entity      Location Qty each   First Time Occurrences Frequency  Logic
-----
-----

material1 dummy    1           0           inf         E(2)
pickup = pickup_dist()

L1:

destination= destination_dist()
if
(pickup=destination) then goto L1

weight = N(25000,5000)

load_time=U(6,2)

unload_time=U(6,2)

arrival_hour = clock()

due_date = due_date_dist()

//display "due date=",due_date

due_date = clock() + (due_date * 8)

//Do

//Begin

//{inc dum_flag

//display "distance",distance[1,dum_flag]}

//end

//while dum_flag <= 20

//display "arrival hour=",arrival_hour

//display "pickup loc=",pickup

//display "destination loc=",destination

//display "weight=",weight

task=1

```

```

rule = 1 then
    trucknumber = shortest_distance()
rule = 2 then
    {
        rule_att = due_date
        trucknumber = earliest_due_date()
    }
rule = 3 then
    {
        rule_att = arrival_hour - clock()
        trucknumber = longest_time_in_system()
    }
rule = 4 then
    {
        trucknumber = Smallest_Slack_Time_Pickup()
        rule_att = (due_date - clock()) -
        distance[pickup,destination]/65-load_time-unload_time
    }

//display "rule_att=",rule_att

```

```

*****
*****
*
*
*
*****
*****

```

Attributes

ID	Type	Classification
#Pickup location		
pickup	Integer	Entity
#Delivery location		
destination	Integer	Entity
weight	Real	Entity
trucknumber	Integer	Entity

```

load_time      Real      Entity
unload_time    Real      Entity
arrival_hour    Real      Entity
due_date       Real      Entity
#
#attribute changes depending on the rule
#rule = 1:  The distance between pickup/delivery location and
currentpoint
#rule = 2:  earliest due date
rule_att       Real      Entity
#
#pickup task when task=1
#delivery task when task=2
task           Integer   Entity
dum           Integer   Entity

```

```

*****
*****
*                               Variables (global)
*
*****
*****

```

ID	Type	Initial value	Stats
rule	Integer	rule_ch	Time Series
sim_day	Integer	1	Time Series
workday_hrs	Integer	workday_hrs_ch	Time Series
number	Integer	0	Time Series
Lateness	Real	0	Time Series
Var_Lateness	Real	0	Time Series
Avg_Lateness	Real	0	Time Series
Avg_Tardiness	Real	0	Time Series
Tardiness	Real	0	Time Series
Total_lateness	Real	0	Time Series
Total_tardiness	Real	0	Time Series
Total_square_lateness	Real	0	Time Series
NUM	Integer	0	Time Series
num_tardy	Integer	0	Time Series
pcnt_tardy	Real	0	Time Series
tt	Real	0	Time Series
cap1	Real	0	Time Series
cap2	Real	0	Time Series
cap3	Real	0	Time Series
cap4	Real	0	Time Series
cap5	Real	0	Time Series
cap6	Real	0	Time Series
cap7	Real	0	Time Series
cap8	Real	0	Time Series
cap9	Real	0	Time Series
cap10	Real	0	Time Series
flag	Integer	0	Time Series
dum_flag	Integer	0	Time Series
min_rule	Real	0	Time Series
num_waiting	Integer	0	Time Series
counter	Integer	0	Time Series

temp_rule	Real	0	Time Series
tie	Integer	0	Time Series

```
*****
*****
*
*                               Arrays
*
*****
*****
```

ID	Dimensions	Type
distance	20,20	Real
truck_capacity	10	Real
truck_location	10	Integer
truck_used	10	Integer

```
*****
*****
*
*                               Macros
*
*****
*****
```

ID	Text
rule_ch	1
workday_hrs_ch	8
fleet_size	2

```
*****
*****
*
*                               Subroutines
*
*****
*****
```

ID	Type	Parameter	Type	Logic
shortest_distance_not_used	None	cpoint	Integer	int
i=1,first_pickup=0,first_delivery=0				real
nearest=999999.0				while
i<=4	Do			Begin
if (pickup_arr[i]>0)	then			{
if (nearest>distance[cpoint,i])	then			{

```

nearest=distance[cpoint,i]
first_pickup=i
task=1
}
}
if ( pickup_arr[i]=0 and destination_arr[i]>0) then
{
if ( nearest>distance[cpoint,i]) then
{
nearest=distance[cpoint,i]
first_delivery=i
task=2
}
}
inc i
}
(task=1) then return first_pickup
(task=2) then return first_delivery
(task=0) then return 0
shortest_distance      Integer      int
i=1
nearest=999999.0      real
number=0
i<=fleet_size Do      while
Begin
if ((truck_capacity[i]+weight)<=50000 and FreeUnits(Res(i))>0) then
{
if ( nearest>distance[pickup,truck_location[i]] ) then
{
nearest=distance[pickup,truck_location[i]]
}
}
}
}

```

```

number=i
}
}
inc i
End

if(number>0) then rule_att=nearest
else
rule_att=999999.0

return number
shortest_distance_after_pickup None
rule_att=distance[truck_location[trucknumber],destination]
earliest_due_date Integer int
i=1 real
nearest=999999.0

number=0
while
i<=fleet_size Do
Begin
if ((truck_capacity[i]+weight)<=50000 and FreeUnits(Res(i))> 0) then
{
if ( nearest>distance[pickup,truck_location[i]] ) then
{
nearest=distance[pickup,truck_location[i]]
number=i
}
}
inc i
End

return number
longest_time_in_system Integer int
i=1 real
nearest=999999.0

number=0
while
i<=fleet_size Do
Begin

```

```

if ((truck_capacity[i]+weight)<=50000 and FreeUnits(Res(i))> 0) then
{
if ( nearest>distance[pickup,truck_location[i]] ) then
{
nearest=distance[pickup,truck_location[i]]
number=i
}
}
inc i
End

return number
Smallest_Slack_Time_Pickup Integer int
i=1 real
nearest=999999.0
number=0
i<=fleet_size Do while
Begin
if ((truck_capacity[i]+weight)<=50000 and FreeUnits(Res(i))> 0) then
{
if ( nearest>distance[pickup,truck_location[i]] ) then
{
nearest=distance[pickup,truck_location[i]]
number=i
}
}
inc i
End

return number
calendar None while
sim_day <= 5 do
{
wait workday_hrs

```

```

inc sim_day
}

```

```

*****
*****
*
*                               Table Functions
*
*****
*****

```

```

ID          Independent Value Dependent Value
-----
Fun1

```

```

*****
*****
*
*                               User Distributions
*
*****
*****

```

ID	Type	Cumulative	Percentage	Value
pickup_dist	Discrete	No	5	1
			5	2
			5	3
			5	4
			5	5
			5	6
			5	7
			5	8
			5	9
			5	10
			5	11
			5	12
			5	13
			5	14
			5	15
			5	16
			5	17
			5	18
			5	19
			destination_dist	Discrete
5	1			
5	2			
5	3			
5	4			
5	5			
5	6			
5	7			
5	8			
5	9			

			5	10
			5	11
			5	12
			5	13
			5	14
			5	15
			5	16
			5	17
			5	18
			5	19
			5	20
due_date_dist	Discrete	No	20	6
			20	7
			20	8
			20	9
			20	10

```

*****
*****
*                                     External Files
*
*****
*****

```

ID	Type	File Name
Prompt		

(null)		C:\Documents and
Settings\ydessouky\Application Data\Qualcomm\Eudora\attach\cities.xls		

APPENDIX B: Program Listing for Simulation Model for STCV Mode of Van Lines Operations

```
*****
*
*
*           Formatted Listing of Model:
*
*       C:\Documents\RESEARCH\Path\Truck\trail0901_20loc_path-hub3.MOD
*
*
*
*****
```

```
Time Units:           Hours
Distance Units:      Feet
Initialization Logic:  ACTIVATE calendar ()

                        int i=1
                        while i<=fleet_size Do
                        {
                            truck_location[i] = i
                            inc i
                        }

Termination Logic:    pcnt_tardy = num_tardy / num
```

```
*****
*****
*
*           Locations
*
*****
*****
```

Name Cost	Cap	Units	Stats	Rules
input	1	1	Time Series	Min(rule_att),
Min(rule_att), Redding	inf	1	Time Series	Min(rule_att),
Min(rule_att), Chico	inf	1	Time Series	Min(rule_att),
Min(rule_att), Sacramento	inf	1	Time Series	Min(rule_att),
Min(rule_att), Palm_Springs	inf	1	Time Series	Min(rule_att),
Min(rule_att), Stockton	inf	1	Time Series	Min(rule_att),
Min(rule_att), Santa_Rosa	inf	1	Time Series	Min(rule_att),
Min(rule_att), San_Fransisco	inf	1	Time Series	Min(rule_att),

Oakland	inf	1	Time Series Min(rule_att),
Min(rule_att),			
San_Jose	inf	1	Time Series Min(rule_att),
Min(rule_att),			
Fresno	inf	1	Time Series Min(rule_att),
Min(rule_att),			
Bakersfield	inf	1	Time Series Min(rule_att),
Min(rule_att),			
Los_Angeles	inf	1	Time Series Min(rule_att),
Min(rule_att),			
Long_Beach	inf	1	Time Series Min(rule_att),
Min(rule_att),			
Barstow	inf	1	Time Series Min(rule_att),
Min(rule_att),			
San_Bernardino	inf	1	Time Series Min(rule_att),
Min(rule_att),			
San_Diego	inf	1	Time Series Min(rule_att),
Min(rule_att),			
Santa_Barbara	inf	1	Time Series Min(rule_att),
Min(rule_att),			
San_Luis_Obispo	inf	1	Time Series Min(rule_att),
Min(rule_att),			
Irvine	inf	1	Time Series Min(rule_att),
Min(rule_att),			
Monterey	inf	1	Time Series Min(rule_att),
Min(rule_att),			
pickup_queue	INFINITE	1	Time Series Min(rule_att),
Min(rule_att),			
delivery_queue	INFINITE	1	Time Series Min(rule_att),
Min(rule_att),			
Waiting_queue	inf	1	Time Series Min(rule_att),
Min(rule_att),			
dummy	inf	1	Time Series Min(rule_att),
Min(rule_att),			
dummy1	inf	1	Time Series Min(rule_att),
Min(rule_att),			
dummy2	inf	1	Time Series Min(rule_att),
Min(rule_att),			
hub1	inf	1	Time Series Min(rule_att),
Min(rule_att),			
hub2	inf	1	Time Series Min(rule_att),
Min(rule_att),			
hub3	inf	1	Time Series Min(rule_att),
Min(rule_att),			
Waiting_pickup	INFINITE	1	Time Series Min(rule_att),
Min(rule_att),			
Waiting_delivery	INFINITE	1	Time Series Min(rule_att),
Min(rule_att),			

```

*****
*****
*
*
*
*****
*****

```

Entities

Name	Speed (fpm)	Stats	Cost
material1	150	Time Series	
material2	150	Time Series	
material3	150	Time Series	

 *
 * Path Networks
 *

Name	Type	T/S	From	To	BI	Cost
Dist/Time	Speed	Factor				
Net1	Passing	Speed & Distance	N1	N2	Bi	378576
1			N1	N3	Bi	849552
1			N1	N4	Bi	3423024
1			N1	N5	Bi	1097184
1			N1	N6	Bi	1221792
1			N1	N7	Bi	1134144
1			N1	N8	Bi	1106160
1			N1	N9	Bi	1284096
1			N1	N10	Bi	1759824
1			N1	N11	Bi	2346960
1			N1	N12	Bi	2861232
1			N1	N13	Bi	2984784
1			N1	N14	Bi	3053424
1			N1	N15	Bi	3162192
1			N1	N16	Bi	3489024
1			N1	N17	Bi	2801568
1			N1	N18	Bi	2249808
1			N1	N19	Bi	3065040
1			N1	N20	Bi	1655808

1	N2	N3	Bi	467280
1	N2	N4	Bi	3045504
1	N2	N5	Bi	720192
1	N2	N6	Bi	779856
1	N2	N7	Bi	872784
1	N2	N8	Bi	844800
1	N2	N9	Bi	1022736
1	N2	N10	Bi	1382304
1	N2	N11	Bi	1969440
1	N2	N12	Bi	2483712
1	N2	N13	Bi	2607264
1	N2	N14	Bi	2662176
1	N2	N15	Bi	2784672
1	N2	N16	Bi	3111504
1	N2	N17	Bi	2540736
1	N2	N18	Bi	1988976
1	N2	N19	Bi	2688048
1	N2	N20	Bi	1394448
1	N3	N4	Bi	2583504
1	N3	N5	Bi	258192
1	N3	N6	Bi	538032
1	N3	N7	Bi	449856
1	N3	N8	Bi	421872
1	N3	N9	Bi	599808
1	N3	N10	Bi	920304
1	N3	N11	Bi	1507440
1	N3	N12	Bi	2021712
1	N3	N13	Bi	2145264

1	N3	N14	Bi	2200176
1	N3	N15	Bi	2322672
1	N3	N16	Bi	2649504
1	N3	N17	Bi	2117808
1	N3	N18	Bi	1566048
1	N3	N19	Bi	2226048
1	N3	N20	Bi	971520
1	N4	N5	Bi	2335872
1	N4	N6	Bi	2810016
1	N4	N7	Bi	2565024
1	N4	N8	Bi	2512224
1	N4	N9	Bi	2359632
1	N4	N10	Bi	1709664
1	N4	N11	Bi	1144176
1	N4	N12	Bi	569712
1	N4	N13	Bi	609312
1	N4	N14	Bi	656832
1	N4	N15	Bi	293568
1	N4	N16	Bi	742896
1	N4	N17	Bi	1066560
1	N4	N18	Bi	1617264
1	N4	N19	Bi	497376
1	N4	N20	Bi	2304720
1	N5	N6	Bi	675312
1	N5	N7	Bi	430320
1	N5	N8	Bi	377520
1	N5	N9	Bi	398640
1	N5	N10	Bi	663696

1	N5	N11	Bi	1259280
1	N5	N12	Bi	1773552
1	N5	N13	Bi	1897104
1	N5	N14	Bi	1952016
1	N5	N15	Bi	2073984
1	N5	N16	Bi	2400816
1	N5	N17	Bi	1916640
1	N5	N18	Bi	1364880
1	N5	N19	Bi	1977360
1	N5	N20	Bi	770352
1	N6	N7	Bi	284064
1	N6	N8	Bi	305184
1	N6	N9	Bi	510576
1	N6	N10	Bi	1224432
1	N6	N11	Bi	1732896
1	N6	N12	Bi	2247168
1	N6	N13	Bi	2370720
1	N6	N14	Bi	2425632
1	N6	N15	Bi	2547600
1	N6	N16	Bi	2874960
1	N6	N17	Bi	2031744
1	N6	N18	Bi	1479984
1	N6	N19	Bi	2450976
1	N6	N20	Bi	885456
1	N7	N8	Bi	60720
1	N7	N9	Bi	243936
1	N7	N10	Bi	979968
1	N7	N11	Bi	1488432

1	N7	N12	Bi	2002704
1	N7	N13	Bi	2126256
1	N7	N14	Bi	2181168
1	N7	N15	Bi	2303664
1	N7	N16	Bi	2630496
1	N7	N17	Bi	1765104
1	N7	N18	Bi	1213872
1	N7	N19	Bi	2206512
1	N7	N20	Bi	618816
1	N8	N9	Bi	204864
1	N8	N10	Bi	923472
1	N8	N11	Bi	1431936
1	N8	N12	Bi	1946208
1	N8	N13	Bi	2069760
1	N8	N14	Bi	2124672
1	N8	N15	Bi	2246640
1	N8	N16	Bi	2574000
1	N8	N17	Bi	1727088
1	N8	N18	Bi	1175328
1	N8	N19	Bi	2150016
1	N8	N20	Bi	580800
1	N9	N10	Bi	803088
1	N9	N11	Bi	1279872
1	N9	N12	Bi	1793616
1	N9	N13	Bi	1917168
1	N9	N14	Bi	1279872
1	N9	N15	Bi	2094576
1	N9	N16	Bi	2421408

1	N9	N17	Bi	1530144
1	N9	N18	Bi	978384
1	N9	N19	Bi	1997952
1	N9	N20	Bi	383856
1	N10	N11	Bi	578688
1	N10	N12	Bi	1145760
1	N10	N13	Bi	1269312
1	N10	N14	Bi	1259280
1	N10	N15	Bi	1446720
1	N10	N16	Bi	1773552
1	N10	N17	Bi	1335840
1	N10	N18	Bi	726528
1	N10	N19	Bi	1349568
1	N10	N20	Bi	804672
1	N11	N12	Bi	580800
1	N11	N13	Bi	704352
1	N11	N14	Bi	681648
1	N11	N15	Bi	881760
1	N11	N16	Bi	1208592
1	N11	N17	Bi	770880
1	N11	N18	Bi	636768
1	N11	N19	Bi	785136
1	N11	N20	Bi	1227600
1	N12	N13	Bi	127248
1	N12	N14	Bi	599280
1	N12	N15	Bi	308352
1	N12	N16	Bi	628320
1	N12	N17	Bi	497904

1	N12	N18	Bi	1048608
1	N12	N19	Bi	204336
1	N12	N20	Bi	1741872
1	N13	N14	Bi	664752
1	N13	N15	Bi	368016
1	N13	N16	Bi	586080
1	N13	N17	Bi	602976
1	N13	N18	Bi	1153152
1	N13	N19	Bi	159984
1	N13	N20	Bi	1964688
1	N14	N15	Bi	370128
1	N14	N16	Bi	924528
1	N14	N17	Bi	1064976
1	N14	N18	Bi	1615680
1	N14	N19	Bi	587136
1	N14	N20	Bi	1916640
1	N15	N16	Bi	561792
1	N15	N17	Bi	783552
1	N15	N18	Bi	1334256
1	N15	N19	Bi	260304
1	N15	N20	Bi	2018544
1	N16	N17	Bi	1121472
1	N16	N18	Bi	1672176
1	N16	N19	Bi	441936
1	N16	N20	Bi	2368080
1	N17	N18	Bi	554400
1	N17	N19	Bi	712800
1	N17	N20	Bi	1365408

1	N18	N19	Bi	1267200
1	N18	N20	Bi	792528
1	N19	N20	Bi	1943568

 *
 * Interfaces
 *

Net	Node	Location
-----	-----	-----
Net1	N1	Redding
	N2	Chico
	N3	Sacramento
	N4	Palm_Springs
	N5	Stockton
	N6	Santa_Rosa
	N7	San_Fransisco
	N8	Oakland
	N9	San_Jose
	N10	Fresno
	N11	Bakersfield
	N12	Los_Angeles
	N13	Long_Beach
	N14	Barstow
	N15	San_Bernardino
	N16	San_Diego
	N17	Santa_Barbara
	N18	San_Luis_Obispo
	N19	Irvine
	N20	Monterey
	N10	hub1
	N8	hub2
	N12	hub3

 *
 * Resources
 *

Name	Units	Stats	Res	Ent	Search	Path	Motion
Cost	-----	-----	-----	-----	-----	-----	-----
trailer	15	By Unit	Closest	Min	Net1		Empty: 5720 fpm
					Home: N10		Full: 5720 fpm

truck_hub1	1	By Unit	Closest Min	Net1 Home: N10	Empty: 5720 fpm Full: 5720 fpm
truck_hub2	1	By Unit	Closest Min	Net1 Home: N8	Empty: 5720 fpm Full: 5720 fpm
truck_hub3	1	By Unit	Closest Min	Net1 Home: N12	Empty: 5720 fpm Full: 5720 fpm
truck1	1	By Unit	Closest Min	Net1 Home: N1	Empty: 5720 fpm Full: 5720 fpm
truck2	1	By Unit	Closest Min	Net1 Home: N2	Empty: 5720 fpm Full: 5720 fpm
truck3	1	By Unit	Closest Min	Net1 Home: N3	Empty: 5720 fpm Full: 5720 fpm
truck4	1	By Unit	Closest Min	Net1 Home: N4	Empty: 5720 fpm Full: 5720 fpm
truck5	1	By Unit	Closest Min	Net1 Home: N5	Empty: 5720 fpm Full: 5720 fpm
truck6	1	By Unit	Closest Min	Net1 Home: N6	Empty: 5720 fpm Full: 5720 fpm

```

*****
*****
*
*
*
*****
*****

```

Processing

Process

Routing

Entity	Location	Operation	Blk	Output
Destination	Rule			Move Logic
-----	-----	-----	-----	-----
material1	dummy		1	material1 input
FIRST 1	material1 input	if (task=1) then		
		{		
		if (hub_pickup = 1)and		
		(FreeUnits(truck_hub1)>0) and (FreeUnits(trailer)>=trailernumber) then		
		route 1		
		else if (hub_pickup = 2)and		
		(FreeUnits(truck_hub2)>0) and (FreeUnits(trailer)>=trailernumber) then		
		route 1		
		else if (hub_pickup = 3)and		
		(FreeUnits(truck_hub3)>0) and (FreeUnits(trailer)>=trailernumber) then		
		route 1		
		else route 3		
		}		

```

        if (task=2) then
        {
            if (trucknumber>0) and
(FreeUnits(res(trucknumber+truck_res))>0) then
            {
                route 2
            }
            else route 4
        }
    }

pickup_queue      FIRST 1
1      material1
//display
"Pickup: arrival time="$arrival_hour$" task="$task$" pickup="$pickup$"
destination="$destination$" rule_att="$rule_att$" weight="$weight$"
trailer_number="$trailer_number$" clock="$clock()"

delivery_queue   FIRST 1
2      material1
//display
"Delivery: arrival time="$arrival_hour$" task="$task$"
pickup="$pickup$" destination="$destination$" rule_att="$rule_att$"
weight="$weight$" trailer_number="$trailer_number$" clock="$clock()"

Waiting_pickup   FIRST 1
3      material1
flag1 = 0

//display "Waiting-Pickup: arrival time="$arrival_hour$" task="$task$"
pickup="$pickup$" destination="$destination$" rule_att="$rule_att$"
weight="$weight$" trailer_number="$trailer_number$" clock="$clock()"
4      material1

Waiting_delivery FIRST 1
flag2 = 0

//display "Waiting-delivery1: arrival time="$arrival_hour$"
task="$task$" pickup="$pickup$" destination="$destination$"
rule_att="$rule_att$" weight="$weight$"
trailer_number="$trailer_number$" clock="$clock()"
material1 Waiting_pickup
wait until flag1 = 1

if rule = 3 then
    rule_att = arrival_hour - clock()
if rule = 4 then
{
    if (hub_pickup = 1) then
rule_att=(due_date-clock()-distance[hub1_loc,destination]/65-
load_time-unload_time
        else if (hub_pickup = 2) then
rule_att=(due_date-clock()-distance[hub2_loc,destination]/65-
load_time-unload_time
        else rule_att=(due_date-clock()-
distance[hub3_loc,destination]/65-load_time-unload_time
    }
1      material1 dummy1
FIRST 1
material1 Waiting_delivery wait until flag2 = 1

if (delivery_task = 1) then
{
    trucknumber = select_truck_delivery()
}

```

```

        {
            if rule = 4 then
                if(trucknumber>0) then
rule_att = (due_date - clock()) -
distance[truck_location[trucknumber],pickup]/65-unload_time
                else rule_att=999999.0
            }
        }
    else
    {
        if rule = 1 then

            rule_att=distance[truck_location[trucknumber],next_loc]
                if rule = 4 then
                    rule_att = (due_date-
clock())-distance[truck_location[trucknumber],destination]/65
                }

            if rule = 3 then
                rule_att = arrival_hour - clock()
                    1    material1 dummy2

FIRST 1
    material1 dummy1        inc counter1

            if(hub_pickup = 1) then
            {
                if (freeunits(truck_hub1)>0 and
(freeunits(trailer)>=trailernumber)) then
                {
                    //display "clock",clock()
                    //display "",min_rule1
                    //display "loopp",rule_att
                    if rule_att < min_rule1 then
min_rule1 = rule_att
                }
            }
            else if (hub_pickup = 2) then
            {
                if (freeunits(truck_hub2)>0 and
(FreeUnits(trailer)>=trailernumber)) then
                {
                    if rule_att < min_rule1 then
min_rule1 = rule_att
                }
            }
            else
            {
                if (freeunits(truck_hub3)>0 and
(FreeUnits(trailer)>=trailernumber)) then
                {
                    if rule_att < min_rule1 then
min_rule1 = rule_att
                }
            }
        }

        Wait until counter1 = num_waiting1
    
```

```

//display "dummy 1",rule_att
//display "time",clock()

//display "nim_rule",min_rule1
//display "trucks",freeunits(truck_hub1)
//display "trailers",freeunits(trailer)

if (hub_pickup = 1) and
(FreeUnits(truck_hub1)>0) and (FreeUnits(trailer)>=trailernumber) then
route 1
else if (hub_pickup = 2) and
(FreeUnits(truck_hub2)>0) and (FreeUnits(trailer)>=trailernumber) then
route 1
else if (hub_pickup = 3) and
(FreeUnits(truck_hub3)>0) and (FreeUnits(trailer)>=trailernumber) then
route 1
else route 2

Waiting_pickup IF tie1 = 1, 1 1 material1
flag1 = 0
material1 input
IF rule_att = min_rule1 tie1 = 1
material1
Waiting_pickup IF rule_att <> min_rule1 flag1 = 0
2 material1
flag1 = 0
Waiting_pickup FIRST 1
material1 dummy2 inc counter2

if (trucknumber>0) then
{
if (freeunits(res(trucknumber+truck_res))
> 0) then
{
if rule_att < min_rule2 then
}
}
}

min_rule2 = rule_att

Wait until counter2 = num_waiting2

//display "dummy 2",rule_att
//display "clock",clock()
//display "arrive",arrival_hour
//display "task",delivery_task

//display "nim_rule",min_rule2
//display "trucks no",trucknumber
//display
"trucks",freeunits(res(trucknumber+truck_res))

if (trucknumber>0) and
(FreeUnits(res(trucknumber+truck_res))>0) then route 1
else route 2

Waiting_delivery IF tie2 = 1, 1 1 material1
flag2 = 0

```

```

IF rule_att = min_rule2          tie2 = 1          material1 input
Waiting_delivery IF rule_att <>min_rule2          material1
                                          flag2 = 0
Waiting_delivery FIRST 1          2 material1
  material1 pickup_queue          1 material1 hub1
IF hub_pickup = 1, 1
                                          material1 hub2
IF hub_pickup = 2
                                          material1 hub3
IF hub_pickup = 3
  material1 hub1          get trailernumber trailer and truck_hub1
                                          1 material1 Redding
IF pickup = 1 , 1          move with truck_hub1 then free

flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999
counter1 = 0
tie1 = 0

IF pickup = 2          material1 Chico
          move with truck_hub1 then free

flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999
counter1 = 0
tie1 = 0

Sacramento          IF pickup = 3          material1
truck_hub1 then free          move with

flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999

```

counter1 = 0

tiel = 0

Palm_Springs IF pickup = 4
truck_hub1 then free

material1
move with

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

Stockton IF pickup = 5
truck_hub1 then free

material1
move with

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

Santa_Rosa IF pickup = 6
truck_hub1 then free

material1
move with

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

San_Fransisco IF pickup = 7
truck_hub1 then free

material1
move with

flag1 = 1

```

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

IF pickup = 8
                                material1 Oakland
                                move with truck_hub1 then free

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

San_Jose      IF pickup = 9
truck_hub1 then free
                                material1
                                move with

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

IF pickup = 10
                                material1 Fresno
                                move with truck_hub1 then free

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

Bakersfield  IF pickup = 11
truck_hub1 then free
                                material1
                                move with

```



```

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

Los_Angeles      IF pickup = 12
truck_hub1 then free
material1
move with

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

Long_Beach      IF pickup = 13
truck_hub1 then free
material1
move with

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

IF pickup = 14
material1 Barstow
move with truck_hub1 then free

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

```

```
San_Bernardino  IF pickup = 15
truck_hub1 then free
```

```
material1
  move with
```

```
flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999
counter1 = 0
tiel = 0
```

```
San_Diego      IF pickup = 16
truck_hub1 then free
```

```
material1
  move with
```

```
flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999
counter1 = 0
tiel = 0
```

```
Santa_Barbara  IF pickup = 17
truck_hub1 then free
```

```
material1
  move with
```

```
flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999
counter1 = 0
tiel = 0
```

```
San_Luis_Obispo IF pickup = 18
truck_hub1 then free
```

```
material1
  move with
```

```
flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999
```

```

counter1 = 0

tiel = 0

IF pickup = 19
    material1 Irvine
    move with truck_hub1 then free

flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999
counter1 = 0
tiel = 0

Monterey IF pickup = 20
truck_hub1 then free
    material1
    move with

flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999
counter1 = 0
tiel = 0

material1 hub2
get trailernumber trailer and truck_hub2
1 material1 Redding
IF pickup = 1, 1
    move with truck_hub2 then free

flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999
counter1 = 0
tiel = 0

IF pickup = 2
    material1 Chico
    move with truck_hub2 then free

flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999

```

```

counter1 = 0

tiel = 0

Sacramento      IF pickup = 3
truck_hub2 then free

material1
  move with

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

Palm_Springs   IF pickup = 4
truck_hub2 then free

material1
  move with

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

Stockton        IF pickup = 5
truck_hub2 then free

material1
  move with

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

Santa_Rosa      IF pickup = 6
truck_hub2 then free

material1
  move with

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

```

```

counter1 = 0

tiel = 0

San_Fransisco    IF pickup = 7          material1
truck_hub2 then free                          move with

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

IF pickup = 8          material1 Oakland
move with truck_hub2 then free

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

San_Jose          IF pickup = 9          material1
truck_hub2 then free                          move with

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

IF pickup = 10          material1 Fresno
move with truck_hub2 then free

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

```

```

tiel = 0

Bakersfield      IF pickup = 11      material1
truck_hub2 then free                    move with

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

Los_Angeles     IF pickup = 12      material1
truck_hub2 then free                    move with

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

Long_Beach      IF pickup = 13      material1
truck_hub2 then free                    move with

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

IF pickup = 14      material1 Barstow
                    move with truck_hub2 then free

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

```

```

San_Bernardino  IF pickup = 15
truck_hub2 then free

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

San_Diego      IF pickup = 16
truck_hub2 then free

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

Santa_Barbara  IF pickup = 17
truck_hub2 then free

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

San_Luis_Obispo IF pickup = 18
truck_hub2 then free

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

```

```

material1
  move with

```

```

material1
  move with

```

```

material1
  move with

```

```

material1
  move with

```

```

material1 Irvine
IF pickup = 19          move with truck_hub2 then free

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

Monterey          IF pickup = 20          material1
truck_hub2 then free          move with

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0
material1 hub3          get trailernumber trailer and truck_hub3
                        1 material1 Redding
IF pickup = 1, 1          move with truck_hub3 then free

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

IF pickup = 2          material1 Chico
                        move with truck_hub3 then free

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

Sacramento          IF pickup = 3          material1
truck_hub3 then free          move with

```



```

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

Palm_Springs      IF pickup = 4
truck_hub3 then free

material1
  move with

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

Stockton          IF pickup = 5
truck_hub3 then free

material1
  move with

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

Santa_Rosa        IF pickup = 6
truck_hub3 then free

material1
  move with

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

San_Fransisco     IF pickup = 7
truck_hub3 then free

material1
  move with

```

```

flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999
counter1 = 0
tiel = 0
IF pickup = 8
                                material1 Oakland
                                move with truck_hub3 then free

flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999
counter1 = 0
tiel = 0
San_Jose      IF pickup = 9
truck_hub3 then free
                                material1
                                move with

flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999
counter1 = 0
tiel = 0
IF pickup = 10
                                material1 Fresno
                                move with truck_hub3 then free

flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999
counter1 = 0
tiel = 0
Bakersfield  IF pickup = 11
truck_hub3 then free
                                material1
                                move with

flag1 = 1

```

```

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

Los_Angeles      IF pickup = 12
truck_hub3 then free

material1
  move with

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

Long_Beach      IF pickup = 13
truck_hub3 then free

material1
  move with

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

IF pickup = 14
material1 Barstow
  move with truck_hub3 then free

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

San_Bernardino  IF pickup = 15
truck_hub3 then free

material1
  move with

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

```

```

min_rule1 = 9999999

counter1 = 0

tiel = 0

San_Diego      IF pickup = 16
truck_hub3 then free

material1
  move with

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

Santa_Barbara  IF pickup = 17
truck_hub3 then free

material1
  move with

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

San_Luis_Obispo IF pickup = 18
truck_hub3 then free

material1
  move with

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

IF pickup = 19
  material1 Irvine
  move with truck_hub3 then free

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

```

```

counter1 = 0

tiel = 0

Monterey          IF pickup = 20          material1
truck_hub3 then free                                move with

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0
material1 Redding          if (task=1) then
                            {
                                wait load_time
                                delivery_task = 1
                                next_loc = pickup

                                route 1
                            }
                            else
                            {
                                if (delivery_task = 1) then
                                {

truck_capacity[trucknumber]=truck_capacity[trucknumber]+trailernu
mber

                                get res(trucknumber+truck_res)
                                free res(trucknumber+truck_res)
                                truck_location[trucknumber] =

pickup

                                next_loc = destination
                                delivery_task = 2
                                route 1
                            }
                            else
                            {
                                get res(trucknumber+truck_res)
                                route 2
                            }
                        }

Waiting_delivery FIRST 1          1          material1
                                      task=2

flag2 = 1

num_waiting2 = contents(Waiting_delivery)+1

```

```

min_rule2 = 9999999

counter2 = 0

tie2 = 0

//display "Waiting-delivery: arrival time="$arrival_hour$"
task="$task$" pickup="$pickup$" destination="$destination$"
rule_att="$rule_att$" weight="$weight$"
trailer_number="$trailernumber$" clock="$clock()"
2 material2 Redding
IF destination=1, 1 move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=1

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

material2 Chico
IF destination=2 move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=2

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

material2
Sacramento IF destination=3 move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

```

```

truck_location[trucknumber]=3

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

Palm_Springs      IF destination=4      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=4

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

Stockton          IF destination = 5      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=5

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

Santa_Rosa        IF destination = 6      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

```

```

truck_location[trucknumber]=6

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

San_Fransisco      IF destination = 7      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=7

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

IF destination = 8      move with      material2 Oakland
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=8

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

San_Jose      IF destination = 9      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

```



```

truck_location[trucknumber]=9

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

IF destination = 10                                material2 Fresno
res(trucknumber+truck_res) then free                move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=10

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

Bakersfield    IF destination = 11                material2
res(trucknumber+truck_res) then free                move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=11

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

Los_Angeles    IF destination = 12                material2
res(trucknumber+truck_res) then free                move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

```

```

truck_location[trucknumber]=12

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

Long_Beach      IF destination = 13      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=13

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

IF destination = 14      material2 Barstow
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=14

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

San_Bernardino  IF destination = 15      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

```

```

truck_location[trucknumber]=15

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Diego      IF destination = 16      material2
res(trucknumber+truck_res) then free    move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=16

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Santa_Barbara  IF destination = 17      material2
res(trucknumber+truck_res) then free    move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=17

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Luis_Obispo IF destination = 18      material2
res(trucknumber+truck_res) then free    move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

```

```

truck_location[trucknumber]=18

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 19                                material2 Irvine
res(trucknumber+truck_res) then free               move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=19

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Monterey      IF destination = 20                    material2
res(trucknumber+truck_res) then free                 move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=20

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

material1 Chico      if (task=1) then
                     {
                       wait load_time
                       delivery_task = 1
                       next_loc = pickup

```

```

        route 1
    }
else
{
    if (delivery_task = 1) then
    {
        truck_capacity[trucknumber]=truck_capacity[trucknumber]+trailernu
mber
        get res(trucknumber+truck_res)
        free res(trucknumber+truck_res)
        truck_location[trucknumber] =
pickup
        next_loc = destination
        delivery_task = 2
        route 1
    }
else
{
        get res(trucknumber+truck_res)
        route 2
    }
}

Waiting_delivery FIRST 1
1 material1
task=2

flag2 = 1
num_waiting2 = contents(Waiting_delivery)+1
min_rule2 = 9999999
counter2 = 0
tie2 = 0

//display "Waiting-delivery: arrival time="$arrival_hour$
task="$task$" pickup="$pickup$" destination="$destination$"
rule_att="$rule_att$" weight="$weight$"
trailer_number="$trailernumber$" clock="$clock()"

IF destination=1, 1
2 material2 Redding
res(trucknumber+truck_res) then free
move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=1

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999

```

```

counter2 = 0

tie2 = 0

material2 Chico
IF destination=2          move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=2

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999

counter2 = 0
tie2 = 0

material2
Sacramento      IF destination=3      move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=3

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999

counter2 = 0
tie2 = 0

material2
Palm_Springs    IF destination=4      move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=4

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999

```

```

counter2 = 0

tie2 = 0

Stockton      IF destination = 5      material2
res(trucknumber+truck_res) then free  move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=5

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Santa_Rosa    IF destination = 6      material2
res(trucknumber+truck_res) then free  move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=6

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Fransisco IF destination = 7      material2
res(trucknumber+truck_res) then free  move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=7

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

```

```

counter2 = 0

tie2 = 0

material2 Oakland
IF destination = 8          move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=8

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999

counter2 = 0
tie2 = 0

San_Jose          IF destination = 9          material2
res(trucknumber+truck_res) then free          move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=9

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999

counter2 = 0
tie2 = 0

material2 Fresno
IF destination = 10        move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=10

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999

```



```

counter2 = 0

tie2 = 0

Bakersfield      IF destination = 11      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=11

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Los_Angeles      IF destination = 12      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=12

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Long_Beach       IF destination = 13      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=13

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

```

```

counter2 = 0

tie2 = 0

IF destination = 14
res(trucknumber+truck_res) then free
truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=14

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999

counter2 = 0
tie2 = 0

San_Bernardino IF destination = 15
res(trucknumber+truck_res) then free
truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=15

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999

counter2 = 0
tie2 = 0

San_Diego IF destination = 16
res(trucknumber+truck_res) then free
truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=16

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999

```

```

counter2 = 0

tie2 = 0

Santa_Barbara      IF destination = 17      material2
res(trucknumber+truck_res) then free        move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=17

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Luis_Obispo   IF destination = 18      material2
res(trucknumber+truck_res) then free        move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=18

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 19      material2 Irvine
res(trucknumber+truck_res) then free        move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=19

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

```

```

counter2 = 0

tie2 = 0

Monterey          IF destination = 20          material2
res(trucknumber+truck_res) then free          move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=20

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

material1 Sacramento      if (task=1) then
                           {
                             wait load_time
                             delivery_task = 1
                             next_loc = pickup

                             route 1
                           }
                           else
                           {
                             if (delivery_task = 1) then
                             {

truck_capacity[trucknumber]=truck_capacity[trucknumber]+trailernu
mber

                             get res(trucknumber+truck_res)
                             free res(trucknumber+truck_res)
                             truck_location[trucknumber] =

pickup

                             next_loc = destination
                             delivery_task = 2
                             route 1
                             }
                             else
                             {
                             get res(trucknumber+truck_res)
                             route 2
                             }
                             }
                           }

Waiting_delivery FIRST 1          1          material1
                                   task=2

```

```

flag2 = 1

num_waiting2 = contents(Waiting_delivery)+1

min_rule2 = 9999999

counter2 = 0

tie2 = 0

//display "Waiting-delivery: arrival time="$arrival_hour$"
task="$task$" pickup="$pickup$" destination="$destination$"
rule_att="$rule_att$" weight="$weight$"
trailer_number="$trailer_number$" clock="$clock()"
2 material2 Redding
IF destination=1, 1 move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailer_number
truck_location[trucknumber]=1

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination=2 move with material2 Chico
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailer_number
truck_location[trucknumber]=2

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Sacramento IF destination=3 material2
res(trucknumber+truck_res) then free move with

```

```
truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=3
```

```
flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0
```

```
material2
Palm_Springs      IF destination=4      move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=4
```

```
flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0
```

```
material2
Stockton          IF destination = 5    move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=5
```

```
flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0
```

```
material2
Santa_Rosa        IF destination = 6    move with
res(trucknumber+truck_res) then free
```

```
truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=6
```

```
flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0
```

```
San_Fransisco      IF destination = 7          material2
res(trucknumber+truck_res) then free          move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=7
```

```
flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0
```

```
IF destination = 8          move with          material2 Oakland
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=8
```

```
flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0
```

```
San_Jose           IF destination = 9          material2
res(trucknumber+truck_res) then free          move with
```

```

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=9

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

IF destination = 10                                material2 Fresno
res(trucknumber+truck_res) then free                move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=10

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

Bakersfield    IF destination = 11                    material2
res(trucknumber+truck_res) then free                move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=11

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

Los_Angeles    IF destination = 12                    material2
res(trucknumber+truck_res) then free                move with

```



```
truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=12
```

```
flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0
```

```
Long_Beach      IF destination = 13      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=13
```

```
flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0
```

```
IF destination = 14      material2 Barstow
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=14
```

```
flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0
```

```
San_Bernardino  IF destination = 15      material2
res(trucknumber+truck_res) then free      move with
```

```
truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=15
```

```
flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0
```

```
San_Diego      IF destination = 16      material2
res(trucknumber+truck_res) then free    move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=16
```

```
flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0
```

```
Santa_Barbara  IF destination = 17      material2
res(trucknumber+truck_res) then free    move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=17
```

```
flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0
```

```
San_Luis_Obispo IF destination = 18      material2
res(trucknumber+truck_res) then free    move with
```

```

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=18

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

IF destination = 19                                material2 Irvine
res(trucknumber+truck_res) then free                move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=19

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

Monterey      IF destination = 20                    material2
res(trucknumber+truck_res) then free                move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=20

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

material1 Palm_Springs    if (task=1) then
                           {
                           wait load_time

```

```

        delivery_task = 1
        next_loc = pickup

        route 1
    }
else
{
    if (delivery_task = 1) then
    {
        truck_capacity[trucknumber]=truck_capacity[trucknumber]+trailernu
mber
        get res(trucknumber+truck_res)
        free res(trucknumber+truck_res)
        truck_location[trucknumber] =
pickup
        next_loc = destination
        delivery_task = 2
        route 1
    }
else
{
        get res(trucknumber+truck_res)
        route 2
    }
}

Waiting_delivery FIRST 1
1 material1
task=2

flag2 = 1

num_waiting2 = contents(Waiting_delivery)+1

min_rule2 = 9999999

counter2 = 0

tie2 = 0

//display "Waiting-delivery: arrival time="$arrival_hour$
task="$task$" pickup="$pickup$" destination="$destination$"
rule_att="$rule_att$" weight="$weight$"
trailer_number="$trailernumber$" clock="$clock()"
2 material2 Redding
IF destination=1, 1 move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=1

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

```

```

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination=2                                material2 Chico
res(trucknumber+truck_res) then free           move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=2

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Sacramento      IF destination=3                material2
res(trucknumber+truck_res) then free           move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=3

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Palm_Springs   IF destination=4                material2
res(trucknumber+truck_res) then free           move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=4

flag2 = 1

```

```

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Stockton      IF destination = 5      material2
res(trucknumber+truck_res) then free  move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=5

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Santa_Rosa    IF destination = 6      material2
res(trucknumber+truck_res) then free  move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=6

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Fransisco IF destination = 7      material2
res(trucknumber+truck_res) then free  move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=7

flag2 = 1

```

```

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 8                                material2 Oakland
res(trucknumber+truck_res) then free              move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=8

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Jose            IF destination = 9            material2
res(trucknumber+truck_res) then free              move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=9

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 10                                material2 Fresno
res(trucknumber+truck_res) then free              move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=10

flag2 = 1

```

```

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Bakersfield      IF destination = 11      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=11

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Los_Angeles      IF destination = 12      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=12

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Long_Beach      IF destination = 13      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=13

flag2 = 1

```



```

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 14                                material2 Barstow
res(trucknumber+truck_res) then free                move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=14

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Bernardino IF destination = 15                  material2
res(trucknumber+truck_res) then free                move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=15

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Diego IF destination = 16                       material2
res(trucknumber+truck_res) then free                move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=16

flag2 = 1

```

```

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Santa_Barbara      IF destination = 17                material2
res(trucknumber+truck_res) then free                  move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=17

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Luis_Obispo   IF destination = 18                material2
res(trucknumber+truck_res) then free                  move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=18

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 19                material2 Irvine
res(trucknumber+truck_res) then free  move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=19

flag2 = 1

```

```

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Monterey          IF destination = 20          material2
res(trucknumber+truck_res) then free          move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=20

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

material1 Stockton      if (task=1) then
                        {
                          wait load_time
                          delivery_task = 1
                          next_loc = pickup

                          route 1
                        }
                        else
                        {
                          if (delivery_task = 1) then
                          {

truck_capacity[trucknumber]=truck_capacity[trucknumber]+trailernu
mber

                                get res(trucknumber+truck_res)
                                free res(trucknumber+truck_res)
                                truck_location[trucknumber] =

pickup

                                next_loc = destination
                                delivery_task = 2
                                route 1
                          }
                          else
                          {
                                get res(trucknumber+truck_res)
                                route 2
                          }
                        }
}

```

```

Waiting_delivery FIRST 1
1 material1
task=2

flag2 = 1

num_waiting2 = contents(Waiting_delivery)+1

min_rule2 = 9999999

counter2 = 0

tie2 = 0

//display "Waiting-delivery: arrival time="$arrival_hour$"
task="$task$" pickup="$pickup$" destination="$destination$"
rule_att="$rule_att$" weight="$weight$"
trailer_number="$trailer_number$" clock="$clock()"

2 material2 Redding
IF destination = 1, 1 move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailer_number

truck_location[trucknumber]=1

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

material2 Chico
IF destination = 2 move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailer_number

truck_location[trucknumber]=2

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

```

```

Sacramento      IF destination = 3      material2
res(trucknumber+truck_res) then free    move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=3

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Palm_Springs   IF destination = 4      material2
res(trucknumber+truck_res) then free    move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=4

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Stockton        IF destination = 5      material2
res(trucknumber+truck_res) then free    move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=5

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

```

```

material2
Santa_Rosa      IF destination = 6      move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=6

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

material2
San_Fransisco  IF destination = 7      move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=7

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

material2 Oakland
IF destination = 8      move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=8

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

```

```

San_Jose          IF destination = 9          material2
res(trucknumber+truck_res) then free          move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=9

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 10          material2 Fresno
res(trucknumber+truck_res) then free          move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=10

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Bakersfield      IF destination = 11          material2
res(trucknumber+truck_res) then free          move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=11

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

```

```

Los_Angeles      IF destination = 12      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=12

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Long_Beach      IF destination = 13      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=13

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 14      material2 Barstow
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=14

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

```



```

material2
San_Bernardino  IF destination = 15      move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=15

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

material2
San_Diego      IF destination = 16      move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=16

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

material2
Santa_Barbara  IF destination = 17      move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=17

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

```

```

San_Luis_Obispo IF destination = 18
res(trucknumber+truck_res) then free
material2
    move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=18

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

IF destination = 19
res(trucknumber+truck_res) then free
material2 Irvine
    move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=19

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

Monterey IF destination = 20
res(trucknumber+truck_res) then free
material2
    move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=20

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0
material1 Santa_Rosa if (task=1) then

```

```

        {
            wait load_time
            delivery_task = 1
            next_loc = pickup

            route 1
        }
        else
        {
            if (delivery_task = 1) then
            {
                truck_capacity[trucknumber]=truck_capacity[trucknumber]+trailernumber
                get res(trucknumber+truck_res)
                free res(trucknumber+truck_res)
                truck_location[trucknumber] =
                pickup
                next_loc = destination
                delivery_task = 2
                route 1
            }
            else
            {
                get res(trucknumber+truck_res)
                route 2
            }
        }
    }

    1    material1
    Waiting_delivery FIRST 1    task=2

    flag2 = 1

    num_waiting2 = contents(Waiting_delivery)+1

    min_rule2 = 9999999

    counter2 = 0

    tie2 = 0

    //display "Waiting-delivery: arrival time="$arrival_hour$
    task="$task$" pickup="$pickup$" destination="$destination$"
    rule_att="$rule_att$" weight="$weight$"
    trailer_number="$trailer_number$" clock="$clock()"
    2    material2 Redding
    IF destination = 1, 1    move with
    res(trucknumber+truck_res) then free

    truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

    truck_location[trucknumber]=1

    flag2 = 1

```

```

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 2                                material2 Chico
res(trucknumber+truck_res) then free              move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=2

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Sacramento IF destination = 3                    material2
res(trucknumber+truck_res) then free              move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=3

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Palm_Springs IF destination = 4                  material2
res(trucknumber+truck_res) then free              move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=4

```

```

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Stockton      IF destination = 5      material2
res(trucknumber+truck_res) then free  move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=5

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Santa_Rosa    IF destination = 6      material2
res(trucknumber+truck_res) then free  move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=6

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Fransisco IF destination = 7      material2
res(trucknumber+truck_res) then free  move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=7

```

```

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 8                                material2 Oakland
res(trucknumber+truck_res) then free              move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=8

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Jose      IF destination = 9                    material2
res(trucknumber+truck_res) then free              move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=9

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 10                                material2 Fresno
res(trucknumber+truck_res) then free              move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=10

```

```

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Bakersfield      IF destination = 11      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=11

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Los_Angeles      IF destination = 12      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=12

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Long_Beach      IF destination = 13      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=13

```

```

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 14                                material2 Barstow
res(trucknumber+truck_res) then free                move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=14

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Bernardino IF destination = 15                  material2
res(trucknumber+truck_res) then free                move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=15

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Diego IF destination = 16                       material2
res(trucknumber+truck_res) then free                move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=16

```



```

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Santa_Barbara      IF destination = 17          material2
res(trucknumber+truck_res) then free           move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=17

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Luis_Obispo   IF destination = 18          material2
res(trucknumber+truck_res) then free           move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=18

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 19          move with          material2 Irvine
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=19

```

```

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Monterey          IF destination = 20          material2
res(trucknumber+truck_res) then free          move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=20

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

material1 San_Fransisco  if (task=1) then
                          {
                              wait load_time
                              delivery_task = 1
                              next_loc = pickup

                              route 1
                              }
                          else
                          {
                              if (delivery_task = 1) then
                              {
                                  truck_capacity[trucknumber]=truck_capacity[trucknumber]+trailernu
                                  mber
                                  get res(trucknumber+truck_res)
                                  free res(trucknumber+truck_res)
                                  truck_location[trucknumber] =
                                  pickup
                                  next_loc = destination
                                  delivery_task = 2
                                  route 1
                              }
                          }
                          else
                          {
                              get res(trucknumber+truck_res)

```

```

        }
    }
}

```

```

Waiting_delivery FIRST 1
1 material1
task=2

flag2 = 1
num_waiting2 = contents(Waiting_delivery)+1
min_rule2 = 9999999
counter2 = 0
tie2 = 0

//display "Waiting-delivery: arrival time="$arrival_hour$
task="$task$" pickup="$pickup$" destination="$destination$"
rule_att="$rule_att$" weight="$weight$"
trailer_number="$trailer_number$" clock="$clock()"
2 material2 Redding
IF destination = 1, 1 move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailer_number
truck_location[trucknumber]=1

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

IF destination = 2 move with material2 Chico
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailer_number
truck_location[trucknumber]=2

flag2 = 1
num_waiting2 = contents(Waiting_delivery)

```

```

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Sacramento      IF destination = 3      material2
res(trucknumber+truck_res) then free    move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=3

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Palm_Springs   IF destination = 4      material2
res(trucknumber+truck_res) then free    move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=4

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Stockton        IF destination = 5      material2
res(trucknumber+truck_res) then free    move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=5

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

```

```

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Santa_Rosa      IF destination = 6                material2
res(trucknumber+truck_res) then free              move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=6

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Fransisco  IF destination = 7                material2
res(trucknumber+truck_res) then free              move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=7

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 8                material2 Oakland
res(trucknumber+truck_res) then free              move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=8

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

```

```

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Jose          IF destination = 9          material2
res(trucknumber+truck_res) then free          move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=9

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 10          move with          material2 Fresno
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=10

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Bakersfield      IF destination = 11          material2
res(trucknumber+truck_res) then free          move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=11

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

```

```

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Los_Angeles      IF destination = 12      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=12

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Long_Beach      IF destination = 13      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=13

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 14      material2 Barstow
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=14

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

```

```

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Bernardino    IF destination = 15                material2
res(trucknumber+truck_res) then free                 move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=15

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Diego         IF destination = 16                material2
res(trucknumber+truck_res) then free                 move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=16

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Santa_Barbara    IF destination = 17                material2
res(trucknumber+truck_res) then free                 move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=17

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

```



```

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Luis_Obispo  IF destination = 18          material2
res(trucknumber+truck_res) then free          move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=18

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 19          move with          material2 Irvine
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=19

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Monterey          IF destination = 20          material2
res(trucknumber+truck_res) then free          move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=20

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

```

```

min_rule2 = 9999999

counter2 = 0

tie2 = 0

material1 Oakland          if (task=1) then
                            {
                                wait load_time
                                delivery_task = 1
                                next_loc = pickup

                                route 1
                            }
                            else
                            {
                                if (delivery_task = 1) then
                                {
                                    truck_capacity[trucknumber]=truck_capacity[trucknumber]+trailernum
mber
                                    get res(trucknumber+truck_res)
                                    free res(trucknumber+truck_res)
                                    truck_location[trucknumber] =
pickup
                                    next_loc = destination
                                    delivery_task = 2
                                    route 1
                                }
                                else
                                {
                                    get res(trucknumber+truck_res)
                                    route 2
                                }
                            }
                            }

                            1      material1
Waiting_delivery FIRST 1      task=2

flag2 = 1

num_waiting2 = contents(Waiting_delivery)+1

min_rule2 = 9999999

counter2 = 0

tie2 = 0

//display "Waiting-delivery: arrival time="$arrival_hour$
task="$task$" pickup="$pickup$" destination="$destination$"
rule_att="$rule_att$" weight="$weight$"
trailer_number="$trailernumber$" clock="$clock()"

```

```

                2      material2 Redding
IF destination = 1, 1      move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=1

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

                material2 Chico
IF destination = 2      move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=2

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

                material2
Sacramento      IF destination = 3      move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=3

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

```

```

Palm_Springs      IF destination = 4      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=4

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Stockton          IF destination = 5      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=5

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Santa_Rosa        IF destination = 6      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=6

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

```

```

San_Fransisco      IF destination = 7      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=7

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 8      material2 Oakland
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=8

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Jose      IF destination = 9      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=9

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

```

```

material2 Fresno
IF destination = 10          move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=10

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

Bakersfield      IF destination = 11          material2
res(trucknumber+truck_res) then free          move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=11

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

Los_Angeles      IF destination = 12          material2
res(trucknumber+truck_res) then free          move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=12

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

```

```

Long_Beach      IF destination = 13      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=13

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 14      material2 Barstow
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=14

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Bernardino  IF destination = 15      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=15

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

```

```

San_Diego      IF destination = 16      material2
res(trucknumber+truck_res) then free    move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=16

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Santa_Barbara  IF destination = 17      material2
res(trucknumber+truck_res) then free    move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=17

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Luis_Obispo IF destination = 18      material2
res(trucknumber+truck_res) then free    move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=18

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

```



```

material2 Irvine
IF destination = 19          move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=19

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

Monterey          IF destination = 20          material2
res(trucknumber+truck_res) then free          move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=20

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0
material1 San_Jose          if (task=1) then
                              {
                                  wait load_time
                                  delivery_task = 1
                                  next_loc = pickup

                                  route 1
                              }
                              else
                              {
                                  if (delivery_task = 1) then
                                  {
truck_capacity[trucknumber]=truck_capacity[trucknumber]+trailernu
mber
                              }
                              get res(trucknumber+truck_res)
                              free res(trucknumber+truck_res)
                              truck_location[trucknumber] =
pickup

```

```

                                next_loc = destination
                                delivery_task = 2
                                route 1
                            }
                            else
                            {
                                get res(trucknumber+truck_res)
                                route 2
                            }
                        }

```

1 material1
 Waiting_delivery FIRST 1 task=2

```

flag2 = 1

num_waiting2 = contents(Waiting_delivery)+1

min_rule2 = 9999999

counter2 = 0

tie2 = 0

//display "Waiting-delivery: arrival time="$arrival_hour$"  

task="$task$" pickup="$pickup$" destination="$destination$"  

rule_att="$rule_att$" weight="$weight$"  

trailer_number="$trailer_number$" clock="$clock()"
2 material2 Redding
IF destination = 1, 1 move with  

res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailer_number

truck_location[trucknumber]=1

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

material2 Chico
IF destination = 2 move with  

res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailer_number

truck_location[trucknumber]=2

```

```

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Sacramento      IF destination = 3      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=3

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Palm_Springs    IF destination = 4      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=4

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Stockton         IF destination = 5      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=5

```

```

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Santa_Rosa      IF destination = 6                material2
res(trucknumber+truck_res) then free              move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=6

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Fransisco  IF destination = 7                material2
res(trucknumber+truck_res) then free              move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=7

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 8                material2 Oakland
res(trucknumber+truck_res) then free              move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=8

```

```

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Jose          IF destination = 9          material2
res(trucknumber+truck_res) then free          move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=9

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 10          move with          material2 Fresno
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=10

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Bakersfield      IF destination = 11          material2
res(trucknumber+truck_res) then free          move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=11

```

```

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Los_Angeles      IF destination = 12      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=12

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Long_Beach      IF destination = 13      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=13

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 14      material2 Barstow
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=14

```

```

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Bernardino      IF destination = 15      material2
res(trucknumber+truck_res) then free        move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=15

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Diego           IF destination = 16      material2
res(trucknumber+truck_res) then free        move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=16

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Santa_Barbara      IF destination = 17      material2
res(trucknumber+truck_res) then free        move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=17

```

```

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Luis_Obispo  IF destination = 18          material2
res(trucknumber+truck_res) then free          move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=18

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 19          move with          material2 Irvine
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=19

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Monterey          IF destination = 20          material2
res(trucknumber+truck_res) then free          move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=20

```



```

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0
material1 Fresno
    if (task=1) then
    {
        wait load_time
        delivery_task = 1
        next_loc = pickup

        route 1
    }
    else
    {
        if (delivery_task = 1) then
        {
            truck_capacity[trucknumber]=truck_capacity[trucknumber]+trailernu
mber
            get res(trucknumber+truck_res)
            free res(trucknumber+truck_res)
            truck_location[trucknumber] =
pickup
            next_loc = destination
            delivery_task = 2
            route 1
        }
        else
        {
            get res(trucknumber+truck_res)
            route 2
        }
    }
}

```

```

Waiting_delivery FIRST 1
1 material1
task=2

```

```

flag2 = 1

num_waiting2 = contents(Waiting_delivery)+1

min_rule2 = 9999999

counter2 = 0

tie2 = 0

```

```

//display "Waiting-delivery: arrival time="$arrival_hour$
task="$task$" pickup="$pickup$" destination="$destination$"
rule_att="$rule_att$" weight="$weight$"
trailer_number="$trailernumber$" clock="$clock()"
2 material2 Redding
IF destination = 1, 1 move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=1

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 2 move with material2 Chico
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=2

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Sacramento IF destination = 3 material2
res(trucknumber+truck_res) then free move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=3

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

```

```

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Palm_Springs      IF destination = 4                material2
res(trucknumber+truck_res) then free                move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=4

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Stockton          IF destination = 5                material2
res(trucknumber+truck_res) then free                move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=5

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Santa_Rosa        IF destination = 6                material2
res(trucknumber+truck_res) then free                move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=6

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

```

```

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Fransisco      IF destination = 7                material2
res(trucknumber+truck_res) then free                move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=7

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 8                move with                material2 Oakland
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=8

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Jose           IF destination = 9                material2
res(trucknumber+truck_res) then free                move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=9

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

```

```

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 10                                material2 Fresno
res(trucknumber+truck_res) then free               move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=10

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Bakersfield      IF destination = 11                material2
res(trucknumber+truck_res) then free                move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=11

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Los_Angeles      IF destination = 12                material2
res(trucknumber+truck_res) then free                move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=12

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

```

```

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Long_Beach      IF destination = 13      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=13

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 14      material2 Barstow
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=14

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Bernardino  IF destination = 15      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=15

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

```

```

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Diego      IF destination = 16      material2
res(trucknumber+truck_res) then free    move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=16

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Santa_Barbara  IF destination = 17      material2
res(trucknumber+truck_res) then free    move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=17

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Luis_Obispo  IF destination = 18      material2
res(trucknumber+truck_res) then free    move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=18

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

```

```

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 19                                material2 Irvine
res(trucknumber+truck_res) then free                move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=19

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Monterey      IF destination = 20                    material2
res(trucknumber+truck_res) then free                move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=20

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

material1 Bakersfield    if (task=1) then
                          {
                              wait load_time
                              delivery_task = 1
                              next_loc = pickup

                              route 1
                          }
                          else
                          {
                              if (delivery_task = 1) then

```



```

        {
            truck_capacity[trucknumber]=truck_capacity[trucknumber]+trailernu
mber
                get res(trucknumber+truck_res)
                free res(trucknumber+truck_res)
                truck_location[trucknumber] =
pickup
                    next_loc = destination
                    delivery_task = 2
                    route 1
                }
                else
                {
                    get res(trucknumber+truck_res)
                    route 2
                }
            }
        }
        1      material1
        Waiting_delivery FIRST 1      task=2

flag2 = 1

num_waiting2 = contents(Waiting_delivery)+1

min_rule2 = 9999999

counter2 = 0

tie2 = 0

//display "Waiting-delivery: arrival time="$arrival_hour$"
task="$task$" pickup="$pickup$" destination="$destination$"
rule_att="$rule_att$" weight="$weight$"
trailer_number="$trailernumber$" clock="$clock()"
        2      material2 Redding
IF destination = 1, 1      move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=1

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

```

```

material2 Chico
IF destination = 2          move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=2

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

Sacramento      IF destination = 3          material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=3

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

Palm_Springs   IF destination = 4          material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=4

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

```

```

Stockton          IF destination = 5          material2
res(trucknumber+truck_res) then free          move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=5

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Santa_Rosa       IF destination = 6          material2
res(trucknumber+truck_res) then free          move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=6

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Fransisco    IF destination = 7          material2
res(trucknumber+truck_res) then free          move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=7

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

```

```

material2 Oakland
IF destination = 8                move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=8

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

San_Jose        IF destination = 9                material2
res(trucknumber+truck_res) then free              move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=9

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

material2 Fresno
IF destination = 10                move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=10

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

```

```

Bakersfield      IF destination = 11      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=11

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Los_Angeles      IF destination = 12      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=12

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Long_Beach       IF destination = 13      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=13

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

```

```

material2 Barstow
IF destination = 14          move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=14

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

San_Bernardino  IF destination = 15          material2
res(trucknumber+truck_res) then free          move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=15

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

San_Diego      IF destination = 16          material2
res(trucknumber+truck_res) then free          move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=16

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

```

```

material2
Santa_Barbara    IF destination = 17      move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=17

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

material2
San_Luis_Obispo IF destination = 18      move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=18

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

material2 Irvine
IF destination = 19      move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=19

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

```

```

material2
Monterey      IF destination = 20      move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=20

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

material1 Los_Angeles      if (task=1) then
                           {
                               wait load_time
                               delivery_task = 1
                               next_loc = pickup

                               route 1
                           }
                           else
                           {
                               if (delivery_task = 1) then
                               {
truck_capacity[trucknumber]=truck_capacity[trucknumber]+trailernu
mber
                               get res(trucknumber+truck_res)
                               free res(trucknumber+truck_res)
                               truck_location[trucknumber] =
pickup
                               next_loc = destination
                               delivery_task = 2
                               route 1
                               }
                               else
                               {
                               get res(trucknumber+truck_res)
                               route 2
                               }
                               }
                           }

Waiting_delivery FIRST 1      1      material1
                               task=2

flag2 = 1

num_waiting2 = contents(Waiting_delivery)+1

```



```

min_rule2 = 9999999

counter2 = 0

tie2 = 0

//display "Waiting-delivery: arrival time="$arrival_hour$
task="$task$" pickup="$pickup$" destination="$destination$"
rule_att="$rule_att$" weight="$weight$"
trailer_number="$trailer_number$" clock="$clock()"
2 material2 Redding
IF destination = 1, 1 move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailer_number

truck_location[trucknumber]=1

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 2 move with material2 Chico
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailer_number

truck_location[trucknumber]=2

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Sacramento IF destination = 3 material2
res(trucknumber+truck_res) then free move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailer_number

truck_location[trucknumber]=3

```

```

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Palm_Springs      IF destination = 4
res(trucknumber+truck_res) then free
material2
move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=4

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Stockton          IF destination = 5
res(trucknumber+truck_res) then free
material2
move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=5

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Santa_Rosa        IF destination = 6
res(trucknumber+truck_res) then free
material2
move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=6

```

```

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Fransisco      IF destination = 7                material2
res(trucknumber+truck_res) then free                move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=7

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 8                move with                material2 Oakland
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=8

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Jose           IF destination = 9                material2
res(trucknumber+truck_res) then free                move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=9

```

```

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 10                                material2 Fresno
res(trucknumber+truck_res) then free                move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=10

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Bakersfield    IF destination = 11                    material2
res(trucknumber+truck_res) then free                move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=11

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Los_Angeles    IF destination = 12                    material2
res(trucknumber+truck_res) then free                move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=12

```

```

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Long_Beach      IF destination = 13      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=13

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 14      material2 Barstow
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=14

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Bernardino  IF destination = 15      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=15

```

```

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Diego      IF destination = 16      material2
res(trucknumber+truck_res) then free    move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=16

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Santa_Barbara  IF destination = 17      material2
res(trucknumber+truck_res) then free    move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=17

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Luis_Obispo IF destination = 18      material2
res(trucknumber+truck_res) then free    move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=18

```

```

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 19                                material2 Irvine
res(trucknumber+truck_res) then free               move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=19

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Monterey IF destination = 20                        material2
res(trucknumber+truck_res) then free               move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=20

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

material1 Long_Beach                               if (task=1) then
                                                    {
                                                    wait load_time
                                                    delivery_task = 1
                                                    next_loc = pickup

```

```

        route 1
    }
else
{
    if (delivery_task = 1) then
    {
        truck_capacity[trucknumber]=truck_capacity[trucknumber]+trailernu
mber
        get res(trucknumber+truck_res)
        free res(trucknumber+truck_res)
        truck_location[trucknumber] =
pickup
        next_loc = destination
        delivery_task = 2
        route 1
    }
else
{
    get res(trucknumber+truck_res)
    route 2
}
}
}

1      material1
Waiting_delivery FIRST 1      task=2

flag2 = 1
num_waiting2 = contents(Waiting_delivery)+1
min_rule2 = 9999999
counter2 = 0
tie2 = 0

//display "Waiting-delivery: arrival time="$arrival_hour$
task="$task$" pickup="$pickup$" destination="$destination$"
rule_att="$rule_att$" weight="$weight$"
trailer_number="$trailer_number$" clock="$clock()"
2      material2 Redding
IF destination = 1, 1      move with
res(trucknumber+truck_res) then free
truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailer_number
truck_location[trucknumber]=1

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0

```


tie2 = 0

```
material2 Chico
IF destination = 2          move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=2
```

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

```
material2
Sacramento      IF destination = 3          move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=3
```

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

```
material2
Palm_Springs    IF destination = 4          move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=4
```

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

```

counter2 = 0

tie2 = 0

Stockton      IF destination = 5      material2
res(trucknumber+truck_res) then free  move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=5

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Santa_Rosa    IF destination = 6      material2
res(trucknumber+truck_res) then free  move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=6

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Fransisco IF destination = 7      material2
res(trucknumber+truck_res) then free  move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=7

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

```

```

counter2 = 0

tie2 = 0

material2 Oakland
IF destination = 8          move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=8

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Jose          IF destination = 9          material2
res(trucknumber+truck_res) then free          move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=9

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

material2 Fresno
IF destination = 10        move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=10

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

```

```

counter2 = 0

tie2 = 0

Bakersfield      IF destination = 11      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=11

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Los_Angeles      IF destination = 12      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=12

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Long_Beach       IF destination = 13      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=13

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

```

```

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 14                                material2 Barstow
res(trucknumber+truck_res) then free                move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=14

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Bernardino  IF destination = 15                material2
res(trucknumber+truck_res) then free                move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=15

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Diego       IF destination = 16                material2
res(trucknumber+truck_res) then free                move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=16

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

```

```

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Santa_Barbara      IF destination = 17                material2
res(trucknumber+truck_res) then free                  move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=17

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Luis_Obispo   IF destination = 18                material2
res(trucknumber+truck_res) then free                  move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=18

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 19                material2 Irvine
res(trucknumber+truck_res) then free move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=19

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

```

```

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Monterey          IF destination = 20          material2
res(trucknumber+truck_res) then free          move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=20

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

material1 Barstow          if (task=1) then
                            {
                                wait load_time
                                delivery_task = 1
                                next_loc = pickup

                                route 1
                            }
                            else
                            {
                                if (delivery_task = 1) then
                                {
                                    truck_capacity[trucknumber]=truck_capacity[trucknumber]+trailernu
mber

                                    get res(trucknumber+truck_res)
                                    free res(trucknumber+truck_res)
                                    truck_location[trucknumber] =

pickup

                                    next_loc = destination
                                    delivery_task = 2
                                    route 1
                                }
                                else
                                {
                                    get res(trucknumber+truck_res)
                                    route 2
                                }
                            }
                            }

```

```

Waiting_delivery FIRST 1
1 material1
task=2

flag2 = 1

num_waiting2 = contents(Waiting_delivery)+1

min_rule2 = 9999999

counter2 = 0

tie2 = 0

//display "Waiting-delivery: arrival time="$arrival_hour$"
task="$task$" pickup="$pickup$" destination="$destination$"
rule_att="$rule_att$" weight="$weight$"
trailer_number="$trailer_number$" clock="$clock()"

IF destination = 1, 1 move with material2 Redding
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailer_number

truck_location[trucknumber]=1

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 2 move with material2 Chico
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailer_number

truck_location[trucknumber]=2

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

```



```

Sacramento      IF destination = 3      material2
res(trucknumber+truck_res) then free    move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=3

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Palm_Springs   IF destination = 4      material2
res(trucknumber+truck_res) then free    move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=4

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Stockton        IF destination = 5      material2
res(trucknumber+truck_res) then free    move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=5

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

```

```

material2
Santa_Rosa      IF destination = 6      move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=6

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

material2
San_Fransisco  IF destination = 7      move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=7

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

material2 Oakland
IF destination = 8      move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=8

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

```

```

San_Jose          IF destination = 9          material2
res(trucknumber+truck_res) then free          move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=9

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 10          material2 Fresno
res(trucknumber+truck_res) then free          move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=10

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Bakersfield      IF destination = 11        material2
res(trucknumber+truck_res) then free        move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=11

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

```

```

Los_Angeles      IF destination = 12      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=12

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Long_Beach      IF destination = 13      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=13

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 14      material2 Barstow
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=14

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

```

```

San_Bernardino    IF destination = 15
res(trucknumber+truck_res) then free
material2
    move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=15

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Diego        IF destination = 16
res(trucknumber+truck_res) then free
material2
    move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=16

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Santa_Barbara    IF destination = 17
res(trucknumber+truck_res) then free
material2
    move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=17

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

```

```

San_Luis_Obispo  IF destination = 18
res(trucknumber+truck_res) then free
material2
move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=18

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 19
res(trucknumber+truck_res) then free
material2 Irvine
move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=19

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Monterey        IF destination = 20
res(trucknumber+truck_res) then free
material2
move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=20

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

```

```

material1 San_Bernardino  if (task=1) then
                          {
                              wait load_time
                              delivery_task = 1
                              next_loc = pickup

                              route 1
                          }
                          else
                          {
                              if (delivery_task = 1) then
                              {
                                  truck_capacity[trucknumber]=truck_capacity[trucknumber]+trailer number
                                  get res(trucknumber+truck_res)
                                  free res(trucknumber+truck_res)
                                  truck_location[trucknumber] = pickup

                                  next_loc = destination
                                  delivery_task = 2
                                  route 1
                              }
                              else
                              {
                                  get res(trucknumber+truck_res)
                                  route 2
                              }
                          }
                          }

Waiting_delivery FIRST 1                                1    material1
                                                         task=2

flag2 = 1

num_waiting2 = contents(Waiting_delivery)+1

min_rule2 = 9999999

counter2 = 0

tie2 = 0

//display "Waiting-delivery: arrival time="$arrival_hour$
task="$task$" pickup="$pickup$" destination="$destination$"
rule_att="$rule_att$" weight="$weight$"
trailer_number="$trailer number$" clock="$clock()"

IF destination = 1, 1                                2    material2 Redding
res(trucknumber+truck_res) then free                move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailer number

truck_location[trucknumber]=1

```

```

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 2                                material2 Chico
res(trucknumber+truck_res) then free              move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=2

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Sacramento IF destination = 3                    material2
res(trucknumber+truck_res) then free              move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=3

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Palm_Springs IF destination = 4                  material2
res(trucknumber+truck_res) then free              move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=4

```



```

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Stockton      IF destination = 5      material2
res(trucknumber+truck_res) then free  move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=5

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Santa_Rosa    IF destination = 6      material2
res(trucknumber+truck_res) then free  move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=6

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Fransisco IF destination = 7      material2
res(trucknumber+truck_res) then free  move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=7

```

```

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 8                                material2 Oakland
res(trucknumber+truck_res) then free              move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=8

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Jose      IF destination = 9                    material2
res(trucknumber+truck_res) then free              move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=9

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 10                                material2 Fresno
res(trucknumber+truck_res) then free              move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=10

```

```

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Bakersfield      IF destination = 11      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=11

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Los_Angeles      IF destination = 12      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=12

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Long_Beach       IF destination = 13      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=13

```

```

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 14                                material2 Barstow
res(trucknumber+truck_res) then free               move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=14

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Bernardino IF destination = 15                material2
res(trucknumber+truck_res) then free               move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=15

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Diego IF destination = 16                    material2
res(trucknumber+truck_res) then free               move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=16

```

```

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Santa_Barbara    IF destination = 17                material2
res(trucknumber+truck_res) then free                move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=17

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Luis_Obispo  IF destination = 18                material2
res(trucknumber+truck_res) then free                move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=18

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 19                material2 Irvine
res(trucknumber+truck_res) then free                move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=19

```

```

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Monterey          IF destination = 20          material2
res(trucknumber+truck_res) then free          move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=20

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

material1 San_Diego      if (task=1) then
                        {
                            wait load_time
                            delivery_task = 1
                            next_loc = pickup

                            route 1
                        }
                        else
                        {
                            if (delivery_task = 1) then
                            {
                                truck_capacity[trucknumber]=truck_capacity[trucknumber]+trailernu
                                mber
                                get res(trucknumber+truck_res)
                                free res(trucknumber+truck_res)
                                truck_location[trucknumber] =
                                pickup
                                next_loc = destination
                                delivery_task = 2
                                route 1
                            }
                        }
                        else
                        {

```

```

        get res(trucknumber+truck_res)
        route 2
    }
}

Waiting_delivery FIRST 1
1 material1
task=2

flag2 = 1
num_waiting2 = contents(Waiting_delivery)+1
min_rule2 = 9999999
counter2 = 0
tie2 = 0

//display "Waiting-delivery: arrival time="$arrival_hour$
task="$task$" pickup="$pickup$" destination="$destination$"
rule_att="$rule_att$" weight="$weight$"
trailer_number="$trailer_number$" clock="$clock()"
2 material2 Redding
IF destination = 1, 1 move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailer_number
truck_location[trucknumber]=1

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

IF destination = 2 move with material2 Chico
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailer_number
truck_location[trucknumber]=2

flag2 = 1
num_waiting2 = contents(Waiting_delivery)

```

```

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Sacramento      IF destination = 3      material2
res(trucknumber+truck_res) then free    move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=3

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Palm_Springs   IF destination = 4      material2
res(trucknumber+truck_res) then free    move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=4

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Stockton        IF destination = 5      material2
res(trucknumber+truck_res) then free    move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=5

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

```



```

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Santa_Rosa      IF destination = 6                material2
res(trucknumber+truck_res) then free              move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=6

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Fransisco  IF destination = 7                material2
res(trucknumber+truck_res) then free              move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=7

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 8                material2 Oakland
res(trucknumber+truck_res) then free              move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=8

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

```

```

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Jose          IF destination = 9          material2
res(trucknumber+truck_res) then free          move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=9

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 10          move with          material2 Fresno
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=10

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Bakersfield      IF destination = 11          material2
res(trucknumber+truck_res) then free          move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=11

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

```

```

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Los_Angeles      IF destination = 12      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=12

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Long_Beach      IF destination = 13      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=13

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 14      move with      material2 Barstow
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=14

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

```

```

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Bernardino    IF destination = 15                material2
res(trucknumber+truck_res) then free                move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=15

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Diego          IF destination = 16                material2
res(trucknumber+truck_res) then free                move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=16

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Santa_Barbara     IF destination = 17                material2
res(trucknumber+truck_res) then free                move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=17

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

```

```

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Luis_Obispo  IF destination = 18          material2
res(trucknumber+truck_res) then free          move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=18

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 19          move with          material2 Irvine
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=19

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Monterey          IF destination = 20          material2
res(trucknumber+truck_res) then free          move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=20

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

```

```

min_rule2 = 9999999

counter2 = 0

tie2 = 0

material1 Santa_Barbara    if (task=1) then
                            {
                                wait load_time
                                delivery_task = 1
                                next_loc = pickup

                                route 1
                            }
                            else
                            {
                                if (delivery_task = 1) then
                                {
                                    truck_capacity[trucknumber]=truck_capacity[trucknumber]+trailernu
mber
                                    get res(trucknumber+truck_res)
                                    free res(trucknumber+truck_res)
                                    truck_location[trucknumber] =
pickup
                                    next_loc = destination
                                    delivery_task = 2
                                    route 1
                                }
                                else
                                {
                                    get res(trucknumber+truck_res)
                                    route 2
                                }
                            }
                        }

                            1    material1
Waiting_delivery FIRST 1    task=2

flag2 = 1

num_waiting2 = contents(Waiting_delivery)+1

min_rule2 = 9999999

counter2 = 0

tie2 = 0

//display "Waiting-delivery: arrival time="$arrival_hour$
task="$task$" pickup="$pickup$" destination="$destination$"

```

```

rule_att="$rule_att$" weight="$weight$"
trailer_number="$trailer_number$" clock="$clock()"
2 material2 Redding
IF destination = 1, 1 move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailer_number
truck_location[trucknumber]=1

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

material2 Chico
IF destination = 2 move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailer_number
truck_location[trucknumber]=2

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

material2
Sacramento IF destination = 3 move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailer_number
truck_location[trucknumber]=3

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0

```

```

tie2 = 0

Palm_Springs      IF destination = 4      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=4

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Stockton          IF destination = 5      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=5

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Santa_Rosa        IF destination = 6      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=6

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

```



```

tie2 = 0

San_Fransisco      IF destination = 7      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=7

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 8      move with      material2 Oakland
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=8

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Jose      IF destination = 9      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=9

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

```

```

tie2 = 0

IF destination = 10
res(trucknumber+truck_res) then free
truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=10

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0

tie2 = 0
material2 Fresno
move with
Bakersfield IF destination = 11
res(trucknumber+truck_res) then free
material2
move with
truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=11

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0

tie2 = 0
Los_Angeles IF destination = 12
res(trucknumber+truck_res) then free
material2
move with
truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=12

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0

```

```

tie2 = 0

Long_Beach      IF destination = 13      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=13

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 14      material2 Barstow
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=14

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Bernardino  IF destination = 15      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=15

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

```

```

tie2 = 0

San_Diego      IF destination = 16      material2
res(trucknumber+truck_res) then free    move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=16

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Santa_Barbara  IF destination = 17      material2
res(trucknumber+truck_res) then free    move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=17

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Luis_Obispo  IF destination = 18    material2
res(trucknumber+truck_res) then free    move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=18

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

```

```

tie2 = 0

IF destination = 19
res(trucknumber+truck_res) then free
move with
material2 Irvine

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=19

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

Monterey IF destination = 20
res(trucknumber+truck_res) then free
move with
material2

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=20

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0
material1 San_Luis_Obispo if (task=1) then
{
    wait load_time
    delivery_task = 1
    next_loc = pickup

    route 1
}
else
{
    if (delivery_task = 1) then
    {
        truck_capacity[trucknumber]=truck_capacity[trucknumber]+trailernu
mber
        get res(trucknumber+truck_res)
        free res(trucknumber+truck_res)
    }
}

```

```

truck_location[trucknumber] =
pickup
    next_loc = destination
    delivery_task = 2
    route 1
}
else
{
    get res(trucknumber+truck_res)
    route 2
}
}

Waiting_delivery FIRST 1
1 material1
task=2

flag2 = 1

num_waiting2 = contents(Waiting_delivery)+1

min_rule2 = 9999999

counter2 = 0

tie2 = 0

//display "Waiting-delivery: arrival time="$arrival_hour$
task="$task$" pickup="$pickup$" destination="$destination$"
rule_att="$rule_att$" weight="$weight$"
trailer_number="$trailer_number$" clock="$clock()"
2 material2 Redding
IF destination = 1, 1 move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailer_number

truck_location[trucknumber]=1

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

material2 Chico
IF destination = 2 move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailer_number

```

```

truck_location[trucknumber]=2

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

Sacramento      IF destination = 3      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=3

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

Palm_Springs   IF destination = 4      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=4

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

Stockton        IF destination = 5      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

```

```

truck_location[trucknumber]=5

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

Santa_Rosa      IF destination = 6      material2
res(trucknumber+truck_res) then free    move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=6

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

San_Fransisco  IF destination = 7      material2
res(trucknumber+truck_res) then free    move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=7

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

IF destination = 8      move with      material2 Oakland
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

```



```

truck_location[trucknumber]=8

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Jose          IF destination = 9          material2
res(trucknumber+truck_res) then free          move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=9

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 10          move with          material2 Fresno
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=10

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Bakersfield      IF destination = 11          material2
res(trucknumber+truck_res) then free          move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

```

```

truck_location[trucknumber]=11

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

Los_Angeles      IF destination = 12      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=12

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

Long_Beach      IF destination = 13      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=13

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

IF destination = 14      move with      material2 Barstow
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

```

```

truck_location[trucknumber]=14

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Bernardino    IF destination = 15
res(trucknumber+truck_res) then free
material2
move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=15

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Diego         IF destination = 16
res(trucknumber+truck_res) then free
material2
move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=16

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Santa_Barbara    IF destination = 17
res(trucknumber+truck_res) then free
material2
move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

```

```

truck_location[trucknumber]=17

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

San_Luis_Obispo  IF destination = 18          material2
res(trucknumber+truck_res) then free          move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=18

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

IF destination = 19          move with          material2 Irvine
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=19

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

Monterey          IF destination = 20          material2
res(trucknumber+truck_res) then free          move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

```

```

truck_location[trucknumber]=20

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

material1 Irvine          if (task=1) then
                           {
                               wait load_time
                               delivery_task = 1
                               next_loc = pickup

                               route 1
                           }
                           else
                           {
                               if (delivery_task = 1) then
                               {
                                   truck_capacity[trucknumber]=truck_capacity[trucknumber]+trailernu
                                   mber
                                   get res(trucknumber+truck_res)
                                   free res(trucknumber+truck_res)
                                   truck_location[trucknumber] =
                                   pickup
                                   next_loc = destination
                                   delivery_task = 2
                                   route 1
                               }
                               else
                               {
                                   get res(trucknumber+truck_res)
                                   route 2
                               }
                           }
                           }

Waiting_delivery FIRST 1          1    material1
                                   task=2

flag2 = 1

num_waiting2 = contents(Waiting_delivery)+1

min_rule2 = 9999999

counter2 = 0

tie2 = 0

```

```

//display "Waiting-delivery: arrival time="$arrival_hour$
task="$task$" pickup="$pickup$" destination="$destination$"
rule_att="$rule_att$" weight="$weight$"
trailer_number="$trailernumber$" clock="$clock()"
2 material2 Redding
IF destination = 1, 1 move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=1

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 2 move with material2 Chico
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=2

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Sacramento IF destination = 3 material2
res(trucknumber+truck_res) then free move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=3

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

```

```

counter2 = 0

tie2 = 0

Palm_Springs      IF destination = 4          material2
res(trucknumber+truck_res) then free          move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=4

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Stockton          IF destination = 5          material2
res(trucknumber+truck_res) then free          move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=5

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Santa_Rosa        IF destination = 6          material2
res(trucknumber+truck_res) then free          move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=6

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

```

```

counter2 = 0

tie2 = 0

San_Fransisco      IF destination = 7                material2
res(trucknumber+truck_res) then free                move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=7

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 8                move with                material2 Oakland
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=8

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Jose           IF destination = 9                material2
res(trucknumber+truck_res) then free                move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=9

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

```



```

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 10                                material2 Fresno
res(trucknumber+truck_res) then free               move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=10

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Bakersfield      IF destination = 11                material2
res(trucknumber+truck_res) then free                 move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=11

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Los_Angeles      IF destination = 12                material2
res(trucknumber+truck_res) then free                 move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=12

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

```

```

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Long_Beach      IF destination = 13      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=13

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 14      material2 Barstow
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=14

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Bernardino  IF destination = 15      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=15

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

```

```

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Diego      IF destination = 16      material2
res(trucknumber+truck_res) then free    move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=16

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Santa_Barbara  IF destination = 17      material2
res(trucknumber+truck_res) then free    move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=17

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Luis_Obispo  IF destination = 18      material2
res(trucknumber+truck_res) then free    move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=18

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

```

```

min_rule2 = 9999999

counter2 = 0

tie2 = 0

IF destination = 19                                material2 Irvine
res(trucknumber+truck_res) then free               move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=19

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Monterey      IF destination = 20                    material2
res(trucknumber+truck_res) then free                move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=20

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

material1 Monterey      if (task=1) then
                        {
                            wait load_time
                            delivery_task = 1
                            next_loc = pickup

                            route 1
                        }
                        else
                        {
                            if (delivery_task = 1) then

```

```

        {
            truck_capacity[trucknumber]=truck_capacity[trucknumber]+trailernu
mber
                get res(trucknumber+truck_res)
                free res(trucknumber+truck_res)
                truck_location[trucknumber] =
pickup
                    next_loc = destination
                    delivery_task = 2
                    route 1
                }
                else
                {
                    get res(trucknumber+truck_res)
                    route 2
                }
            }
        }
1      material1
Waiting_delivery FIRST 1      task=2

flag2 = 1

num_waiting2 = contents(Waiting_delivery)+1

min_rule2 = 9999999

counter2 = 0

tie2 = 0

//display "Waiting-delivery: arrival time="$arrival_hour$"
task="$task$" pickup="$pickup$" destination="$destination$"
rule_att="$rule_att$" weight="$weight$"
trailer_number="$trailernumber$" clock="$clock()"
2      material2 Redding
IF destination = 1, 1      move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=1

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

```

```

material2 Chico
IF destination = 2          move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=2

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

Sacramento      IF destination = 3          material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=3

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

Palm_Springs   IF destination = 4          material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=4

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

```

```

Stockton          IF destination = 5          material2
res(trucknumber+truck_res) then free         move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=5

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Santa_Rosa       IF destination = 6          material2
res(trucknumber+truck_res) then free         move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=6

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

San_Fransisco    IF destination = 7          material2
res(trucknumber+truck_res) then free         move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=7

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

```

```

material2 Oakland
IF destination = 8                move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=8

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

San_Jose        IF destination = 9                material2
res(trucknumber+truck_res) then free              move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=9

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

material2 Fresno
IF destination = 10                move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=10

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

```



```

Bakersfield      IF destination = 11      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=11

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Los_Angeles      IF destination = 12      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=12

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

Long_Beach       IF destination = 13      material2
res(trucknumber+truck_res) then free      move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=13

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

```

```

material2 Barstow
IF destination = 14          move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=14

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

San_Bernardino  IF destination = 15          material2
res(trucknumber+truck_res) then free        move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=15

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

San_Diego      IF destination = 16          material2
res(trucknumber+truck_res) then free        move with

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber
truck_location[trucknumber]=16

flag2 = 1
num_waiting2 = contents(Waiting_delivery)
min_rule2 = 9999999
counter2 = 0
tie2 = 0

```

```

material2
Santa_Barbara    IF destination = 17    move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=17

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

material2
San_Luis_Obispo IF destination = 18    move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=18

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

material2 Irvine
IF destination = 19    move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=19

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

```

```

material2
Monterey      IF destination = 20      move with
res(trucknumber+truck_res) then free

truck_capacity[trucknumber]=truck_capacity[trucknumber]-trailernumber

truck_location[trucknumber]=20

flag2 = 1

num_waiting2 = contents(Waiting_delivery)

min_rule2 = 9999999

counter2 = 0

tie2 = 0

material1 delivery_queue
      if (delivery_task=1) then route 1
      else route 2      1      material1 Redding
IF pickup = 1, 1      material1 Chico
IF pickup = 2      material1
Sacramento      IF pickup = 3      material1
Palm_Springs      IF pickup = 4      material1
Stockton      IF pickup = 5      material1
Santa_Rosa      IF pickup = 6      material1
San_Fransisco      IF pickup = 7      material1
IF pickup = 8      material1
San_Jose      IF pickup = 9      material1
IF pickup = 10      material1
Bakersfield      IF pickup = 11      material1
Los_Angeles      IF pickup = 12      material1
Long_Beach      IF pickup = 13      material1
IF pickup = 14      material1
San_Bernardino      IF pickup = 15      material1
San_Diego      IF pickup = 16      material1
Santa_Barbara      IF pickup = 17      material1
San_Luis_Obispo      IF pickup = 18      material1

```

```

IF pickup = 19
material1 Irvine
Monterey
IF pickup = 20
material1
2 material1 Redding
IF truck_location[trucknumber] = 1, 1
material1 Chico
IF truck_location[trucknumber] = 2
material1
Sacramento IF truck_location[trucknumber] = 3
material1
Palm_Springs IF truck_location[trucknumber] = 4
material1
Stockton IF truck_location[trucknumber] = 5
material1
Santa_Rosa IF truck_location[trucknumber] = 6
material1
San_Fransisco IF truck_location[trucknumber] = 7
material1 Oakland
IF truck_location[trucknumber] = 8
material1
San_Jose IF truck_location[trucknumber] = 9
material1 Fresno
IF truck_location[trucknumber] = 10
material1
Bakersfield IF truck_location[trucknumber] = 11
material1
Los_Angeles IF truck_location[trucknumber] = 12
material1
Long_Beach IF truck_location[trucknumber] = 13
material1 Barstow
IF truck_location[trucknumber] = 14
material1
San_Bernardino IF truck_location[trucknumber] = 15
material1
San_Diego IF truck_location[trucknumber] = 16
material1
Santa_Barbara IF truck_location[trucknumber] = 17
material1
San_Luis_Obispo IF truck_location[trucknumber] = 18
material1 Irvine
IF truck_location[trucknumber] = 19
material1
Monterey IF truck_location[trucknumber] = 20
material2 Redding //display "delivery done: arrival
time="$arrival_hour$" task="$task$" pickup="$pickup$"
destination="$destination$" rule_att="$rule_att$" weight="$weight$"
trailer_number="$trailer_number$" clock="$clock()"
wait unload_time
Lateness = clock() - due_date
Total_square_lateness =
Total_square_lateness+Lateness*Lateness
Total_lateness = Total_lateness + Lateness
if (Lateness > 0) then Tardiness = Lateness
else Tardiness = 0

```

```

if tardiness > 0 then inc num_tardy
Total_tardiness = Total_tardiness +
Tardiness
inc NUM
Avg_Lateness = Total_lateness/NUM
if( NUM>1) then Var_Lateness = (
Total_square_lateness - Total_lateness*Total_lateness/NUM)/(NUM-1)
Avg_Tardiness = Total_tardiness/NUM

1* material3 hub1
IF hub_delivery = 1, 1 move with truck_hub1 then free

free trailernumber trailer

flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999
counter1 = 0
tiel = 0

material3 hub2
IF hub_delivery = 2 move with truck_hub2 then free

free trailernumber trailer

flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999
counter1 = 0
tiel = 0

material3 hub3
IF hub_delivery = 3 move with truck_hub3 then free

free trailernumber trailer

flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999
counter1 = 0

```

```

tiel = 0

                                                                 2    material2 EXIT

FIRST 1
  material2 Chico          //display "delivery done: arrival
time="$arrival_hour$" task="$task$" pickup="$pickup$"
destination="$destination$" rule_att="$rule_att$" weight="$weight$"
trailer_number="$trailernumber$" clock="$clock()"

                                wait unload_time

                                Lateness = clock() - due_date
                                Total_square_lateness =
Total_square_lateness+Lateness*Lateness
                                Total_lateness = Total_lateness + Lateness
                                if (Lateness > 0) then Tardiness = Lateness
                                else Tardiness = 0
                                if tardiness > 0 then inc num_tardy
                                Total_tardiness = Total_tardiness +
Tardiness

                                inc NUM
                                Avg_Lateness = Total_lateness/NUM
                                if( NUM>1) then Var_Lateness = (
Total_square_lateness - Total_lateness*Total_lateness/NUM)/(NUM-1)
                                Avg_Tardiness = Total_tardiness/NUM

                                                                 1*    material3 hub1
IF hub_delivery = 1, 1          move with truck_hub1 then free

free trailernumber trailer

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

                                                                 material3 hub2
IF hub_delivery = 2          move with truck_hub2 then free

free trailernumber trailer

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

```

```

counter1 = 0

tiel = 0

material3 hub3
IF hub_delivery = 3      move with truck_hub3 then free

free trailernumber trailer

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

2      material2 EXIT

FIRST 1
  material2 Sacramento      //display "delivery done: arrival
  time="$arrival_hour$" task="$task$" pickup="$pickup$"
  destination="$destination$" rule_att="$rule_att$" weight="$weight$"
  trailer_number="$trailernumber$" clock="$clock()"

  wait unload_time

  Lateness = clock() - due_date
  Total_square_lateness =
Total_square_lateness+Lateness*Lateness
  Total_lateness = Total_lateness + Lateness
  if (Lateness > 0) then Tardiness = Lateness
  else Tardiness = 0
  if tardiness > 0 then inc num_tardy
  Total_tardiness = Total_tardiness +

Tardiness

  inc NUM
  Avg_Lateness = Total_lateness/NUM
  if( NUM>1) then Var_Lateness = (
Total_square_lateness - Total_lateness*Total_lateness/NUM)/(NUM-1)
  Avg_Tardiness = Total_tardiness/NUM

1*      material3 hub1
IF hub_delivery = 1, 1      move with truck_hub1 then free

free trailernumber trailer

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

```



```

counter1 = 0

tiel = 0

IF hub_delivery = 2
    material3 hub2
    move with truck_hub2 then free

free trailernumber trailer

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

IF hub_delivery = 3
    material3 hub3
    move with truck_hub3 then free

free trailernumber trailer

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

2 material2 EXIT

FIRST 1
    material2 Palm_Springs //display "delivery done: arrival
time="$arrival_hour$" task="$task$" pickup="$pickup$"
destination="$destination$" rule_att="$rule_att$" weight="$weight$"
trailer_number="$trailernumber$" clock="$clock()"

    wait unload_time

    Lateness = clock() - due_date
    Total_square_lateness =
Total_square_lateness+Lateness*Lateness
    Total_lateness = Total_lateness + Lateness
    if (Lateness > 0) then Tardiness = Lateness
    else Tardiness = 0
    if tardiness > 0 then inc num_tardy
    Total_tardiness = Total_tardiness +
Tardiness

    inc NUM
    Avg_Lateness = Total_lateness/NUM

```

```

                                if( NUM>1) then Var_Lateness = (
Total_square_lateness - Total_lateness*Total_lateness/NUM)/(NUM-1)
                                Avg_Tardiness = Total_tardiness/NUM

                                1*  material3 hub1
IF hub_delivery = 1, 1          move with truck_hub1 then free

free trailernumber trailer

flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999
counter1 = 0
tiel = 0

                                material3 hub2
IF hub_delivery = 2          move with truck_hub2 then free

free trailernumber trailer

flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999
counter1 = 0
tiel = 0

                                material3 hub3
IF hub_delivery = 3          move with truck_hub3 then free

free trailernumber trailer

flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999
counter1 = 0
tiel = 0

                                2  material2 EXIT
FIRST 1

```

```

material2 Stockton //display "delivery done: arrival
time="$arrival_hour$" task="$task$" pickup="$pickup$"
destination="$destination$" rule_att="$rule_att$" weight="$weight$"
trailer_number="$trailer_number$" clock="$clock()"

wait unload_time

Lateness = clock() - due_date
Total_square_lateness =
Total_square_lateness+Lateness*Lateness
Total_lateness = Total_lateness + Lateness
if (Lateness > 0) then Tardiness = Lateness
else Tardiness = 0
if tardiness > 0 then inc num_tardy
Total_tardiness = Total_tardiness +
Tardiness

inc NUM
Avg_Lateness = Total_lateness/NUM
if( NUM>1) then Var_Lateness = (
Total_square_lateness - Total_lateness*Total_lateness/NUM)/(NUM-1)
Avg_Tardiness = Total_tardiness/NUM

1* material3 hub1
IF hub_delivery = 1, 1 move with truck_hub1 then free

free trailernumber trailer

flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999
counter1 = 0
tiel = 0

material3 hub2
IF hub_delivery = 2 move with truck_hub2 then free

free trailernumber trailer

flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999
counter1 = 0
tiel = 0

material3 hub3
IF hub_delivery = 3 move with truck_hub3 then free

```

```

free trailernumber trailer

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

                                                                 2   material2 EXIT

FIRST 1
  material2 Santa_Rosa      //display "delivery done: arrival
time="$arrival_hour$" task="$task$" pickup="$pickup$"
destination="$destination$" rule_att="$rule_att$" weight="$weight$"
trailer_number="$trailernumber$" clock="$clock()"

                                wait unload_time

                                Lateness = clock() - due_date
                                Total_square_lateness =
Total_square_lateness+Lateness*Lateness
                                Total_lateness = Total_lateness + Lateness
                                if (Lateness > 0) then Tardiness = Lateness
                                else Tardiness = 0
                                if tardiness > 0 then inc num_tardy
                                Total_tardiness = Total_tardiness +
Tardiness

                                inc NUM
                                Avg_Lateness = Total_lateness/NUM
                                if( NUM>1) then Var_Lateness = (
Total_square_lateness - Total_lateness*Total_lateness/NUM)/(NUM-1)
                                Avg_Tardiness = Total_tardiness/NUM

                                                                 1*   material3 hub1
IF hub_delivery = 1, 1      move with truck_hub1 then free

free trailernumber trailer

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

```

```

material3 hub2
IF hub_delivery = 2          move with truck_hub2 then free

free trailernumber trailer

flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999
counter1 = 0
tiel = 0

material3 hub3
IF hub_delivery = 3          move with truck_hub3 then free

free trailernumber trailer

flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999
counter1 = 0
tiel = 0

2 material2 EXIT
FIRST 1
material2 San_Fransisco //display "delivery done: arrival
time="$arrival_hour$" task="$task$" pickup="$pickup$"
destination="$destination$" rule_att="$rule_att$" weight="$weight$"
trailer_number="$trailernumber$" clock="$clock()"

wait unload_time

Lateness = clock() - due_date
Total_square_lateness =
Total_square_lateness+Lateness*Lateness
Total_lateness = Total_lateness + Lateness
if (Lateness > 0) then Tardiness = Lateness
else Tardiness = 0
if tardiness > 0 then inc num_tardy
Total_tardiness = Total_tardiness +

Tardiness

inc NUM
Avg_Lateness = Total_lateness/NUM
if( NUM>1) then Var_Lateness = (
Total_square_lateness - Total_lateness*Total_lateness/NUM)/(NUM-1)
Avg_Tardiness = Total_tardiness/NUM

```

```

1* material3 hub1
IF hub_delivery = 1, 1      move with truck_hub1 then free

free trailernumber trailer

flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999
counter1 = 0
tiel = 0

material3 hub2
IF hub_delivery = 2      move with truck_hub2 then free

free trailernumber trailer

flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999
counter1 = 0
tiel = 0

material3 hub3
IF hub_delivery = 3      move with truck_hub3 then free

free trailernumber trailer

flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999
counter1 = 0
tiel = 0

2 material2 EXIT
FIRST 1
material2 Oakland      //display "delivery done: arrival
time="$arrival_hour$" task="$task$" pickup="$pickup$"
destination="$destination$" rule_att="$rule_att$" weight="$weight$"
trailer_number="$trailernumber$" clock="$clock()"

wait unload_time

```

```

                                Lateness = clock() - due_date
                                Total_square_lateness =
Total_square_lateness+Lateness*Lateness
                                Total_lateness = Total_lateness + Lateness
                                if (Lateness > 0) then Tardiness = Lateness
                                else Tardiness = 0
                                if tardiness > 0 then inc num_tardy
                                Total_tardiness = Total_tardiness +
Tardiness
                                inc NUM
                                Avg_Lateness = Total_lateness/NUM
                                if( NUM>1) then Var_Lateness = (
Total_square_lateness - Total_lateness*Total_lateness/NUM)/(NUM-1)
                                Avg_Tardiness = Total_tardiness/NUM

```

```

                                1* material3 hub1
IF hub_delivery = 1, 1          move with truck_hub1 then free
free trailernumber trailer

```

```

flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999
counter1 = 0
tiel = 0

```

```

                                material3 hub2
IF hub_delivery = 2          move with truck_hub2 then free
free trailernumber trailer

```

```

flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999
counter1 = 0
tiel = 0

```

```

                                material3 hub3
IF hub_delivery = 3          move with truck_hub3 then free
free trailernumber trailer

```

```

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

                                                                 2   material2 EXIT

FIRST 1
  material2 San_Jose           //display "delivery done: arrival
time="$arrival_hour$" task="$task$" pickup="$pickup$"
destination="$destination$" rule_att="$rule_att$" weight="$weight$"
trailer_number="$trailernumber$" clock="$clock()"

                                wait unload_time

                                Lateness = clock() - due_date
                                Total_square_lateness =
Total_square_lateness+Lateness*Lateness
                                Total_lateness = Total_lateness + Lateness
                                if (Lateness > 0) then Tardiness = Lateness
                                else Tardiness = 0
                                if tardiness > 0 then inc num_tardy
                                Total_tardiness = Total_tardiness +
Tardiness

                                inc NUM
                                Avg_Lateness = Total_lateness/NUM
                                if( NUM>1) then Var_Lateness = (
Total_square_lateness - Total_lateness*Total_lateness/NUM)/(NUM-1)
                                Avg_Tardiness = Total_tardiness/NUM

                                                                 1*   material3 hub1
IF hub_delivery = 1, 1           move with truck_hub1 then free

free trailernumber trailer

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

                                                                 material3 hub2
IF hub_delivery = 2           move with truck_hub2 then free

free trailernumber trailer

```



```

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

IF hub_delivery = 3
                                material3 hub3
                                move with truck_hub3 then free

free trailernumber trailer

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

                                2   material2 EXIT
FIRST 1
  material2 Fresno              //display "delivery done: arrival
time="$arrival_hour$" task="$task$" pickup="$pickup$"
destination="$destination$" rule_att="$rule_att$" weight="$weight$"
trailer_number="$trailernumber$" clock="$clock()"

                                wait unload_time

                                Lateness = clock() - due_date
                                Total_square_lateness =
Total_square_lateness+Lateness*Lateness
                                Total_lateness = Total_lateness + Lateness
                                if (Lateness > 0) then Tardiness = Lateness
                                else Tardiness = 0
                                if tardiness > 0 then inc num_tardy
                                Total_tardiness = Total_tardiness +
Tardiness

                                inc NUM
                                Avg_Lateness = Total_lateness/NUM
                                if( NUM>1) then Var_Lateness = (
Total_square_lateness - Total_lateness*Total_lateness/NUM)/(NUM-1)
                                Avg_Tardiness = Total_tardiness/NUM

                                1*   material3 hub1
IF hub_delivery = 1, 1
                                move with truck_hub1 then free

free trailernumber trailer

```

```

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

IF hub_delivery = 2
                                material3 hub2
                                move with truck_hub2 then free

free trailernumber trailer

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

IF hub_delivery = 3
                                material3 hub3
                                move with truck_hub3 then free

free trailernumber trailer

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

FIRST 1
                                2    material2 EXIT
material2 Bakersfield //display "delivery done: arrival
time="$arrival_hour$" task="$task$" pickup="$pickup$"
destination="$destination$" rule_att="$rule_att$" weight="$weight$"
trailer_number="$trailernumber$" clock="$clock()"

                                wait unload_time

                                Lateness = clock() - due_date
                                Total_square_lateness =
Total_square_lateness+Lateness*Lateness
                                Total_lateness = Total_lateness + Lateness
                                if (Lateness > 0) then Tardiness = Lateness

```

```

else Tardiness = 0
if tardiness > 0 then inc num_tardy
Total_tardiness = Total_tardiness +
Tardiness
inc NUM
Avg_Lateness = Total_lateness/NUM
if( NUM>1) then Var_Lateness = (
Total_square_lateness - Total_lateness*Total_lateness/NUM)/(NUM-1)
Avg_Tardiness = Total_tardiness/NUM

1* material3 hub1
IF hub_delivery = 1, 1 move with truck_hub1 then free
free trailernumber trailer

flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999
counter1 = 0
tiel = 0

material3 hub2
IF hub_delivery = 2 move with truck_hub2 then free
free trailernumber trailer

flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999
counter1 = 0
tiel = 0

material3 hub3
IF hub_delivery = 3 move with truck_hub3 then free
free trailernumber trailer

flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999
counter1 = 0

```

```

tiel = 0

                                                                 2    material2 EXIT

FIRST 1
  material2 Los_Angeles      //display "delivery done: arrival
time="$arrival_hour$" task="$task$" pickup="$pickup$"
destination="$destination$" rule_att="$rule_att$" weight="$weight$"
trailer_number="$trailernumber$" clock="$clock()"

                                wait unload_time

                                Lateness = clock() - due_date
                                Total_square_lateness =
Total_square_lateness+Lateness*Lateness
                                Total_lateness = Total_lateness + Lateness
                                if (Lateness > 0) then Tardiness = Lateness
                                else Tardiness = 0
                                if tardiness > 0 then inc num_tardy
                                Total_tardiness = Total_tardiness +
Tardiness

                                inc NUM
                                Avg_Lateness = Total_lateness/NUM
                                if( NUM>1) then Var_Lateness = (
Total_square_lateness - Total_lateness*Total_lateness/NUM)/(NUM-1)
                                Avg_Tardiness = Total_tardiness/NUM

                                                                 1*    material3 hub1
IF hub_delivery = 1, 1          move with truck_hub1 then free

free trailernumber trailer

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

                                                                 material3 hub2
IF hub_delivery = 2          move with truck_hub2 then free

free trailernumber trailer

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

```

```

tiel = 0

IF hub_delivery = 3
    material3 hub3
    move with truck_hub3 then free

free trailernumber trailer

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

FIRST 1
    material2 Long_Beach //display "delivery done: arrival
    time="$arrival_hour$" task="$task$" pickup="$pickup$"
    destination="$destination$" rule_att="$rule_att$" weight="$weight$"
    trailer_number="$trailernumber$" clock="$clock()"

    wait unload_time

    Lateness = clock() - due_date
    Total_square_lateness =
Total_square_lateness+Lateness*Lateness
    Total_lateness = Total_lateness + Lateness
    if (Lateness > 0) then Tardiness = Lateness
    else Tardiness = 0
    if tardiness > 0 then inc num_tardy
    Total_tardiness = Total_tardiness +
Tardiness

    inc NUM
    Avg_Lateness = Total_lateness/NUM
    if( NUM>1) then Var_Lateness = (
Total_square_lateness - Total_lateness*Total_lateness/NUM)/(NUM-1)
    Avg_Tardiness = Total_tardiness/NUM

IF hub_delivery = 1, 1
    1* material3 hub1
    move with truck_hub1 then free

free trailernumber trailer

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

```

```

counter1 = 0

tiel = 0

IF hub_delivery = 2
    material3 hub2
    move with truck_hub2 then free

free trailernumber trailer

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

IF hub_delivery = 3
    material3 hub3
    move with truck_hub3 then free

free trailernumber trailer

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

2 material2 EXIT

FIRST 1
    material2 Barstow //display "delivery done: arrival
time="$arrival_hour$" task="$task$" pickup="$pickup$"
destination="$destination$" rule_att="$rule_att$" weight="$weight$"
trailer_number="$trailernumber$" clock="$clock()"

    wait unload_time

    Lateness = clock() - due_date
    Total_square_lateness =
Total_square_lateness+Lateness*Lateness
    Total_lateness = Total_lateness + Lateness
    if (Lateness > 0) then Tardiness = Lateness
    else Tardiness = 0
    if tardiness > 0 then inc num_tardy
    Total_tardiness = Total_tardiness +

Tardiness

    inc NUM
    Avg_Lateness = Total_lateness/NUM

```

```

                                if( NUM>1) then Var_Lateness = (
Total_square_lateness - Total_lateness*Total_lateness/NUM)/(NUM-1)
                                Avg_Tardiness = Total_tardiness/NUM

                                1* material3 hub1
IF hub_delivery = 1, 1          move with truck_hub1 then free

free trailernumber trailer

flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999
counter1 = 0
tiel = 0

                                material3 hub2
IF hub_delivery = 2          move with truck_hub2 then free

free trailernumber trailer

flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999
counter1 = 0
tiel = 0

                                material3 hub3
IF hub_delivery = 3          move with truck_hub3 then free

free trailernumber trailer

flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999
counter1 = 0
tiel = 0

                                2 material2 EXIT
FIRST 1

```

```

material2 San_Bernardino //display "delivery done: arrival
time="$arrival_hour$" task="$task$" pickup="$pickup$"
destination="$destination$" rule_att="$rule_att$" weight="$weight$"
trailer_number="$trailer_number$" clock="$clock()"

wait unload_time

Lateness = clock() - due_date
Total_square_lateness =
Total_square_lateness+Lateness*Lateness
Total_lateness = Total_lateness + Lateness
if (Lateness > 0) then Tardiness = Lateness
else Tardiness = 0
if tardiness > 0 then inc num_tardy
Total_tardiness = Total_tardiness +
Tardiness

inc NUM
Avg_Lateness = Total_lateness/NUM
if( NUM>1) then Var_Lateness = (
Total_square_lateness - Total_lateness*Total_lateness/NUM)/(NUM-1)
Avg_Tardiness = Total_tardiness/NUM

1* material3 hub1
IF hub_delivery = 1, 1 move with truck_hub1 then free

free trailer_number trailer

flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999
counter1 = 0
tie1 = 0

material3 hub2
IF hub_delivery = 2 move with truck_hub2 then free

free trailer_number trailer

flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999
counter1 = 0
tie1 = 0

```



```

material3 hub3
IF hub_delivery = 3          move with truck_hub3 then free

free trailernumber trailer

flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999
counter1 = 0
tiel = 0

2 material2 EXIT
FIRST 1
  material2 San_Diego //display "delivery done: arrival
time="$arrival_hour$" task="$task$" pickup="$pickup$"
destination="$destination$" rule_att="$rule_att$" weight="$weight$"
trailer_number="$trailernumber$" clock="$clock()"

      wait unload_time

      Lateness = clock() - due_date
      Total_square_lateness =
Total_square_lateness+Lateness*Lateness
      Total_lateness = Total_lateness + Lateness
      if (Lateness > 0) then Tardiness = Lateness
      else Tardiness = 0
      if tardiness > 0 then inc num_tardy
      Total_tardiness = Total_tardiness +
Tardiness

      inc NUM
      Avg_Lateness = Total_lateness/NUM
      if( NUM>1) then Var_Lateness = (
Total_square_lateness - Total_lateness*Total_lateness/NUM)/(NUM-1)
      Avg_Tardiness = Total_tardiness/NUM

1* material3 hub1
IF hub_delivery = 1, 1      move with truck_hub1 then free

free trailernumber trailer

flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999
counter1 = 0
tiel = 0

```

```

                                material3 hub2
IF hub_delivery = 2                move with truck_hub2 then free

free trailernumber trailer

flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999
counter1 = 0
tiel = 0

                                material3 hub3
IF hub_delivery = 3                move with truck_hub3 then free

free trailernumber trailer

flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999
counter1 = 0
tiel = 0

                                2    material2 EXIT
FIRST 1
  material2 Santa_Barbara //display "delivery done: arrival
time="$arrival_hour$" task="$task$" pickup="$pickup$"
destination="$destination$" rule_att="$rule_att$" weight="$weight$"
trailer_number="$trailernumber$" clock="$clock()"

                                wait unload_time

                                Lateness = clock() - due_date
                                Total_square_lateness =
Total_square_lateness+Lateness*Lateness
                                Total_lateness = Total_lateness + Lateness
                                if (Lateness > 0) then Tardiness = Lateness
                                else Tardiness = 0
                                if tardiness > 0 then inc num_tardy
                                Total_tardiness = Total_tardiness +
Tardiness

                                inc NUM
                                Avg_Lateness = Total_lateness/NUM
                                if( NUM>1) then Var_Lateness = (
Total_square_lateness - Total_lateness*Total_lateness/NUM)/(NUM-1)
                                Avg_Tardiness = Total_tardiness/NUM

```

```

1* material3 hub1
IF hub_delivery = 1, 1      move with truck_hub1 then free

free trailernumber trailer

flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999
counter1 = 0
tiel = 0

material3 hub2
IF hub_delivery = 2      move with truck_hub2 then free

free trailernumber trailer

flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999
counter1 = 0
tiel = 0

material3 hub3
IF hub_delivery = 3      move with truck_hub3 then free

free trailernumber trailer

flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999
counter1 = 0
tiel = 0

2 material2 EXIT
FIRST 1
material2 San_Luis_Obispo //display "delivery done: arrival
time="$arrival_hour$" task="$task$" pickup="$pickup$"
destination="$destination$" rule_att="$rule_att$" weight="$weight$"
trailer_number="$trailernumber$" clock="$clock()"

```

```

wait unload_time

Lateness = clock() - due_date
Total_square_lateness =
Total_square_lateness+Lateness*Lateness
Total_lateness = Total_lateness + Lateness
if (Lateness > 0) then Tardiness = Lateness
else Tardiness = 0
if tardiness > 0 then inc num_tardy
Total_tardiness = Total_tardiness +

Tardiness

inc NUM
Avg_Lateness = Total_lateness/NUM
if( NUM>1) then Var_Lateness = (
Total_square_lateness - Total_lateness*Total_lateness/NUM)/(NUM-1)
Avg_Tardiness = Total_tardiness/NUM

1* material3 hub1
IF hub_delivery = 1, 1 move with truck_hub1 then free

free trailernumber trailer

flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999
counter1 = 0
tiel = 0

material3 hub2
IF hub_delivery = 2 move with truck_hub2 then free

free trailernumber trailer

flag1 = 1
num_waiting1 = contents(Waiting_pickup)
min_rule1 = 9999999
counter1 = 0
tiel = 0

material3 hub3
IF hub_delivery = 3 move with truck_hub3 then free

free trailernumber trailer

```

```

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

                                                                 2   material2 EXIT

FIRST 1
  material2 Irvine           //display "delivery done: arrival
time="$arrival_hour$" task="$task$" pickup="$pickup$"
destination="$destination$" rule_att="$rule_att$" weight="$weight$"
trailer_number="$trailernumber$" clock="$clock()"

                                wait unload_time

                                Lateness = clock() - due_date
                                Total_square_lateness =
Total_square_lateness+Lateness*Lateness
                                Total_lateness = Total_lateness + Lateness
                                if (Lateness > 0) then Tardiness = Lateness
                                else Tardiness = 0
                                if tardiness > 0 then inc num_tardy
                                Total_tardiness = Total_tardiness +
Tardiness

                                inc NUM
                                Avg_Lateness = Total_lateness/NUM
                                if( NUM>1) then Var_Lateness = (
Total_square_lateness - Total_lateness*Total_lateness/NUM)/(NUM-1)
                                Avg_Tardiness = Total_tardiness/NUM

                                                                 1*   material3 hub1
IF hub_delivery = 1, 1           move with truck_hub1 then free

free trailernumber trailer

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

                                                                 material3 hub2
IF hub_delivery = 2           move with truck_hub2 then free

free trailernumber trailer

```

```

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

IF hub_delivery = 3
                                material3 hub3
                                move with truck_hub3 then free

free trailernumber trailer

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

                                2   material2 EXIT
FIRST 1
  material2 Monterey           //display "delivery done: arrival
time="$arrival_hour$" task="$task$" pickup="$pickup$"
destination="$destination$" rule_att="$rule_att$" weight="$weight$"
trailer_number="$trailernumber$" clock="$clock()"

                                wait unload_time

                                Lateness = clock() - due_date
                                Total_square_lateness =
Total_square_lateness+Lateness*Lateness
                                Total_lateness = Total_lateness + Lateness
                                if (Lateness > 0) then Tardiness = Lateness
                                else Tardiness = 0
                                if tardiness > 0 then inc num_tardy
                                Total_tardiness = Total_tardiness +
Tardiness

                                inc NUM
                                Avg_Lateness = Total_lateness/NUM
                                if( NUM>1) then Var_Lateness = (
Total_square_lateness - Total_lateness*Total_lateness/NUM)/(NUM-1)
                                Avg_Tardiness = Total_tardiness/NUM

                                1*   material3 hub1
IF hub_delivery = 1, 1
                                move with truck_hub1 then free

free trailernumber trailer

```

```

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

IF hub_delivery = 2                                material3 hub2
                                                    move with truck_hub2 then free

free trailernumber trailer

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

IF hub_delivery = 3                                material3 hub3
                                                    move with truck_hub3 then free

free trailernumber trailer

flag1 = 1

num_waiting1 = contents(Waiting_pickup)

min_rule1 = 9999999

counter1 = 0

tiel = 0

FIRST 1                                           2    material2 EXIT
  material3 hub1                                   1    material3 EXIT
FIRST 1                                           //display "Exit: arrival
time="$arrival_hour$" task="$task$" pickup="$pickup$"
destination="$destination$" rule_att="$rule_att$" weight="$weight$"
trailer_number="$trailernumber$" clock="$clock()"
  material3 hub2                                   1    material3 EXIT
FIRST 1
  material3 hub3                                   1    material3 EXIT
FIRST 1

```

```

*****
*****
*
*
*
*****
*****

```

Arrivals

```

Entity      Location Qty each  First Time Occurrences Frequency  Logic
-----
material1 dummy    1          0          inf          E(2)
pickup = pickup_dist()

```

L1:

```

destination= destination_dist()
(pickup=destination) then goto L1

```

if

```

weight = N(25000,5000)
load_time=U(6,2)
unload_time=U(6,2)
arrival_hour = clock()
due_date = due_date_dist()
due_date = clock() + (due_date * 8)

trailernumber = ROUND(weight/17000+0.5)

```

```

task=1

hub_pickup = select_hub_pickup()
hub_delivery = select_hub_delivery()

rule = 1 then
    if (hub_pickup = 1) then rule_att=distance[hub1_loc,pickup]
    else if (hub_pickup = 2) then rule_att=distance[hub2_loc,pickup]
else rule_att=distance[hub3_loc,pickup]

rule = 2 then

```

if
{
}
if


```

        rule_att = due_date
                                                    if
rule = 3 then
        rule_att = arrival_hour - clock()
                                                    if
rule = 4 then
                                                    {

        if (hub_pickup = 1) then rule_att=(due_date-clock())-
distance[hub1_loc,pickup]/65-load_time-unload_time

        else if (hub_pickup = 2) then rule_att=(due_date-clock())-
distance[hub2_loc,pickup]/65-load_time-unload_time

        else rule_att=(due_date-clock())-distance[hub3_loc,pickup]/65-
load_time-unload_time
                                                    }

//display "Arrival: arrival time="$arrival_hour$" task="$task$"
pickup="$pickup$" destination="$destination$" rule_att="$rule_att$"
weight="$weight$" trailer_number="$trailer_number"

```

```

*****
*****
*
*
*
*****
*****

```

Attributes

```

ID           Type           Classification
-----
#
#Pickup location
pickup      Integer          Entity
#
#Delivery location
destination  Integer          Entity
weight      Real             Entity
trailer_number Integer        Entity
trucknumber Integer        Entity
load_time   Real             Entity
unload_time Real             Entity
arrival_hour Real          Entity
due_date    Real             Entity
#
#attribute changes depending on the rule
#rule = 1:  The distance between pickup/delivery location and
currentpoint
#rule = 2:  earliest due date
rule_att    Real             Entity
#
#pickup task when task=1
#delivery task when task=2

```

```

task          Integer      Entity
delivery_task Integer      Entity
next_loc      Integer      Entity
hub_pickup   Integer      Entity
hub_delivery  Integer      Entity

```

```

*****
*****
*
*                               Variables (global)
*
*****
*****

```

ID	Type	Initial value	Stats
rule	Integer	rule_ch	Time Series
sim_day	Integer	1	Time Series
workday_hrs	Integer	workday_hrs_ch	Time Series
number	Integer	0	Time Series
Lateness	Real	0	Time Series
Var_Lateness	Real	0	Time Series
Avg_Lateness	Real	0	Time Series
Avg_Tardiness	Real	0	Time Series
Tardiness	Real	0	Time Series
Total_lateness	Real	0	Time Series
Total_tardiness	Real	0	Time Series
Total_square_lateness	Real	0	Time Series
NUM	Integer	0	Time Series
num_tardy	Integer	0	Time Series
pcnt_tardy	Real	0	Time Series
flag1	Integer	0	Time Series
flag2	Integer	0	Time Series
min_rule1	Real	0	Time Series
min_rule2	Real	0	Time Series
num_waiting1	Integer	0	Time Series
num_waiting2	Integer	0	Time Series
counter1	Integer	0	Time Series
counter2	Integer	0	Time Series
hub_No	Integer	0	Time Series
tie1	Integer	0	Time Series
tie2	Integer	0	Time Series

```

*****
*****
*
*                               Arrays
*
*****
*****

```

ID	Dimensions	Type
distance	20,20	Real
truck_capacity	5	Real
truck_location	5	Integer

```

*****
*****
*
*                               Macros
*
*
*****
*****

```

ID	Text
rule_ch	1
workday_hrs_ch	8
fleet_size	2
truck_res	4
max_capacity	3
Total_hub	3
hub1_loc	10
hub2_loc	8
hub3_loc	12

```

*****
*****
*
*                               Subroutines
*
*
*****
*****

```

ID	Type	Parameter	Type	Logic
calendar sim_day <= 5 do	None			while {
wait workday_hrs				
inc sim_day				}
select_truck_delivery Integer				int i=1
nearest=999999.0				real
i<=fleet_size Do				number=0
				while
				Begin
				if
((truck_capacity[i]+trailernumber)<=max_capacity and FreeUnits(Res(i+truck_res))=1) then				{
(nearest>distance[truck_location[i],next_loc]) then				if
				{
nearest=distance[truck_location[i],next_loc]				}

```

number=i
}
}
inc i
End
if rule =
1 then
{if(number>0) then rule_att=nearest
rule_att=999999.0}
else
return
number

select_hub_pickup Integer real
nearest
hub_No = 0
if
(Total_hub = 1) then hub_No = 1
else if
(Total_hub = 2) then
{
if
(distance[pickup, hub2_loc]<=distance[pickup, hub3_loc]) then hub_No =
2
else hub_No = 3
}
else
{
if
(distance[pickup, hub1_loc]<=distance[pickup, hub2_loc]) then
{
nearest = distance[pickup, hub1_loc]
hub_No = 1
}
else
{
nearest = distance[pickup, hub2_loc]
hub_No = 2
}
}
if
(distance[pickup, hub3_loc]<=nearest) then
{
nearest = distance[pickup, hub3_loc]
hub_No = 3
}
}
}

```



```

*****
*****
*
*
*
*****
*****

```

External Files

ID Prompt	Type	File Name
(null)		C:\Documents and Settings\ydessouky\Application Data\Qualcomm\Eudora\attach\cities.xls

APPENDIX C

CONVENTIONAL MODEL (NO HUB) 95% CONFIDENCE INTERVALS

FLEET SIZE	TIME IN SYSTEM															
	DEMAND								DEMAND							
	E (2)								E (4)							
	SD		EOD		LTIS		SST		SD		EOD		LTIS		SST	
95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	
2 trucks	173.79	178.76	432.74	438.71	433.50	439.11	442.19	448.08	141.91	148.44	325.15	334.93	326.12	335.82	339.29	348.87
3 trucks	144.31	149.07	379.98	387.08	381.57	388.40	394.14	401.16	99.31	104.62	222.10	233.71	222.57	234.52	241.07	253.09
4 trucks	122.09	126.42	327.73	335.80	328.77	336.75	346.11	354.08	55.35	60.72	122.14	134.60	122.28	134.51	143.38	156.55
5 trucks	103.07	106.84	275.66	284.73	276.47	285.13	297.42	306.35	28.36	29.90	44.97	51.94	44.67	51.70	59.47	69.03
6 trucks	86.74	90.55	223.25	232.81	223.90	233.45	247.90	257.50	22.25	22.83	23.87	25.03	23.36	24.54	25.61	27.69
7 trucks	69.94	74.34	171.23	181.36	171.19	181.37	198.85	208.90	19.94	20.25	20.29	20.70	19.97	20.35	20.65	21.20
8 trucks	47.61	51.97	120.50	131.01	120.54	131.02	148.67	159.59	18.81	19.01	18.89	19.11	18.74	18.93	19.02	19.29
9 trucks	31.15	33.13	73.26	82.89	73.53	83.20	100.44	111.51	18.20	18.33	18.23	18.37	18.17	18.30	18.27	18.43
10 trucks	24.59	25.41	38.47	44.53	37.86	43.78	56.94	66.30	17.86	17.86	17.86	17.86	17.86	17.86	17.86	18.00
11 trucks	21.63	22.12	24.34	26.03	23.91	25.71	29.73	34.40	17.65	17.76	17.66	17.76	17.65	17.75	17.66	17.77
12 trucks	19.96	20.28	20.72	21.32	20.32	20.87	21.65	22.76	17.53	17.63	17.58	17.63	17.53	17.63	17.53	17.64
13 trucks	18.97	19.19	19.24	19.56	19.00	19.27	19.53	19.99	17.46	17.56	17.46	17.56	17.46	17.56	17.46	17.56

FLEET SIZE	TIME IN SYSTEM															
	DEMAND								DEMAND							
	E (6)								E (8)							
	SD		EOD		LTIS		SST		SD		EOD		LTIS		SST	
95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	
2 trucks	105.94	112.83	221.26	235.63	221.84	236.45	234.49	249.22	67.46	74.89	127.56	143.16	128.14	143.87	142.22	158.94
3 trucks	42.17	46.85	80.32	93.75	79.41	92.37	94.05	109.18	26.60	27.83	30.51	33.55	29.85	32.89	33.20	37.43
4 trucks	24.40	25.40	26.98	29.42	26.43	28.73	29.04	32.26	20.81	21.21	21.14	21.70	20.87	21.38	21.53	22.19
5 trucks	20.51	20.91	20.87	21.45	20.49	21.00	21.27	21.99	19.08	19.30	19.13	19.36	18.98	19.20	19.20	19.46
6 trucks	18.99	19.22	19.02	19.29	18.87	19.10	19.14	19.44	18.31	18.47	18.33	18.49	18.28	18.43	18.36	18.53
7 trucks	18.26	18.42	18.29	18.46	18.23	18.38	18.33	18.51	17.94	18.08	17.95	18.09	17.93	18.07	17.96	18.09
8 trucks	17.90	18.03	17.91	18.03	17.89	18.01	17.91	18.04	17.74	17.86	17.73	17.86	17.73	17.85	17.74	17.86
9 trucks	17.70	17.81	17.70	17.81	17.69	17.81	17.70	17.82	17.61	17.73	17.61	17.74	17.61	17.73	17.62	17.74
10 trucks	17.58	17.69	17.58	17.69	17.58	17.69	17.58	17.69	17.54	17.66	17.54	17.66	17.54	17.66	17.54	17.66
11 trucks	17.51	17.62	17.51	17.63	17.51	17.62	17.51	17.63	17.51	17.63	17.51	17.63	17.51	17.63	17.51	17.63
12 trucks	17.48	17.59	17.48	17.59	17.48	17.59	17.48	17.59	17.50	17.62	17.50	17.62	17.50	17.62	17.50	17.62
13 trucks	17.47	17.58	17.47	17.58	17.47	17.58	17.47	17.58	17.50	17.62	17.50	17.62	17.50	17.62	17.50	17.62

FLEET SIZE	AVERAGE LATENESS															
	DEMAND								DEMAND							
	E (2)								E (4)							
	SD		EOD		LTIS		SST		SD		EOD		LTIS		SST	
95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	
2 trucks	43.30	46.03	160.66	164.29	159.25	162.60	167.17	170.86	24.48	27.80	106.59	112.54	105.80	111.53	114.27	120.19
3 trucks	28.35	30.84	134.04	138.32	133.31	137.37	142.47	146.61	1.42	4.56	55.42	62.30	54.80	61.83	64.93	72.01
4 trucks	15.77	18.39	108.11	112.96	107.71	112.49	118.17	122.99	-21.47	-18.23	7.73	14.89	7.21	14.29	17.77	25.46
5 trucks	5.53	7.78	82.40	87.79	81.82	87.03	93.64	99.11	-37.09	-35.61	-27.64	-23.53	-28.35	-24.18	-21.05	-15.57
6 trucks	-4.10	-1.63	56.59	62.35	56.36	62.12	69.20	75.09	-42.14	-41.38	-40.75	-39.57	-41.40	-40.23	-39.47	-37.83
7 trucks	-14.22	-11.39	31.13	37.30	30.45	36.59	44.84	51.12	-44.18	-43.62	-43.85	-43.21	-44.19	-43.61	-43.53	-42.84
8 trucks	-26.03	-23.36	6.67	12.89	5.93	12.14	20.08	26.75	-45.20	-44.71	-45.10	-44.59	-45.27	-44.80	-44.99	-44.46
9 trucks	-35.41	-33.74	-15.81	-10.34	-18.31	-10.78	-3.49	3.06	-45.74	-45.28	-45.71	-45.24	-45.78	-45.33	-45.66	-45.18
10 trucks	-40.20	-39.24	-32.34	-28.75	-33.13	-29.58	-23.93	-18.60	-46.03	-45.59	-46.02	-45.58	-46.04	-45.61	-46.00	-45.56
11 trucks	-42.70	-42.04	-40.52	-39.02	-41.05	-39.51	-37.35	-34.35	-46.19	-45.75	-46.17	-45.74	-46.19	-45.76	-46.17	-45.73
12 trucks	-44.12	-43.63	-43.40	-42.65	-43.82	-43.12	-42.63	-41.50	-46.26	-45.83	-46.04	-45.83	-46.26	-45.84	-46.25	-45.82
13 trucks	-45.00	-44.58	-44.73	-44.21	-44.99	-44.54	-44.45	-43.82	-46.29	-45.86	-46.29	-45.86	-46.29	-45.87	-46.29	-45.86

FLEET SIZE	AVERAGE LATENESS															
	DEMAND								DEMAND							
	E (6)								E (8)							
	SD		EOD		LTIS		SST		SD		EOD		LTIS		SST	
95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	
2 trucks	4.61	8.66	55.78	64.10	55.17	63.53	62.67	71.29	-14.42	-9.81	12.17	21.11	11.42	20.50	19.31	28.98
3 trucks	-28.29	-25.18	-11.26	-3.81	-12.26	-5.09	-4.86	3.57	-38.65	-37.33	-35.90	-33.60	-36.52	-34.26	-34.05	-31.16
4 trucks	-40.31	-39.19	-38.49	-36.30	-39.11	-37.13	-37.12	-34.43	-43.44	-42.71	-43.12	-42.28	-43.38	-42.57	-42.80	-41.86
5 trucks	-43.60	-42.93	-43.28	-42.50	-43.65	-42.94	-42.94	-42.05	-44.97	-44.38	-44.92	-44.32	-45.05	-44.46	-44.86	-44.23
6 trucks	-44.93	-44.36	-44.86	-44.28	-45.03	-44.47	-44.75	-44.15	-45.65	-45.10	-45.63	-45.07	-45.68	-45.13	-45.60	-45.03
7 trucks	-45.56	-45.04	-45.52	-44.99	-45.59	-45.07	-45.48	-44.94	-45.97	-45.42	-45.96	-45.42	-45.97	-45.43	-45.95	-45.40
8 trucks	-45.86	-45.35	-45.86	-45.34	-45.88	-45.37	-45.84	-45.33	-46.13	-45.60	-46.13	-45.60	-46.13	-45.60	-46.12	-45.59
9 trucks	-46.02	-45.51	-46.02	-45.51	-46.03	-45.51	-46.01	-45.51	-46.21	-45.68	-46.20	-45.68	-46.21	-45.68	-46.20	-45.68
10 trucks	-46.09	-45.58	-46.09	-45.58	-46.09	-45.58	-46.09	-45.58	-46.25	-45.72	-46.25	-45.72	-46.25	-45.72	-46.25	-45.72
11 trucks	-46.12	-45.61	-46.12	-45.61	-46.12	-45.61	-46.12	-45.61	-46.26	-45.73	-46.26	-45.73	-46.26	-45.73	-46.26	-45.73
12 trucks	-46.13	-45.61	-46.13	-45.61	-46.13	-45.61	-46.12	-45.61	-46.25	-45.73	-46.25	-45.73	-46.25	-45.73	-46.25	-45.73
13 trucks	-46.13	-45.61	-46.13	-45.61	-46.13	-45.61	-46.12	-45.61	-46.25	-45.72	-46.25	-45.72	-46.25	-45.72	-46.25	-45.72

AVERAGE TARDINESS																
FLEET SIZE	DEMAND E (2)								DEMAND E (4)							
	SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High
2 trucks	56.39	58.85	165.13	168.54	165.27	168.54	171.26	174.75	40.22	43.12	113.17	118.70	113.51	118.84	120.44	125.94
3 trucks	43.52	45.64	139.41	143.47	139.97	143.90	147.41	151.34	22.13	24.49	64.79	71.04	65.19	71.55	73.60	80.07
4 trucks	33.14	35.27	114.48	119.04	115.14	119.71	123.99	128.56	6.90	8.80	23.28	28.70	23.71	29.04	31.63	37.79
5 trucks	25.19	26.96	90.01	95.03	90.45	95.34	100.55	105.69	0.44	0.84	1.21	2.75	1.65	3.16	4.20	6.81
6 trucks	18.34	20.15	65.88	71.09	66.49	71.72	77.42	82.85	0.02	0.05	0.00	0.02	0.00	0.04	-0.01	0.14
7 trucks	11.69	13.52	42.93	48.11	43.19	48.34	55.13	60.64	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
8 trucks	4.74	6.11	22.17	26.72	22.57	27.09	33.59	38.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9 trucks	0.96	1.47	6.22	9.18	6.91	9.86	15.16	19.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10 trucks	0.17	0.30	0.44	1.19	0.60	1.36	3.02	5.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11 trucks	0.03	0.06	0.00	0.01	0.01	0.04	0.08	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12 trucks	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13 trucks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

AVERAGE TARDINESS																
FLEET SIZE	DEMAND E (6)								DEMAND E (8)							
	SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High
2 trucks	24.06	27.25	65.01	72.45	65.41	72.90	71.45	79.20	10.94	13.94	26.94	34.01	27.48	34.57	32.88	40.84
3 trucks	3.05	4.61	9.88	14.68	10.01	14.52	14.29	20.21	0.29	0.52	0.16	0.44	0.27	0.63	0.39	1.09
4 trucks	0.10	0.21	0.00	0.33	0.05	0.30	0.07	0.58	0.00	0.02	0.00	0.00	0.00	0.01	0.00	0.01
5 trucks	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6 trucks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7 trucks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8 trucks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9 trucks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10 trucks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11 trucks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12 trucks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13 trucks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

AVERAGE TRUCK UTILIZATION																
FLEET SIZE	DEMAND E (2)								DEMAND E (4)							
	SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High
2 trucks	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.18	100.28	99.98	100.01	99.98	100.01	100.00	100.00
3 trucks	99.04	100.30	99.99	100.00	99.99	100.00	99.93	100.02	99.17	100.21	99.95	100.00	99.95	100.00	99.96	100.00
4 trucks	97.77	99.98	99.99	100.00	99.99	100.00	99.98	100.00	98.59	99.37	99.47	99.82	99.48	99.82	99.50	99.83
5 trucks	97.95	100.13	99.98	100.00	99.99	100.00	99.98	100.01	89.58	91.36	94.91	96.70	94.92	96.86	96.12	97.67
6 trucks	98.65	100.13	99.99	100.00	99.97	100.00	99.99	100.00	76.74	78.91	79.60	82.04	79.57	82.02	80.78	83.37
7 trucks	99.10	100.05	99.98	100.00	99.97	100.00	99.97	100.00	65.34	67.64	66.42	68.84	66.42	68.86	66.77	69.24
8 trucks	98.97	99.64	99.82	99.95	99.80	99.94	99.84	99.96	56.15	58.56	56.57	58.98	56.56	58.97	56.68	59.12
9 trucks	96.05	97.29	99.03	99.59	99.04	99.59	99.31	99.71	49.06	51.42	49.18	51.59	49.17	51.60	49.21	51.63
10 trucks	90.33	91.82	95.65	97.17	95.70	97.19	97.13	98.43	43.44	45.91	43.47	45.96	43.47	45.96	43.49	45.96
11 trucks	83.24	85.07	87.03	89.25	87.11	89.34	89.36	91.88	38.95	41.50	38.94	41.54	38.96	41.54	38.95	41.54
12 trucks	76.00	78.02	77.99	80.18	78.07	80.29	78.92	81.30	35.33	37.97	36.66	37.97	35.34	37.97	35.33	37.98
13 trucks	69.40	71.49	70.38	72.55	70.38	72.59	70.73	72.95	32.38	35.04	32.38	35.05	32.38	35.05	32.38	35.05

AVERAGE TRUCK UTILIZATION																
FLEET SIZE	DEMAND E (6)								DEMAND E (8)							
	SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High
2 trucks	99.79	99.95	99.84	99.97	99.86	99.97	99.84	99.97	97.56	98.73	98.95	99.52	98.93	99.48	99.08	99.59
3 trucks	94.53	96.17	97.50	98.57	97.56	98.58	98.02	98.87	77.38	80.05	81.02	84.06	80.97	83.95	82.10	85.25
4 trucks	76.60	79.15	79.71	82.68	79.78	82.72	80.70	83.81	58.47	61.14	59.51	62.26	59.49	62.29	59.75	62.55
5 trucks	61.29	63.95	62.35	65.16	62.32	65.06	62.66	65.53	45.82	48.38	46.04	48.57	46.03	48.61	46.11	48.63
6 trucks	50.11	52.69	50.40	53.02	50.36	52.99	50.48	53.11	37.23	39.75	37.30	39.83	37.30	39.83	37.31	39.84
7 trucks	42.01	44.58	42.09	44.71	42.08	44.69	42.09	44.74	31.27	33.83	31.29	33.85	31.27	33.85	31.29	33.85
8 trucks	36.08	38.65	36.11	38.67	36.11	38.66	36.11	38.66	26.88	29.48	26.88	29.49	26.88	29.49	26.88	29.49
9 trucks	31.58	34.21	31.60	34.20	31.60	34.20	31.60	34.20	23.60	26.17	23.60	26.18	23.60	26.18	23.60	26.18
10 trucks	28.14	30.71	28.14	30.71	28.15	30.70	28.14	30.71	21.03	23.60	21.02	23.60	21.03	23.59	21.02	23.60
11 trucks	25.34	27.96	25.35	27.95	25.35	27.95	25.35	27.95	18.95	21.55	18.95	21.55	18.95	21.55	18.95	21.55
12 trucks	23.06	25.71	23.06	25.71	23.06	25.71	23.06	25.71	17.26	19.85	17.26	19.85	17.26	19.85	17.26	19.85
13 trucks	21.17	23.82	21.17	23.82	21.17	23.82	21.17	23.82	15.85	18.40	15.85	18.40	15.85	18.40	15.85	18.40

FLEET SIZE	NUMBER OF TARDY JOBS															
	DEMAND E (2)								DEMAND E (4)							
	SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High
2 trucks	43.76	44.97	46.80	47.39	46.34	46.95	43.25	43.74	37.14	38.58	44.33	45.21	44.01	44.87	41.91	42.74
3 trucks	59.13	60.52	68.34	69.08	68.23	68.97	63.60	64.29	40.16	42.58	60.39	62.46	60.10	62.17	58.49	60.22
4 trucks	67.79	70.27	88.78	89.98	88.78	89.86	82.79	83.94	24.99	29.40	58.50	65.81	59.53	66.17	61.28	67.30
5 trucks	72.62	75.60	106.89	108.67	106.78	108.70	100.86	102.58	4.44	6.33	15.11	23.80	17.85	26.29	30.62	42.02
6 trucks	71.11	74.95	120.71	124.27	121.12	124.58	116.20	119.05	0.50	0.95	-0.06	0.64	0.14	1.04	0.27	2.19
7 trucks	61.04	66.77	127.66	134.23	128.47	134.74	125.80	130.74	0.05	0.16	0.00	0.00	-0.01	0.03	-0.01	0.02
8 trucks	39.06	46.20	120.21	133.30	120.92	133.25	127.17	136.47	-0.02	0.06	0.00	0.00	0.00	0.00	0.00	0.00
9 trucks	14.38	18.87	80.10	100.35	82.96	102.17	108.40	125.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10 trucks	3.92	5.51	13.87	29.70	18.06	33.02	49.68	71.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11 trucks	1.00	1.59	-0.12	1.14	0.54	2.27	4.08	14.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12 trucks	0.23	0.44	0.00	0.00	-0.01	0.07	-0.06	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13 trucks	0.04	0.19	0.00	0.00	-0.01	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

FLEET SIZE	NUMBER OF TARDY JOBS															
	DEMAND E (8)								DEMAND E (8)							
	SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High
2 trucks	28.09	30.17	40.21	41.73	40.11	41.62	39.09	40.54	16.55	19.38	30.29	34.25	30.36	34.12	31.17	34.63
3 trucks	11.18	14.23	28.33	35.78	28.90	36.02	32.32	39.14	1.58	2.36	1.57	3.53	2.35	4.35	3.20	5.94
4 trucks	1.01	1.76	0.37	3.07	1.01	3.12	1.27	4.60	0.08	0.25	-0.02	0.06	0.01	0.13	-0.03	0.09
5 trucks	0.04	0.15	0.00	0.01	0.00	0.03	0.00	0.01	0.00	0.01	0.00	0.00	-0.01	0.02	0.00	0.00
6 trucks	-0.01	0.04	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00
7 trucks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8 trucks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9 trucks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10 trucks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11 trucks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12 trucks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13 trucks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

FLEET SIZE	PERCENT OF TARDY JOBS															
	DEMAND E (2)								DEMAND E (4)							
	SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High
2 trucks	0.70	0.72	0.94	0.95	0.94	0.94	0.95	0.95	0.65	0.66	0.91	0.92	0.91	0.92	0.92	0.93
3 trucks	0.65	0.66	0.93	0.93	0.93	0.93	0.94	0.94	0.50	0.52	0.87	0.89	0.87	0.89	0.89	0.90
4 trucks	0.58	0.60	0.92	0.92	0.92	0.92	0.92	0.93	0.25	0.29	0.73	0.79	0.74	0.79	0.78	0.82
5 trucks	0.51	0.53	0.90	0.91	0.90	0.91	0.91	0.92	0.04	0.05	0.18	0.27	0.20	0.29	0.37	0.48
6 trucks	0.43	0.45	0.87	0.89	0.87	0.89	0.89	0.90	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.02
7 trucks	0.34	0.36	0.83	0.85	0.83	0.85	0.86	0.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8 trucks	0.20	0.23	0.74	0.79	0.75	0.79	0.80	0.83	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9 trucks	0.06	0.08	0.52	0.61	0.52	0.61	0.67	0.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10 trucks	0.02	0.02	0.10	0.19	0.12	0.20	0.34	0.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11 trucks	0.00	0.01	0.00	0.01	0.00	0.01	0.03	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12 trucks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13 trucks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

FLEET SIZE	PERCENT OF TARDY JOBS															
	DEMAND E (8)								DEMAND E (8)							
	SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High
2 trucks	0.53	0.55	0.87	0.89	0.87	0.89	0.88	0.90	0.34	0.39	0.74	0.79	0.74	0.79	0.77	0.82
3 trucks	0.16	0.20	0.53	0.63	0.53	0.62	0.60	0.68	0.03	0.04	0.03	0.07	0.04	0.08	0.06	0.11
4 trucks	0.01	0.02	0.01	0.04	0.02	0.04	0.03	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5 trucks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6 trucks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7 trucks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8 trucks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9 trucks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10 trucks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11 trucks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12 trucks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13 trucks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

FLEET SIZE	THROUGHPUT															
	DEMAND E (2)								DEMAND E (4)							
	SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High
2 trucks	133.38	134.02	100.19	100.95	99.65	100.47	92.00	92.84	129.72	131.29	100.32	101.10	100.13	100.87	93.91	94.69
3 trucks	197.95	200.23	150.43	151.37	150.11	151.17	137.97	138.98	188.31	190.11	150.66	151.64	150.39	151.37	141.34	142.42
4 trucks	258.90	263.30	200.45	201.59	200.04	201.16	184.39	185.49	234.59	238.37	199.44	200.82	199.37	200.65	188.56	189.91
5 trucks	320.66	325.36	250.44	251.60	250.18	251.50	231.13	232.45	246.02	252.00	239.12	243.18	239.05	242.99	232.17	235.17
6 trucks	380.50	384.29	300.93	302.31	300.55	302.07	278.41	279.71	247.26	253.52	246.80	252.90	246.69	252.75	246.29	252.14
7 trucks	435.65	439.41	350.89	352.29	350.64	352.24	325.51	326.93	247.41	253.69	247.35	253.65	247.45	253.77	247.30	253.66
8 trucks	477.77	483.85	400.77	402.49	400.53	402.11	372.68	374.28	247.48	253.84	247.61	253.87	247.44	253.78	247.57	253.93
9 trucks	494.15	502.83	448.61	451.39	447.85	450.41	419.85	421.85	247.56	253.97	247.59	253.99	247.55	253.95	247.60	254.00
10 trucks	497.38	506.56	484.70	490.60	485.02	490.86	464.08	467.60	247.54	253.92	247.56	253.94	247.54	253.92	247.58	253.96
11 trucks	498.43	507.89	496.78	505.66	496.69	505.61	492.55	500.05	247.56	253.94	247.58	253.96	247.55	253.93	247.59	253.97
12 trucks	498.87	508.27	498.64	507.93	498.58	507.94	497.98	507.16	247.58	253.94	247.58	253.95	247.55	253.91	247.60	253.96
13 trucks	499.24	508.64	499.19	508.61	499.10	508.50	499.05	508.43	247.57	253.95	247.57	253.95	247.55	253.93	247.57	253.95

FLEET SIZE	THROUGHPUT															
	DEMAND E (6)								DEMAND E (8)							
	SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High
2 trucks	124.49	125.63	100.02	100.86	99.77	100.65	95.46	96.32	114.89	117.21	99.56	100.44	99.08	100.12	95.92	96.86
3 trucks	160.56	165.10	146.91	148.69	147.12	148.82	141.90	143.20	124.14	128.50	123.37	127.47	123.50	127.60	122.91	126.83
4 trucks	164.31	169.77	163.40	168.60	163.40	168.62	162.94	167.95	124.72	129.24	124.68	129.18	124.62	129.12	124.64	129.12
5 trucks	164.49	170.11	164.41	169.99	164.44	170.00	164.41	170.01	124.81	129.39	124.76	129.32	124.76	129.34	124.74	129.30
6 trucks	164.56	170.20	164.53	170.19	164.49	170.13	164.58	170.22	124.83	129.41	124.83	129.41	124.83	129.41	124.83	129.41
7 trucks	164.49	170.13	164.50	170.14	164.47	170.11	164.52	170.16	124.84	129.42	124.84	129.42	124.84	129.42	124.84	129.42
8 trucks	164.47	170.12	164.47	170.13	164.45	170.09	164.49	170.15	124.84	129.44	124.84	129.44	124.84	129.44	124.84	129.44
9 trucks	164.50	170.14	164.50	170.14	164.50	170.14	164.51	170.15	124.86	129.46	124.86	129.46	124.86	129.46	124.86	129.46
10 trucks	164.49	170.13	164.49	170.13	164.49	170.13	164.50	170.14	124.88	129.50	124.88	129.50	124.88	129.50	124.88	129.50
11 trucks	164.50	170.14	164.50	170.14	164.50	170.14	164.50	170.15	124.88	129.48	124.88	129.48	124.88	129.48	124.88	129.48
12 trucks	164.52	170.16	164.52	170.16	164.52	170.16	164.53	170.17	124.89	129.49	124.89	129.49	124.89	129.49	124.89	129.49
13 trucks	164.52	170.16	164.52	170.16	164.52	170.16	164.53	170.17	124.89	129.49	124.89	129.49	124.89	129.49	124.89	129.49

FLEET SIZE	OVERALL TRUCK WEIGHT															
	DEMAND E (2)								DEMAND E (4)							
	SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High
2 trucks	34053.75	34405.95	12798.90	13452.60	12574.75	13291.90	23978.10	24857.00	33312.85	33751.05	12594.10	13056.25	12513.70	13056.75	19590.10	20258.90
3 trucks	33957.87	34324.63	12821.40	13720.43	12615.67	13243.97	22103.63	22858.37	30675.67	31370.03	12825.00	12870.00	12548.27	12825.83	17664.67	18211.77
4 trucks	33993.85	34463.05	12799.73	13607.30	12640.23	13295.38	20512.13	21212.05	24696.45	25821.05	12694.35	13002.48	12489.90	12720.80	16292.08	16804.00
5 trucks	33481.24	33985.60	12688.90	13234.36	12680.70	13411.44	19104.82	19748.78	16295.80	17246.10	12600.30	12908.24	12015.48	12318.48	14763.42	15263.08
6 trucks	32120.38	32735.55	12714.83	13227.17	12730.40	13362.18	18089.18	18883.10	11767.15	12383.38	11043.40	11474.58	10305.33	10645.12	11846.58	12412.95
7 trucks	29752.70	30550.60	12758.26	13233.37	12658.70	13145.20	17067.73	17640.94	9370.30	9826.61	9194.03	9605.03	8831.06	9171.09	9449.36	9922.17
8 trucks	25981.63	27051.76	12755.80	13103.59	12621.14	12957.74	16399.65	16906.49	7907.19	8302.84	7847.66	8219.17	7701.85	8056.55	7935.19	8341.86
9 trucks	20494.63	21639.98	12814.58	13114.08	12565.80	12847.56	15649.56	16144.91	6896.82	7259.53	6880.12	7245.28	6826.95	7187.58	6906.64	7283.25
10 trucks	15999.31	16849.75	12822.23	13126.57	12212.47	12472.30	14795.96	15254.81	6140.69	6515.73	6136.01	6511.24	6121.42	6492.11	6144.23	6523.08
11 trucks	13128.55	13736.42	12169.39	12595.14	11349.60	11654.04	13339.35	13921.11	5549.46	5933.04	5547.22	5936.00	5541.21	5926.13	5552.49	5941.18
12 trucks	11273.64	11763.91	11023.78	11431.92	10421.58	10739.14	11502.83	12002.19	5060.35	5456.63	5257.71	5456.11	5058.03	5453.21	5061.53	5458.32
13 trucks	10017.18	10426.93	9923.17	10312.61	9606.29	9939.89	10135.58	10568.34	4652.40	5051.58	4651.98	5052.76	4651.91	5051.17	4653.19	5052.61

FLEET SIZE	OVERALL TRUCK WEIGHT															
	DEMAND E (6)								DEMAND E (8)							
	SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High	95% Cl Low	95% Cl High
2 trucks	29739.55	30483.30	12646.55	12901.10	12537.40	12847.30	17138.60	17689.30	23781.85	25035.15	12617.95	12927.45	12372.85	12586.55	16066.65	16567.25
3 trucks	19973.80	21325.63	12596.07	12875.30	12287.37	12535.67	15489.10	15998.80	12607.23	13447.43	11034.37	11509.03	10295.00	10709.83	12219.90	12881.00
4 trucks	12203.70	12992.90	10970.80	11458.88	10232.13	10620.20	11935.95	12589.05	8307.69	8797.74	8104.75	8536.54	7782.23	8170.85	8344.67	8834.64
5 trucks	8800.34	9292.47	8593.55	9034.73	8211.09	8584.61	8850.86	9363.08	6338.94	6729.73	6314.18	6697.07	6197.28	6562.91	6355.72	6744.21
6 trucks	6995.44	7413.05	6943.38	7335.78	6817.24	7189.80	7015.31	7431.70	5171.12	5547.68	5166.34	5543.53	5132.48	5502.75	5183.94	5566.26
7 trucks	5860.98	6245.23	5850.77	6239.78	5812.04	6193.73	5871.58	6265.84	4382.67	4752.85	4383.37	4752.40	4375.43	4742.38	4385.52	4756.84
8 trucks	5078.05	5458.44	5078.62	5449.87	5065.23	5438.67	5083.83	5457.10	3805.11	4180.69	3803.89	4180.61	3802.47	4176.95	3804.30	4183.07
9 trucks	4478.66	4867.98	4480.32	4866.04	4476.43	4862.21	4480.77	4868.02	3359.81	3735.35	3359.31	3737.42	3358.97	3735.52	3359.50	3737.23
10 trucks	4014.64	4395.47	4013.55	4395.69	4013.43	4393.13	4013.41	4395.68	3004.61	3381.60	3004.45	3381.81	3004.53	3381.07	3004.45	3381.81
11 trucks	3626.23	4016.85	3627.04	4016.18	3626.96	4015.96	3627.46	4016.60	2713.37	3092.55	2713.36	3092.54	2713.38	3092.55	2713.36	3092.54
12 trucks	3306.82	3699.17	3306.91	3699.12	3306.85	3699.59	3307.58	3699.22	2472.34	2850.10	2472.32	2850.08	2472.34	2850.09	2472.32	2850.08
13 trucks	3038.50	3429.06	3038.53	3429.07	3038.45	3429.52	3039.01	3429.30	2270.83	2642.23	2270.82	2642.22	2270.84	2642.23	2270.82	2642.22

APPENDIX D

STCV 1 HUB MODEL 95% CONFIDENCE INTERVALS

		TIME IN SYSTEM															
		DEMAND E (2)								DEMAND E (4)							
TRUCK HUB	FLEET SIZE	SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
		95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High
1 truck	2 trucks	81.64	87.25	445.23	451.93	445.62	451.87	433.07	451.42	73.75	80.15	354.11	364.40	347.87	363.94	355.31	366.41
	3 trucks	75.33	80.45	449.19	455.41	448.35	454.41	450.44	456.68	71.41	77.30	356.35	367.12	357.71	367.71	358.47	368.70
	4 trucks	74.11	78.97	449.22	455.30	448.58	454.87	451.00	457.26	68.44	71.51	357.23	366.91	356.35	366.86	359.46	369.33
2 trucks	2 trucks	61.88	66.17	365.94	374.13	365.96	373.41	365.85	373.91	55.55	60.06	197.27	210.01	196.75	209.46	196.92	210.11
	3 trucks	59.59	63.52	358.61	366.76	359.20	367.07	359.04	366.98	54.21	58.60	182.33	195.71	183.12	195.89	182.91	195.94
	4 trucks	59.83	63.79	360.68	368.49	360.94	368.87	360.56	368.41	54.85	59.14	181.54	194.81	182.90	195.49	182.08	195.43
3 trucks	2 trucks	50.03	53.02	298.91	307.20	299.43	308.05	301.99	310.87	48.09	51.55	93.58	104.72	93.87	105.46	98.55	110.31
	3 trucks	50.57	53.67	274.54	283.51	276.41	285.12	275.08	284.30	39.97	43.42	48.55	55.23	49.21	56.46	49.65	56.30
	4 trucks	49.82	52.72	269.25	278.10	269.93	279.21	269.49	278.86	37.13	40.48	43.55	49.32	43.59	49.61	43.97	49.83

		TIME IN SYSTEM															
TRUCK HUB	FLEET SIZE	DEMAND E (6)								DEMAND E (8)							
		SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
		95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High
1 truck	2 trucks	67.24	72.89	267.14	281.38	267.59	280.70	267.87	280.95	64.84	70.60	190.11	206.26	188.96	205.20	189.72	206.08
	3 trucks	85.31	70.26	267.17	281.06	268.63	281.88	268.55	282.25	62.32	67.94	187.22	203.40	185.75	202.40	187.99	203.92
	4 trucks	62.86	67.88	268.80	282.34	268.44	282.08	268.86	282.20	60.99	66.57	187.53	203.88	186.67	203.71	187.07	203.31
	4 trucks	45.23	49.70	61.66	72.91	60.77	71.80	61.88	72.37	30.01	31.47	30.99	32.84	31.00	33.14	30.96	32.94
2 trucks	3 trucks	40.80	45.21	50.31	58.79	49.55	58.05	50.77	59.26	27.91	29.15	28.40	29.69	28.41	29.91	28.47	29.74
	4 trucks	40.08	44.57	48.55	56.68	48.63	56.91	48.22	56.67	27.38	28.45	27.81	29.02	27.72	28.94	27.98	29.39
	2 trucks	28.09	29.12	29.13	30.55	29.27	30.67	29.53	31.21	25.33	25.73	25.53	26.01	25.55	26.01	25.60	26.09
	3 trucks	25.09	25.57	25.24	25.76	25.25	25.79	25.28	25.83	23.72	23.98	23.75	24.00	23.74	24.00	23.74	24.00
3 trucks	4 trucks	24.26	24.64	24.41	24.84	24.44	24.91	24.44	24.88	23.15	23.37	23.17	23.39	23.17	23.39	23.17	23.39

		AVERAGE LATENCY															
TRUCK HUB	FLEET SIZE	DEMAND E (2)								DEMAND E (4)							
		SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
		95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High
1 truck	2 trucks	-4.47	-1.24	163.09	166.87	162.68	166.18	159.20	167.69	-8.91	-5.81	118.83	124.44	115.31	123.16	119.44	125.25
	3 trucks	-8.12	-5.55	164.64	168.06	163.41	166.77	165.22	168.75	-10.71	-7.80	119.62	125.03	118.45	124.11	120.35	125.88
	4 trucks	-9.13	-6.52	164.08	167.54	162.87	166.27	164.85	168.41	-12.91	-10.24	119.20	124.58	117.43	123.25	120.17	125.52
	4 trucks	-16.63	-14.24	126.36	130.88	125.76	130.20	126.64	131.21	-19.86	-17.73	44.46	51.85	43.62	50.84	44.40	51.95
2 trucks	3 trucks	-17.86	-15.64	121.01	125.58	120.41	124.86	121.40	125.85	-21.13	-19.07	36.10	43.67	36.02	43.24	36.36	43.85
	4 trucks	-17.23	-15.06	121.11	125.48	120.33	124.69	121.17	125.49	-21.39	-19.50	34.87	42.39	35.15	42.27	35.14	42.70
	2 trucks	-21.73	-19.93	96.36	101.25	95.87	100.73	98.59	103.70	-25.30	-23.36	-3.33	3.15	-3.30	3.22	-0.70	6.12
	3 trucks	-22.85	-21.03	81.81	87.07	82.25	87.40	82.29	87.03	-30.29	-28.27	-25.02	-21.10	-24.72	-20.39	-24.26	-20.27
3 trucks	4 trucks	-23.40	-21.76	78.04	83.17	77.93	83.30	78.06	83.48	-32.21	-30.20	-27.69	-24.11	-27.92	-24.30	-27.59	-23.94

		AVERAGE LATENCY															
TRUCK HUB	FLEET SIZE	DEMAND E (6)								DEMAND E (8)							
		SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
		95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High
1 truck	2 trucks	-12.30	-9.74	77.48	85.15	77.43	84.68	78.27	85.61	-14.30	-11.53	41.62	50.94	40.42	49.68	41.29	50.83
	3 trucks	-14.16	-11.75	78.57	84.10	78.76	83.98	77.13	84.57	-16.20	-13.45	39.84	48.91	38.19	47.67	39.96	49.24
	4 trucks	-15.08	-12.76	78.77	84.12	78.47	83.76	76.86	84.14	-16.85	-14.13	39.21	48.72	37.91	47.56	39.09	48.53
	4 trucks	-26.76	-24.17	-18.13	-11.85	-19.07	-13.04	-17.98	-12.04	-36.51	-34.15	-34.77	-33.09	-34.75	-32.93	-34.77	-33.04
2 trucks	3 trucks	-29.82	-27.44	-24.21	-19.25	-24.92	-20.26	-23.90	-18.94	-37.22	-36.01	-36.88	-35.53	-36.88	-35.54	-36.86	-35.52
	4 trucks	-30.57	-28.21	-25.53	-20.88	-25.70	-20.95	-25.64	-20.79	-37.93	-36.75	-37.57	-36.26	-37.59	-36.24	-37.45	-36.10
	2 trucks	-36.66	-35.61	-35.73	-34.36	-35.77	-34.49	-35.48	-33.98	-39.14	-38.43	-38.93	-38.15	-38.93	-38.11	-38.88	-38.08
	3 trucks	-39.23	-38.57	-39.06	-38.38	-39.08	-38.37	-39.01	-38.31	-40.61	-39.98	-40.58	-39.94	-40.60	-39.95	-40.58	-39.94
3 trucks	4 trucks	-40.07	-39.45	-39.98	-39.32	-39.92	-39.24	-39.94	-39.28	-41.29	-40.69	-41.27	-40.66	-41.26	-40.66	-41.26	-40.65

		AVERAGE TARDINESS															
TRUCK HUB	FLEET SIZE	DEMAND E (2)								DEMAND E (4)							
		SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
		95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High
1 truck	2 trucks	17.09	19.78	168.72	172.40	169.24	172.66	165.22	173.13	14.21	16.65	125.69	131.03	123.25	130.56	126.35	131.91
	3 trucks	14.48	16.68	170.37	173.56	170.16	173.42	170.99	174.33	12.94	15.27	126.65	131.78	126.39	131.74	127.43	132.66
	4 trucks	13.81	15.91	169.93	173.17	169.70	173.02	170.73	174.11	11.23	13.40	126.40	131.47	125.51	131.04	127.37	132.43
	4 trucks	10.88	12.78	132.21	136.61	132.45	136.73	132.52	136.95	8.59	10.19	54.43	61.06	54.38	60.83	54.42	61.16
2 trucks	3 trucks	9.81	11.51	127.70	132.11	127.84	132.16	128.04	132.34	7.81	9.35	47.48	54.10	48.08	54.41	47.66	54.24
	4 trucks	9.84	11.59	128.00	132.21	128.02	132.24	128.07	132.23	7.62	9.02	46.70	53.24	47.63	53.78	47.05	53.60
	2 trucks	7.31	8.73	103.06	107.69	103.16	107.82	105.08	109.94	5.39	6.71	13.74	18.16	14.50	18.97	15.68	20.52
	3 trucks	7.43	8.87	89.40	94.41	90.54	95.45	89.89	94.95	3.25	4.39	1.75	3.20	2.41	4.12	2.01	3.51
3 trucks	4 trucks	7.08	8.35	86.30	91.18	86.99	92.09	86.33	91.48	2.52	3.57	1.10	2.23	1.43	2.69	1.11	2.30

		AVERAGE TARDINESS															
TRUCK HUB	FLEET SIZE	DEMAND E (6)								DEMAND E (8)							
		SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
		95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High
1 truck	2 trucks	11.80	13.87	85.93	93.07	86.52	93.26	86.71	93.53	11.08	13.25	52.72	61.02	52.30	60.49	52.31	60.64
	3 trucks	10.54	12.42	85.28	92.29	86.06	92.78	85.85	92.74	9.71	11.80	50.92	59.18	50.39	58.74	51.22	59.45
	4 trucks	9.81	11.63	85.64	92.48	85.95	92.71	85.73	92.47	9.45	11.50	50.95	59.36	50.47	58.93	50.81	59.14
	4 trucks	4.44	6.05	5.23	8.81	5.13	8.59	5.10	8.39	0.58	1.07	0.06	0.29	0.20	0.55	0.07	0.29
2 trucks	3 trucks	3.09	4.48	2.67	4.89	2.74	4.94	2.75	5.05	0.29	0.73	0.02	0.15	0.07	0.21	0.02	0.15
	4 trucks	2.80	4.13	2.24	4.27	2.63	4.81	2.28	4.45	0.21	0.55	0.01	0.08	0.03	0.23	0.01	0.13
	2 trucks	0.24	0.48	0.01	0.07	0.05	0.13	0.03	0.14	0.01	0.04	0.00	0.00	0.00	0.02	0.00	0.00
	3 trucks	0.02	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3 trucks	4 trucks	0.01	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

		AVERAGE TRUCK UTILIZATION															
TRUCK HUB	FLEET SIZE	DEMAND E (2)								DEMAND E (4)							
		SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
		95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High
1 truck	2 trucks	32.09	32.86	29.51	30.68	29.65	30.74	29.07	30.73	32.36	33.29	29.86	30.93	29.30	30.74	29.63	30.67
	3 trucks	22.26	23.02	17.58	18.69	17.47	18.62	17.52	18.72	21.43	22.58	17.53	18.73	17.60	18.75	17.54	18.66
	4 trucks	16.50	17.48	12.22	13.38	12.18	13.37	12.22	13.35	15.52	17.15	12.26	13.40	12.27	13.49	12.25	13.36
	4 trucks	63.84	64.71	61.58	62.80	61.66	62.82	62.07	63.40	61.52	62.75	61.66	62.78	61.41	62.61	62.44	63.63
2 trucks	3 trucks	42.97	43.98	38.72	39.85	38.39	39.60	38.61	39.80	39.95	41.20	38.57	39.82	38.55	39.76	38.63	39.88
	4 trucks	32.33	33.41	26.36	27.64	26.25	27.53	26.31	27.52	28.28	29.56	26.35	27.62	26.39	27.61	26.49	27.68
	2 trucks	83.99	84.92	87.22	88.17	86.88	87.86	88.18	89.20	81.44	82.47	84.37	85.57	84.24	85.46	85.44	86.62
	3 trucks	62.60	63.80	61.02	62.19	60.87	62.08	61.21	62.49	57.38	58.94	57.68	58.28	57.30	58.85	58.09	59.62
3 trucks	4 trucks	46.41	47.58	42.43	43.67	42.43	43.69	42.42	43.69	39.78	41.29	39.43	41.01	39.48	41.01	39.64	41.21

AVERAGE TRUCK UTILIZATION																	
TRUCK HUB	FLEET SIZE	DEMAND E (6)								DEMAND E (8)							
		SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
		95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High
1 truck	2 trucks	31.07	32.06	29.83	30.96	29.80	30.85	29.69	30.84	30.11	31.16	29.08	30.20	29.30	30.39	29.26	30.31
	3 trucks	19.80	20.92	17.63	18.90	17.71	18.89	17.60	18.81	18.57	19.73	17.52	18.68	17.47	18.73	17.55	18.73
	4 trucks	13.99	15.51	12.32	13.48	12.30	13.58	12.34	13.50	13.01	14.38	12.19	13.36	12.13	13.45	12.23	13.40
2 trucks	2 trucks	57.85	59.51	58.36	59.93	58.06	59.74	58.50	60.24	45.82	47.79	45.99	48.07	45.89	47.94	45.97	48.01
	3 trucks	35.90	37.53	35.73	37.23	35.66	37.19	35.93	37.45	27.47	29.17	27.43	29.01	27.33	28.94	27.43	29.03
	4 trucks	24.88	26.29	24.64	26.00	24.58	25.97	24.64	26.02	18.94	20.49	18.97	20.41	19.02	20.40	18.92	20.42
3 trucks	2 trucks	60.80	63.16	62.38	64.92	62.71	65.21	62.81	65.50	45.98	48.06	46.42	48.53	46.45	48.56	46.56	48.71
	3 trucks	37.47	39.38	37.62	39.55	37.64	39.57	37.59	39.51	27.61	29.30	27.67	29.33	27.65	29.31	27.66	29.31
	4 trucks	25.71	27.27	25.78	27.38	25.75	27.34	25.78	27.38	19.09	20.59	19.12	20.59	19.14	20.55	19.11	20.58

NUMBER OF TARDY JOBS																	
TRUCK HUB	FLEET SIZE	DEMAND E (2)								DEMAND E (4)							
		SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
		95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High
1 truck	2 trucks	15.35	16.53	38.94	39.70	38.78	39.53	38.23	39.98	12.80	13.84	37.48	38.40	36.49	38.05	37.24	38.17
	3 trucks	15.73	16.83	39.54	40.27	39.07	39.75	39.29	39.98	13.02	14.19	37.96	38.81	37.64	38.39	37.83	38.68
	4 trucks	16.17	17.42	39.65	40.38	39.03	39.78	39.47	40.15	12.74	13.93	38.00	38.87	37.67	38.45	37.88	38.77
2 trucks	2 trucks	17.69	19.20	73.86	75.06	73.34	74.49	73.87	75.05	14.35	15.64	62.52	65.53	62.16	64.88	62.45	65.34
	3 trucks	18.15	19.64	75.88	77.21	75.44	76.80	76.05	77.44	14.36	15.62	62.02	65.76	62.29	65.69	62.41	65.99
	4 trucks	19.17	20.70	76.20	77.47	75.99	77.17	76.25	77.59	14.08	15.37	61.87	65.59	62.31	65.71	61.37	65.40
3 trucks	2 trucks	17.98	19.76	95.67	97.48	95.36	96.97	95.04	96.81	13.12	14.79	51.91	61.15	52.94	61.63	54.25	63.33
	3 trucks	19.40	21.17	106.78	109.08	106.33	108.46	106.66	109.03	9.56	11.63	18.41	27.92	21.89	31.60	21.28	31.30
	4 trucks	19.39	21.04	108.30	110.84	108.01	110.34	108.30	110.71	7.91	9.98	13.78	22.36	16.07	24.16	14.22	23.08

NUMBER OF TARDY JOBS																	
TRUCK HUB	FLEET SIZE	DEMAND E (6)								DEMAND E (8)							
		SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
		95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High
1 truck	2 trucks	11.27	12.26	35.22	36.30	34.94	36.10	35.23	36.39	10.01	11.02	31.50	33.44	31.27	33.17	31.56	33.44
	3 trucks	11.06	12.14	35.60	36.72	35.23	36.36	35.56	36.67	9.74	10.66	31.96	33.93	31.47	33.46	31.84	33.82
	4 trucks	11.00	12.02	35.46	36.60	35.37	36.49	35.50	36.66	9.57	10.52	31.61	33.63	31.29	33.26	31.74	33.72
2 trucks	2 trucks	8.64	10.58	20.85	28.78	21.02	28.39	21.32	28.99	1.90	2.74	0.79	2.17	1.75	3.51	0.82	2.19
	3 trucks	8.77	8.68	14.77	22.02	14.39	20.92	14.62	21.80	1.17	1.89	0.34	1.34	0.82	1.78	0.30	1.33
	4 trucks	8.68	8.57	12.90	19.92	14.26	20.99	12.70	19.85	1.02	1.70	0.26	0.81	0.59	1.58	0.35	1.23
3 trucks	2 trucks	1.28	2.14	0.31	1.07	0.80	1.87	0.42	1.56	0.11	0.31	0.00	0.02	0.02	0.20	0.00	0.03
	3 trucks	0.25	0.56	0.00	0.06	0.06	0.22	0.00	0.09	-0.01	0.07	0.00	0.00	-0.01	0.03	0.00	0.00
	4 trucks	0.13	0.29	0.00	0.04	0.03	0.14	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00

PERCENT OF TARDY JOBS																	
TRUCK HUB	FLEET SIZE	DEMAND E (2)								DEMAND E (4)							
		SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
		95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High
1 truck	2 trucks	0.34	0.36	0.93	0.94	0.93	0.94	0.91	0.95	0.30	0.32	0.91	0.92	0.90	0.92	0.91	0.92
	3 trucks	0.32	0.34	0.94	0.94	0.93	0.94	0.94	0.94	0.29	0.31	0.92	0.93	0.91	0.92	0.92	0.93
	4 trucks	0.32	0.34	0.94	0.94	0.93	0.94	0.94	0.94	0.27	0.29	0.92	0.93	0.91	0.92	0.92	0.93
2 trucks	2 trucks	0.21	0.23	0.93	0.93	0.92	0.93	0.93	0.93	0.18	0.19	0.85	0.87	0.85	0.87	0.85	0.87
	3 trucks	0.21	0.22	0.92	0.93	0.92	0.92	0.92	0.93	0.18	0.19	0.83	0.86	0.83	0.86	0.83	0.86
	4 trucks	0.21	0.22	0.92	0.93	0.92	0.92	0.92	0.93	0.17	0.19	0.83	0.86	0.83	0.86	0.83	0.85
3 trucks	2 trucks	0.16	0.17	0.90	0.91	0.90	0.91	0.90	0.91	0.14	0.15	0.63	0.70	0.63	0.70	0.65	0.73
	3 trucks	0.15	0.17	0.90	0.91	0.90	0.91	0.90	0.91	0.09	0.11	0.22	0.32	0.24	0.34	0.24	0.34
	4 trucks	0.15	0.16	0.89	0.90	0.89	0.90	0.89	0.90	0.08	0.09	0.16	0.24	0.17	0.25	0.16	0.25

PERCENT OF TARDY JOBS																	
TRUCK HUB	FLEET SIZE	DEMAND E (6)								DEMAND E (8)							
		SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
		95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High
1 truck	2 trucks	0.27	0.29	0.89	0.90	0.88	0.90	0.89	0.90	0.25	0.28	0.84	0.87	0.83	0.86	0.84	0.87
	3 trucks	0.26	0.28	0.89	0.90	0.89	0.90	0.89	0.90	0.24	0.26	0.84	0.87	0.83	0.86	0.84	0.87
	4 trucks	0.25	0.27	0.89	0.90	0.89	0.90	0.89	0.90	0.24	0.26	0.84	0.87	0.83	0.86	0.84	0.87
2 trucks	2 trucks	0.13	0.15	0.36	0.48	0.37	0.47	0.37	0.48	0.03	0.04	0.02	0.04	0.03	0.06	0.02	0.04
	3 trucks	0.10	0.12	0.25	0.36	0.25	0.34	0.25	0.36	0.02	0.03	0.01	0.02	0.01	0.03	0.01	0.02
	4 trucks	0.10	0.12	0.22	0.33	0.24	0.34	0.22	0.32	0.02	0.03	0.01	0.01	0.01	0.02	0.01	0.02
3 trucks	2 trucks	0.02	0.03	0.00	0.01	0.01	0.03	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	3 trucks	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	4 trucks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

THROUGHPUT																	
TRUCK HUB	FLEET SIZE	DEMAND E (2)								DEMAND E (4)							
		SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
		95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High
1 truck	2 trucks	95.71	97.09	82.92	84.20	82.91	84.17	81.01	84.51	92.90	94.30	83.42	84.70	81.61	84.67	83.06	84.18
	3 trucks	102.81	104.25	83.63	84.87	83.30	84.58	83.24	84.48	97.47	99.07	83.29	84.91	83.78	85.02	83.43	84.59
	4 trucks	105.58	107.16	83.48	84.74	83.04	84.28	83.39	84.55	98.52	99.92	83.62	84.90	83.86	85.08	83.52	84.64
2 trucks	2 trucks	183.60	185.54	162.35	164.13	163.03	164.69	162.34	164.02	173.33	175.37	162.58	164.19	162.40	164.12	162.90	164.56
	3 trucks	191.13	193.29	168.28	169.90	168.31	170.03	168.80	170.54	180.00	182.05	168.39	170.05	168.82	170.52	169.13	170.73
	4 trucks	195.54	197.58	168.32	169.94	168.47	170.03	168.34	170.00	182.47	184.33	169.24	170.92	169.16	170.64	168.87	170.53
3 trucks	2 trucks	243.61	245.65	222.04	223.88	221.65	223.54	219.14	221.12	222.93	225.51	215.93	218.15	215.64	217.92	213.56	215.84
	3 trucks	275.49	277.77	251.02	253.00												

		THROUGHPUT															
TRUCK HUB	FLEET SIZE	DEMAND E (5)								DEMAND E (6)							
		SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
		95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High
1 truck	2 trucks	90.43	91.79	83.51	84.79	83.20	84.56	83.39	84.73	87.92	89.18	83.01	84.23	83.49	84.75	83.10	84.52
	3 trucks	93.43	94.73	84.03	85.39	84.00	85.24	84.04	85.24	89.49	90.75	83.98	85.24	84.13	85.37	83.74	85.04
	4 trucks	93.76	95.00	83.84	85.00	84.10	85.30	84.09	85.25	89.37	90.59	83.88	85.12	83.87	85.09	83.73	84.97
	2 trucks	156.40	159.64	154.32	157.14	154.18	157.00	154.36	157.36	123.98	128.31	123.82	128.10	123.85	128.09	123.76	127.96
2 trucks	3 trucks	159.32	163.28	157.95	161.76	157.84	161.46	157.95	161.62	124.16	128.52	124.05	128.43	124.05	128.39	124.07	128.44
	4 trucks	159.54	163.52	158.45	162.11	158.32	162.04	158.54	162.24	124.17	128.61	124.11	128.51	124.23	128.65	124.09	128.47
	2 trucks	164.01	169.35	163.05	168.97	163.72	169.00	163.58	168.86	124.65	129.13	124.58	129.06	124.60	129.07	124.61	129.07
	3 trucks	164.39	169.89	164.47	169.97	164.37	169.85	164.48	170.00	124.68	129.16	124.70	129.18	124.69	129.17	124.70	129.18
4 trucks	164.36	169.86	164.37	169.83	164.36	169.84	164.35	169.85	124.70	129.22	124.68	129.20	124.72	129.22	124.67	129.17	

		OVERALL TRAILER UTILIZATION															
TRUCK HUB	FLEET SIZE	DEMAND E (2)								DEMAND E (4)							
		SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
		95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High
1 truck	2 trucks	68.61	69.08	65.29	65.84	65.27	65.77	65.13	66.67	67.33	67.84	65.33	65.99	65.02	66.44	65.05	65.59
	3 trucks	61.53	62.03	50.49	51.08	50.12	50.72	50.07	50.70	58.22	58.96	50.47	51.51	50.31	51.02	50.28	50.94
	4 trucks	53.83	54.55	40.05	40.57	39.76	40.28	39.86	40.34	48.26	48.97	40.03	40.82	39.94	40.54	39.95	40.49
	2 trucks	89.71	90.25	88.66	89.16	88.72	89.19	88.68	89.22	88.96	89.85	88.81	89.08	88.54	89.11	88.91	89.44
2 trucks	3 trucks	77.00	77.56	74.26	74.75	74.22	74.73	74.37	74.86	75.72	76.25	74.26	74.78	74.29	74.75	74.32	74.80
	4 trucks	68.90	69.31	63.21	63.70	63.13	63.61	63.04	63.55	65.64	66.19	63.19	63.65	63.05	63.52	63.16	63.66
	2 trucks	96.30	96.54	97.23	97.51	97.12	97.41	97.43	97.75	93.59	94.26	94.53	95.28	94.56	95.29	94.94	95.63
	3 trucks	90.34	90.78	89.31	89.70	89.11	89.55	89.39	89.81	84.28	85.87	84.29	85.89	84.05	85.64	84.61	86.16
4 trucks	80.95	81.39	78.40	78.88	78.30	78.73	78.35	78.80	72.83	74.52	72.62	74.22	72.48	74.10	72.67	74.31	

		OVERALL TRAILER UTILIZATION															
TRUCK HUB	FLEET SIZE	DEMAND E (5)								DEMAND E (6)							
		SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
		95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High
1 truck	2 trucks	66.73	67.28	65.65	66.21	65.41	65.99	65.51	66.11	66.01	66.67	64.84	65.50	65.00	65.64	64.90	65.54
	3 trucks	55.31	56.06	50.72	51.41	50.73	51.45	50.57	51.25	53.13	53.86	50.49	51.18	50.38	51.08	50.28	50.98
	4 trucks	44.76	45.46	40.32	40.86	40.25	40.87	40.12	40.69	42.86	43.29	40.05	40.82	40.08	40.85	39.96	40.54
	2 trucks	83.69	85.48	83.58	85.31	83.48	85.21	83.90	85.63	85.32	87.81	85.00	86.14	85.41	87.96	85.59	88.13
2 trucks	3 trucks	68.52	70.47	68.26	70.19	68.23	70.09	68.42	70.29	51.50	53.65	51.54	53.68	51.47	53.60	51.63	53.76
	4 trucks	57.56	59.38	57.34	59.11	57.38	59.14	57.33	59.08	42.69	44.52	42.60	44.42	42.51	44.33	42.66	44.52
	2 trucks	68.18	70.72	69.00	71.66	69.17	71.85	69.29	72.05	50.76	52.84	50.97	53.10	51.03	53.12	51.06	53.20
	3 trucks	54.99	57.11	55.08	57.21	55.07	57.22	55.10	57.24	40.73	42.39	40.71	42.33	40.71	42.34	40.70	42.33
4 trucks	46.29	48.04	46.34	48.13	46.37	48.18	46.37	48.18	34.29	35.67	34.29	35.66	34.30	35.69	34.30	35.67	

		OVERALL TRUCK HUB UTILIZATION															
TRUCK HUB	FLEET SIZE	DEMAND E (2)								DEMAND E (4)							
		SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
		95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High
1 truck	2 trucks	88.25	89.09	99.06	99.31	98.96	99.23	99.07	99.32	92.68	93.60	98.84	99.13	98.89	99.16	98.75	99.07
	3 trucks	95.53	96.15	99.94	99.98	99.93	99.98	99.93	99.99	98.90	99.18	99.96	100.00	99.93	99.98	99.93	99.98
	4 trucks	99.05	99.34	100.00	100.00	100.00	100.00	100.00	100.00	99.90	99.96	100.00	100.00	100.00	100.00	99.99	100.00
	2 trucks	85.48	86.14	90.57	91.05	90.58	91.21	90.29	90.86	87.74	88.41	89.94	90.60	89.96	90.56	89.85	90.50
2 trucks	3 trucks	92.50	93.18	98.14	98.45	98.24	98.54	98.12	98.45	96.11	96.64	97.54	97.91	97.62	97.98	97.63	98.00
	4 trucks	96.49	96.92	99.74	99.84	99.72	99.82	99.71	99.82	99.18	99.38	99.53	99.70	99.45	99.65	99.51	99.69
	2 trucks	73.94	74.70	76.15	76.83	76.13	76.82	74.74	75.60	74.33	75.13	73.54	74.34	73.66	74.48	72.57	73.37
	3 trucks	89.37	89.94	92.74	93.14	92.45	92.93	92.75	93.23	87.64	89.10	87.62	89.08	87.62	89.19	87.65	89.13
4 trucks	94.94	95.50	98.05	98.33	97.83	98.16	97.96	98.24	91.07	92.94	91.08	92.92	90.90	92.78	91.14	93.02	

		OVERALL TRUCK HUB UTILIZATION															
TRUCK HUB	FLEET SIZE	DEMAND E (5)								DEMAND E (6)							
		SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
		95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High
1 truck	2 trucks	94.43	95.21	98.37	98.71	98.25	98.63	98.51	98.80	95.50	96.22	97.83	98.25	97.72	98.18	97.68	98.19
	3 trucks	99.59	99.74	99.88	99.95	99.85	99.93	99.80	99.96	99.28	99.61	99.43	99.73	99.35	99.70	99.42	99.73
	4 trucks	99.92	99.98	99.93	99.99	99.92	99.99	99.93	99.99	99.44	99.76	99.50	99.79	99.47	99.79	99.49	99.79
	2 trucks	85.10	86.75	85.04	86.71	84.93	86.63	85.14	86.84	68.38	70.89	68.54	71.04	68.39	70.97	68.58	71.13
2 trucks	3 trucks	89.92	92.22	90.08	92.43	90.00	92.23	90.06	92.30	69.66	72.42	69.89	72.64	69.64	72.40	69.88	72.65
	4 trucks	91.16	93.66	91.42	93.91	91.53	93.96	91.36	93.78	70.07	72.89	70.01	72.82	69.82	72.60	70.12	73.02
	2 trucks	57.10	59.05	56.78	58.79	56.81	58.81	56.60	58.52	43.23	45.00	43.14	44.92	43.19	44.92	43.11	44.87
	3 trucks	59.07	61.34	59.06	61.33	59.00	61.30	59.06	61.36	43.87	45.75	43.77	45.57	43.79	45.60	43.79	45.60
4 trucks	59.30	61.56	59.30	61.57	59.41	61.74	59.36	61.67	43.85	45.69	43.83	45.66	43.85	45.70	43.85	45.68	

APPENDIX E

STCV 2 HUB MODEL 95% CONFIDENCE INTERVALS

		THROUGHPUT															
		DEMAND															
TRUCK HUB	FLEET SIZE	E (2)								E (4)							
		SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
		95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High
1 truck	2 trucks	217.93	219.48	201.68	203.43	201.46	203.12	200.45	202.17	203.91	205.81	196.50	198.46	196.88	198.80	196.03	197.81
	3 trucks	267.95	270.37	252.12	254.18	248.60	254.78	251.52	253.82	236.17	240.21	234.47	238.37	235.10	238.88	234.73	238.69
	4 trucks	307.84	310.40	287.28	289.86	287.75	290.29	287.01	289.56	245.41	251.13	244.90	250.48	244.94	250.56	244.93	250.47
	2 trucks	300.43	302.66	248.02	251.12	247.83	250.57	230.03	232.87	246.04	251.80	237.52	241.70	237.32	241.84	226.88	230.44
2 trucks	3 trucks	375.85	378.25	349.90	352.40	349.34	351.76	342.50	345.28	247.71	254.01	247.68	253.96	247.64	253.98	247.81	253.91
	4 trucks	437.98	440.70	424.80	427.45	424.74	427.34	423.42	426.34	247.82	254.10	247.89	254.23	247.83	254.11	247.88	254.20
	2 trucks	347.42	350.72	249.87	252.72	250.38	253.48	217.27	219.73	247.32	253.56	238.97	243.45	238.80	243.32	222.87	225.99
	3 trucks	446.20	449.30	374.22	377.46	375.21	378.85	335.06	338.64	247.93	254.33	247.98	254.36	247.95	254.31	247.90	254.21
3 trucks	4 trucks	493.57	501.47	475.96	481.04	476.71	481.81	456.00	460.40	247.95	254.31	247.96	254.32	247.97	254.32	247.99	254.35

		THROUGHPUT															
		DEMAND															
TRUCK HUB	FLEET SIZE	E (6)								E (8)							
		SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
		95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High
1 truck	2 trucks	163.20	168.38	162.95	168.13	163.00	168.16	162.82	167.96	124.74	129.18	124.70	129.08	124.73	129.13	124.73	129.13
	3 trucks	164.40	169.96	164.39	169.93	164.39	169.97	164.33	169.89	124.97	129.49	124.98	129.48	124.93	129.43	124.96	129.48
	4 trucks	164.51	170.13	164.50	170.14	164.49	170.11	164.50	170.11	124.93	129.43	124.95	129.45	124.89	129.41	124.96	129.48
	2 trucks	164.72	170.32	164.53	170.11	164.59	170.15	164.43	169.95	125.12	129.64	125.11	129.63	125.09	129.61	125.13	129.65
2 trucks	3 trucks	164.70	170.34	164.74	170.40	164.71	170.35	164.75	170.42	125.07	129.63	125.07	129.63	125.06	129.62	125.07	129.63
	4 trucks	164.64	170.22	164.63	170.21	164.63	170.21	164.63	170.23	124.98	129.52	124.98	129.52	124.98	129.52	124.98	129.52
	2 trucks	164.86	170.50	164.81	170.17	164.66	170.24	164.45	170.01	125.16	129.70	125.20	129.74	125.16	129.70	125.20	129.72
	3 trucks	164.73	170.37	164.75	170.39	164.76	170.40	164.76	170.42	125.05	129.61	125.05	129.61	125.05	129.63	125.05	129.63
3 trucks	4 trucks	164.61	170.21	164.62	170.22	164.64	170.26	164.62	170.22	124.96	129.50	124.96	129.50	124.96	129.50	124.96	129.50

		OVERALL TRAILER UTILIZATION															
		DEMAND															
TRUCK HUB	FLEET SIZE	E (2)								E (4)							
		SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
		95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High
1 truck	2 trucks	97.11	97.36	97.57	97.75	97.51	97.72	97.57	97.76	95.83	96.30	96.26	96.76	96.26	96.69	96.31	96.76
	3 trucks	93.94	94.22	93.68	93.99	93.74	94.04	93.75	94.05	87.19	88.70	87.43	88.94	87.28	88.84	87.28	88.81
	4 trucks	91.09	91.43	89.19	89.61	89.11	89.51	89.27	89.64	73.01	75.12	73.03	75.14	73.06	75.22	73.17	75.24
	2 trucks	98.73	98.87	99.56	99.65	99.59	99.69	99.67	99.76	80.97	83.63	80.97	83.63	80.97	83.63	80.97	83.63
2 trucks	3 trucks	97.96	98.12	98.95	99.10	98.91	99.06	99.04	99.16	60.77	62.68	61.59	63.61	61.66	63.72	62.11	64.24
	4 trucks	97.41	97.73	97.87	98.19	97.94	98.23	98.01	98.31	50.01	51.50	50.14	51.66	50.13	51.63	50.19	51.71
	2 trucks	98.96	99.06	99.78	99.84	99.80	99.86	99.83	99.88	60.33	62.68	60.83	65.18	60.77	65.40	60.42	62.77
	3 trucks	97.72	98.21	99.20	99.43	99.24	99.45	99.43	99.61	45.78	47.18	46.98	48.67	47.05	48.72	47.71	49.65
3 trucks	4 trucks	90.32	92.33	94.74	96.43	94.70	96.44	96.49	97.78	38.85	39.97	38.98	40.11	39.00	40.14	39.04	40.19

		OVERALL TRAILER UTILIZATION															
		DEMAND															
TRUCK HUB	FLEET SIZE	E (6)								E (8)							
		SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
		95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High
1 truck	2 trucks	76.09	78.90	76.62	79.54	76.56	79.50	76.95	79.87	55.68	57.99	55.89	58.21	55.94	58.27	56.02	58.37
	3 trucks	57.09	59.31	57.22	59.48	57.15	59.39	57.25	59.50	41.98	43.67	41.93	43.63	42.00	43.73	41.94	43.63
	4 trucks	45.79	47.55	45.87	47.67	45.78	47.57	45.89	47.69	33.89	35.23	33.88	35.20	33.88	35.23	33.88	35.21
	2 trucks	48.63	50.65	50.42	52.86	50.52	52.93	51.35	54.04	35.39	36.87	35.92	37.53	35.85	37.42	36.11	37.75
2 trucks	3 trucks	38.10	39.55	38.25	39.73	38.24	39.70	38.28	39.76	28.39	29.51	28.42	29.54	28.42	29.55	28.42	29.54
	4 trucks	32.17	33.34	32.19	33.37	32.19	33.37	32.20	33.38	24.15	25.07	24.15	25.07	24.15	25.08	24.15	25.07
	2 trucks	35.61	37.08	37.36	39.33	37.43	39.34	38.40	40.78	25.99	27.05	26.45	27.61	26.38	27.54	26.64	27.85
	3 trucks	28.97	30.05	29.08	30.18	29.08	30.18	29.13	30.25	21.62	22.47	21.63	22.49	21.64	22.50	21.66	22.52
3 trucks	4 trucks	25.17	26.07	25.17	26.08	25.17	26.08	25.18	26.09	18.93	19.65	18.93	19.66	18.93	19.65	18.93	19.66

		OVERALL TRUCK HUB UTILIZATION															
		DEMAND															
TRUCK HUB	FLEET SIZE	E (2)								E (4)							
		SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
		95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High
1 truck	2 trucks	60.50	61.58	64.91	66.36	64.93	66.31	64.58	65.96	62.74	63.85	63.39	64.88	63.58	65.12	63.12	64.56
	3 trucks	73.79	74.70	79.65	80.77	79.00	80.79	79.45	80.57	72.96	74.82	73.72	75.81	73.47	75.58	73.67	75.72
	4 trucks	83.92	84.66	88.94	89.73	88.90	89.77	88.92	89.68	72.09	74.85	72.38	75.27	72.48	75.43	72.56	75.39
	2 trucks	46.82	47.70	42.58	43.63	42.85	43.82	39.75	40.66	39.37	41.11	39.83	41.34	39.84	41.37	38.65	39.92
2 trucks	3 trucks	58.12	58.93	57.59	58.69	57.71	58.82	56.64	57.76	35.27	36.85	35.35	36.94	35.43	37.02	35.56	37.12
	4 trucks	68.11	68.89	68.05	69.19	68.32	69.53	67.95	69.17	33.28	34.74	33.29	34.75	33.30	34.74	33.29	34.74
	2 trucks	37.37	38.15	28.79	29.45	28.85	29.56	24.80	25.48	22.26	23.39	24.70	25.93	24.73	26.04	24.35	25.32
	3 trucks	49.18	50.00	42.58	43.41	42.87	43.73	38.19	39.04	20.50	21.44	20.67	21.63	20.66	21.62	20.75	21.74
3 trucks	4 trucks	52.20	53.99	51.80	53.15	51.81	53.22	50.41	51.56	20.01	20.92	20.02	20.91	20.02	20.91	20.02	20.92

		OVERALL TRUCK HUB UTILIZATION															
		DEMAND															
TRUCK HUB	FLEET SIZE	E (6)								E (8)							
		SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
		95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High
1 truck	2 trucks	51.37	53.82	51.35	53.78	51.15	53.59	51.33	53.82	37.37	39.39	37.42	39.45	37.40	39.43	37.50	39.53
	3 trucks	48.10	50.47	48.23	50.66	48.13	50.51	48.22	50.63	35.39	37.32	35.33	37.25	35.39	37.33	35.32	37.23
	4 trucks	45.79	48.08	45.93	48.27	45.83	48.15	45.97	48.30	34.18	36.01	34.14	35.96	34.15	35.99	34.14	35.96
	2 trucks	22.74	23.96	22.93	24.20	23.10	24.40	23.02	24.32	16.51	17.47	16.55	17.52	16.53	17.50	16.57	17.53
2 trucks	3 trucks	21.55	22.71	21.60	22.75	21.57	22.72	21.59	22.75	16.03	16.94	16.03	16.93	16.02	16.93	16.03	16.93
	4 trucks	21.11	22.20	21.12	22.22	21.11	22.20	21.11	22.21	15.74	16.62	15.74	16.61	15.75	16.62	15.74	16.61
	2 trucks	13.26	14.01	13.30	14.06	13.30	14.07	13.41	14.21	9.80	10.38	9.81	10.39	9.81	10.39	9.82	10.40
	3 trucks	12.98	13.68	12.97	13.												

APPENDIX F

STCV 3 HUB MODEL 95% CONFIDENCE INTERVALS

TIME IN SYSTEM																	
TRUCK HUB	FLEET SIZE	DEMAND															
		E (2)								E (4)							
		SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
		95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High
1 truck	2 trucks	63.26	66.38	284.66	293.26	285.41	294.18	289.93	298.55	46.23	49.73	71.91	81.26	71.75	81.37	79.35	89.53
	3 trucks	56.06	59.17	202.05	210.63	202.53	210.78	203.54	212.47	27.29	28.46	28.18	29.54	28.05	29.41	28.38	29.81
	4 trucks	49.11	51.91	146.86	155.12	146.24	154.81	146.75	155.13	23.79	24.33	24.06	24.66	24.11	24.74	24.16	24.83
	4 trucks	54.93	57.24	276.05	286.13	275.28	285.64	309.52	319.45	27.06	27.75	49.48	56.62	49.43	56.56	79.07	90.91
2 trucks	3 trucks	44.58	46.74	148.32	159.57	149.25	160.84	189.05	200.95	22.36	22.60	23.09	23.48	23.06	23.48	23.56	24.18
	4 trucks	31.20	33.45	49.91	57.64	49.81	57.34	67.29	77.72	20.96	21.13	21.05	21.33	21.04	21.27	21.07	21.27
	2 trucks	58.55	61.05	274.45	284.65	273.34	283.34	310.28	319.73	26.19	26.74	48.97	56.14	48.87	56.03	79.85	91.72
	3 trucks	33.79	36.46	146.27	158.21	147.93	158.98	194.49	206.20	22.01	22.22	22.72	23.12	22.74	23.14	23.21	23.83
3 trucks	4 trucks	24.08	24.44	41.80	48.52	43.12	49.85	84.29	96.39	20.65	20.81	20.74	20.92	20.73	20.91	20.77	20.96

TIME IN SYSTEM																	
TRUCK HUB	FLEET SIZE	DEMAND															
		E (6)								E (8)							
		SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
		95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High
1 truck	2 trucks	25.98	26.69	26.97	27.97	26.82	27.75	27.26	28.40	23.57	23.91	23.85	24.25	23.89	24.27	23.97	24.40
	3 trucks	22.63	22.92	22.77	23.10	22.75	23.07	22.78	23.10	21.70	21.93	21.75	22.00	21.74	21.99	21.76	22.01
	4 trucks	21.59	21.83	21.66	21.92	21.63	21.88	21.65	21.92	21.00	21.22	21.02	21.25	21.02	21.25	21.03	21.25
	4 trucks	23.44	23.72	24.87	25.60	24.71	25.35	25.51	26.56	22.45	22.71	22.85	23.22	22.84	23.21	23.00	23.41
2 trucks	2 trucks	21.20	21.39	21.30	21.52	21.28	21.49	21.34	21.57	20.80	20.99	20.83	21.02	20.83	21.03	20.84	21.04
	4 trucks	20.35	20.52	20.37	20.54	20.36	20.54	20.37	20.55	20.16	20.32	20.16	20.32	20.16	20.33	20.16	20.33
	2 trucks	23.16	23.44	24.58	25.28	24.48	25.15	25.26	26.38	22.22	22.46	22.63	22.99	22.61	22.94	22.79	23.18
	3 trucks	20.96	21.14	21.05	21.25	21.04	21.24	21.09	21.30	20.61	20.79	20.64	20.82	20.65	20.83	20.66	20.84
3 trucks	4 trucks	20.14	20.30	20.16	20.32	20.15	20.32	20.16	20.33	20.00	20.16	20.00	20.16	20.00	20.17	20.00	20.16

AVERAGE LATENESS																	
TRUCK HUB	FLEET SIZE	DEMAND															
		E (2)								E (4)							
		SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
		95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High
1 truck	2 trucks	-14.52	-12.92	89.90	94.98	89.70	94.96	93.25	98.49	-26.39	-24.16	-12.68	-7.17	-12.92	-7.31	-8.73	-2.71
	3 trucks	-19.59	-17.91	48.14	53.30	48.11	53.19	49.58	54.94	-37.72	-36.62	-36.83	-35.45	-37.06	-35.72	-36.72	-35.36
	4 trucks	-24.27	-22.75	21.22	26.24	20.36	25.33	21.19	26.21	-40.65	-39.98	-40.33	-39.59	-40.32	-39.58	-40.27	-39.54
	4 trucks	-18.42	-17.13	85.70	91.77	84.58	90.73	101.08	106.88	-37.40	-36.57	-23.39	-18.87	-23.76	-19.41	-10.27	-3.37
2 trucks	3 trucks	-26.67	-25.11	22.08	28.98	22.72	29.70	41.62	49.07	-41.64	-41.14	-40.95	-40.32	-41.02	-40.39	-40.57	-39.81
	4 trucks	-35.31	-33.83	-24.89	-20.32	-25.00	-20.65	-16.92	-10.84	-43.04	-42.58	-42.96	-42.48	-42.97	-42.49	-42.93	-42.45
	2 trucks	-15.86	-14.39	85.36	91.43	84.14	90.15	101.88	107.58	-38.07	-37.33	-23.76	-19.24	-23.94	-19.51	-9.95	-3.02
	3 trucks	-32.93	-31.19	21.39	28.58	22.41	29.15	43.95	51.24	-41.94	-41.44	-41.27	-40.64	-41.27	-40.65	-40.84	-40.10
3 trucks	4 trucks	-40.13	-39.61	-28.91	-24.83	-28.25	-24.11	-10.18	-3.16	-43.31	-42.85	-43.20	-42.72	-43.21	-42.74	-43.17	-42.68

AVERAGE LATENESS																	
TRUCK HUB	FLEET SIZE	DEMAND															
		E (6)								E (8)							
		SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
		95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High
1 truck	2 trucks	-38.40	-37.56	-37.45	-36.38	-37.62	-36.58	-37.20	-35.95	-40.62	-39.96	-40.34	-39.63	-40.33	-39.59	-40.23	-39.44
	3 trucks	-41.35	-40.76	-41.18	-40.55	-41.23	-40.61	-41.17	-40.54	-42.35	-41.76	-42.30	-41.71	-42.31	-41.72	-42.28	-41.69
	4 trucks	-42.39	-41.81	-42.30	-41.72	-42.33	-41.75	-42.30	-41.72	-43.10	-42.54	-43.08	-42.51	-43.08	-42.51	-43.08	-42.51
	4 trucks	-40.51	-39.89	-39.20	-38.26	-39.36	-38.51	-38.75	-37.65	-41.59	-40.99	-41.17	-40.47	-41.18	-40.48	-41.05	-40.33
2 trucks	3 trucks	-42.60	-42.05	-42.49	-41.93	-42.53	-41.98	-42.46	-41.90	-43.13	-42.57	-43.10	-42.54	-43.09	-42.52	-43.08	-42.51
	4 trucks	-43.49	-42.94	-43.48	-42.93	-43.48	-42.93	-43.47	-42.92	-43.84	-43.30	-43.84	-43.30	-43.83	-43.29	-43.83	-43.29
	2 trucks	-40.73	-40.09	-39.46	-38.55	-39.54	-38.66	-38.92	-37.77	-41.74	-41.14	-41.32	-40.64	-41.34	-40.63	-41.21	-40.49
	3 trucks	-42.79	-42.25	-42.70	-42.14	-42.72	-42.17	-42.66	-42.10	-43.25	-42.70	-43.22	-42.66	-43.21	-42.64	-43.19	-42.63
3 trucks	4 trucks	-43.67	-43.11	-43.65	-43.09	-43.65	-43.10	-43.64	-43.09	-43.95	-43.40	-43.94	-43.40	-43.94	-43.40	-43.94	-43.40

AVERAGE TARDINESS																	
TRUCK HUB	FLEET SIZE	DEMAND															
		E (2)								E (4)							
		SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
		95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High
1 truck	2 trucks	11.68	13.03	96.54	101.37	97.03	102.02	99.60	104.61	4.57	5.85	7.59	10.87	8.04	11.33	10.11	13.83
	3 trucks	9.01	10.30	58.65	63.23	59.35	63.92	59.93	64.76	0.35	0.64	0.73	0.14	0.07	0.22	0.04	0.17
	4 trucks	6.63	7.73	36.75	40.99	36.66	40.85	36.74	40.95	0.05	0.12	0.00	0.02	0.01	0.03	0.00	0.01
	4 trucks	7.56	8.60	91.98	97.72	91.58	97.40	106.99	112.55	0.08	0.17	1.97	3.76	2.40	4.04	9.65	13.88
2 trucks	3 trucks	4.54	5.52	33.97	39.53	34.97	40.69	51.75	58.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	4 trucks	1.16	1.83	1.81	3.66	2.19	3.96	5.68	8.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2 trucks	8.77	9.89	91.55	97.28	91.13	96.80	107.70	113.17	0.07	0.14	1.84	3.62	2.34	4.03	9.86	14.11
	3 trucks	1.19	1.89	33.30	39.12	34.58	40.09	53.99	60.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3 trucks	4 trucks	0.01	0.04	0.74	1.96	1.14	2.56	10.18	14.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

AVERAGE TARDINESS																	
TRUCK HUB	FLEET SIZE	DEMAND															
		E (6)								E (8)							
		SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
		95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High
1 truck	2 trucks	0.08	0.16	0.00	0.02	0.02	0.06	0.01	0.03	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00
	3 trucks	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
	4 trucks	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	4 trucks	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2 trucks	3 trucks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	4 trucks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2 trucks	0.00	0.01	0.00													

AVERAGE TRUCK UTILIZATION																	
TRUCK HUB	FLEET SIZE	DEMAND															
		E (2)								E (4)							
		SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
		95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High
1 truck	2 trucks	88.54	89.31	93.76	94.40	94.10	94.71	94.71	95.35	85.48	86.80	89.91	91.17	89.77	91.11	90.66	91.87
	3 trucks	75.05	76.04	78.80	79.80	78.76	79.83	79.20	80.14	58.72	60.72	59.65	61.75	59.76	61.86	60.07	62.20
	4 trucks	62.68	63.77	64.21	65.29	64.18	65.36	64.30	65.42	40.32	42.04	40.48	42.26	40.48	42.26	40.57	42.34
	4 trucks	99.64	99.75	99.83	99.90	99.82	99.89	99.86	99.93	84.69	86.50	94.48	96.28	94.40	96.25	96.74	98.13
2 trucks	3 trucks	97.00	97.41	99.38	99.54	99.43	99.59	99.56	99.70	58.47	60.37	60.49	62.67	60.50	62.69	61.58	63.99
	4 trucks	86.58	88.05	93.31	94.74	93.29	94.72	95.52	96.72	40.83	42.49	41.16	42.91	41.18	42.91	41.23	43.05
	2 trucks	99.85	99.92	99.87	99.93	99.89	99.94	99.88	99.94	84.19	85.92	94.32	96.20	94.42	96.31	96.82	98.23
	3 trucks	97.71	98.36	99.68	99.81	99.71	99.82	99.73	99.85	58.46	60.39	60.60	62.70	60.78	62.91	61.63	63.97
3 trucks	4 trucks	84.67	86.21	94.77	96.37	95.15	96.70	97.64	98.71	40.92	42.67	41.28	43.09	41.31	43.08	41.42	43.24

AVERAGE TRUCK UTILIZATION																	
TRUCK HUB	FLEET SIZE	DEMAND															
		E (6)								E (8)							
		SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
		95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High
1 truck	2 trucks	60.80	63.18	62.56	65.26	62.44	65.04	63.01	65.68	45.67	47.66	46.34	48.47	46.40	48.52	46.61	48.80
	3 trucks	37.39	39.22	37.66	39.52	37.61	39.45	37.64	39.53	27.62	29.17	27.84	29.23	27.66	29.27	27.68	29.28
	4 trucks	25.70	27.29	25.73	27.35	25.72	27.32	25.74	27.37	19.10	20.55	19.09	20.57	19.12	20.57	19.09	20.58
	4 trucks	99.64	99.75	99.83	99.90	99.82	99.89	99.86	99.93	84.69	86.50	94.48	96.28	94.40	96.25	96.74	98.13
2 trucks	3 trucks	59.89	62.12	62.91	65.61	62.79	65.43	63.86	66.69	45.62	47.67	46.87	48.87	46.70	48.89	46.99	49.21
	4 trucks	37.54	39.36	37.87	39.75	37.83	39.67	37.97	39.88	27.71	29.33	27.80	29.41	27.83	29.42	27.81	29.44
	4 trucks	25.82	27.42	25.86	27.46	25.85	27.48	25.86	27.47	19.16	20.57	19.18	20.58	19.18	20.59	19.20	20.58
	2 trucks	99.85	99.92	99.87	99.93	99.89	99.94	99.88	99.94	84.19	85.92	94.32	96.20	94.42	96.31	96.82	98.23
3 trucks	3 trucks	37.60	39.48	37.91	39.78	37.90	39.76	38.03	39.90	27.81	29.37	27.89	29.46	27.91	29.49	27.93	29.51
	4 trucks	25.85	27.43	25.92	27.51	25.90	27.49	25.93	27.52	19.18	20.66	19.20	20.67	19.21	20.67	19.21	20.67

NUMBER OF TARDY JOBS																	
TRUCK HUB	FLEET SIZE	DEMAND															
		E (2)								E (4)							
		SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
		95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High
1 truck	2 trucks	28.08	29.74	101.20	103.07	101.26	102.94	100.44	102.26	13.08	15.33	40.90	50.93	42.10	52.06	46.51	56.67
	3 trucks	29.47	31.58	114.44	118.99	113.39	117.51	114.56	118.90	2.59	3.69	0.85	2.39	1.47	3.04	1.08	2.59
	4 trucks	25.48	27.43	105.77	111.57	105.76	111.66	106.16	112.35	0.63	1.04	0.07	0.33	0.27	0.71	0.07	0.39
	4 trucks	32.41	34.03	108.10	110.29	108.63	110.85	96.04	97.82	1.17	1.85	20.11	30.47	22.90	32.46	43.87	54.85
2 trucks	3 trucks	23.39	26.13	129.74	139.06	130.65	139.68	127.15	133.41	0.00	0.00	-0.01	0.02	0.00	0.02	-0.01	0.03
	4 trucks	9.20	12.20	35.76	55.79	41.56	60.26	69.89	92.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2 trucks	44.46	46.53	108.73	110.75	108.92	111.16	95.54	97.29	1.19	1.78	19.84	30.16	22.72	32.68	45.27	56.08
	3 trucks	13.38	17.38	129.76	139.91	132.48	141.00	125.62	131.37	0.00	0.03	0.00	0.00	0.00	0.03	0.00	0.00
3 trucks	4 trucks	0.41	0.88	18.88	37.51	27.67	45.51	93.15	114.55	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

NUMBER OF TARDY JOBS																	
TRUCK HUB	FLEET SIZE	DEMAND															
		E (6)								E (8)							
		SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
		95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High
1 truck	2 trucks	0.66	1.12	0.13	0.43	0.41	0.92	0.28	0.74	0.01	0.16	0.00	0.04	0.02	0.12	-0.01	0.03
	3 trucks	0.03	0.13	-0.01	0.05	0.00	0.07	-0.01	0.05	0.00	0.05	0.00	0.00	-0.01	0.03	0.00	0.00
	4 trucks	0.01	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	4 trucks	0.05	0.19	0.00	0.08	0.04	0.18	0.05	0.33	0.00	0.02	0.00	0.00	0.00	0.05	0.00	0.00
2 trucks	3 trucks	-0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	4 trucks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2 trucks	0.05	0.19	-0.01	0.03	0.06	0.22	0.05	0.33	0.00	0.03	0.00	0.00	0.00	0.04	0.00	0.00
	3 trucks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3 trucks	4 trucks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

PERCENT OF TARDY JOBS																	
TRUCK HUB	FLEET SIZE	DEMAND															
		E (2)								E (4)							
		SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
		95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High
1 truck	2 trucks	0.23	0.24	0.90	0.91	0.90	0.91	0.90	0.91	0.13	0.15	0.48	0.57	0.49	0.58	0.55	0.63
	3 trucks	0.20	0.21	0.81	0.83	0.80	0.82	0.81	0.83	0.02	0.03	0.01	0.02	0.01	0.03	0.01	0.02
	4 trucks	0.15	0.16	0.66	0.68	0.66	0.68	0.66	0.68	0.01	0.01	0.00	0.00	0.00	0.01	0.00	0.00
	4 trucks	0.20	0.21	0.91	0.92	0.91	0.92	0.92	0.93	0.01	0.01	0.23	0.33	0.25	0.34	0.54	0.64
2 trucks	3 trucks	0.12	0.13	0.81	0.84	0.81	0.84	0.85	0.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	4 trucks	0.04	0.05	0.23	0.34	0.25	0.35	0.44	0.55	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2 trucks	0.25	0.26	0.91	0.92	0.91	0.92	0.92	0.93	0.01	0.01	0.23	0.33	0.24	0.34	0.55	0.65
	3 trucks	0.06	0.08	0.81	0.84	0.82	0.85	0.86	0.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3 trucks	4 trucks	0.00	0.00	0.13	0.23	0.16	0.26	0.59	0.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

PERCENT OF TARDY JOBS																	
TRUCK HUB	FLEET SIZE	DEMAND															
		E (6)								E (8)							
		SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
		95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High
1 truck	2 trucks	0.01	0.01	0.00	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	3 trucks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	4 trucks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	4 trucks	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2 trucks	3 trucks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	4 trucks	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2 trucks	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00</								

		THROUGHPUT															
		DEMAND															
TRUCK HUB	FLEET SIZE	E (2)								E (4)							
		SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
		95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High
1 truck	2 trucks	266.46	268.58	237.03	238.96	236.92	239.13	232.92	235.24	236.17	240.11	227.78	230.94	227.79	230.77	224.54	227.48
	3 trucks	332.13	334.31	313.28	315.66	312.53	315.05	312.44	314.88	246.81	252.97	246.51	252.58	246.39	252.59	246.53	252.65
	4 trucks	379.45	382.17	365.55	368.65	366.07	368.81	365.83	369.03	247.38	253.64	247.28	253.54	247.27	253.47	247.30	253.56
	2 trucks	353.84	356.78	249.97	253.00	250.31	253.37	218.03	220.35	247.27	253.55	239.02	243.50	238.65	243.11	222.65	225.71
2 trucks	3 trucks	453.48	457.00	374.85	378.02	374.17	377.73	335.64	339.34	247.76	254.10	247.67	254.04	247.79	254.15	247.74	254.09
	4 trucks	494.21	502.27	476.84	481.88	477.33	482.52	456.92	461.38	247.87	254.19	247.90	254.22	247.89	254.19	247.88	254.20
	2 trucks	384.56	388.78	250.02	252.96	251.05	254.09	215.90	218.32	247.59	253.85	238.69	243.15	238.96	243.52	222.26	225.28
	3 trucks	492.88	500.96	376.06	379.68	375.64	379.38	325.94	329.12	247.92	254.30	247.85	254.15	247.88	254.24	247.83	254.11
4 trucks	498.92	508.30	484.61	490.79	483.80	490.00	436.21	440.24	247.94	254.28	248.00	254.34	247.96	254.30	247.96	254.30	

		THROUGHPUT															
		DEMAND															
TRUCK HUB	FLEET SIZE	E (5)								E (8)							
		SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
		95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High
1 truck	2 trucks	164.39	169.94	164.28	169.76	164.23	169.71	164.13	169.59	124.82	129.31	124.87	129.37	124.86	129.36	124.84	129.34
	3 trucks	164.53	170.13	164.61	170.23	164.58	170.15	164.61	170.21	124.85	129.39	124.88	129.42	124.85	129.39	124.87	129.41
	4 trucks	164.56	170.14	164.58	170.18	164.57	170.17	164.58	170.17	124.87	129.41	124.88	129.42	124.87	129.43	124.89	129.43
	2 trucks	164.72	170.32	164.49	170.05	164.50	170.02	164.30	169.77	124.95	129.47	124.99	129.53	125.01	129.55	124.98	129.52
2 trucks	3 trucks	164.61	170.21	164.63	170.23	164.63	170.23	164.62	170.22	124.98	129.54	124.97	129.53	124.98	129.54	124.98	129.54
	4 trucks	164.61	170.23	164.60	170.20	164.60	170.21	164.60	170.20	124.93	129.51	124.92	129.50	124.93	129.51	124.92	129.50
	2 trucks	164.75	170.35	164.53	170.13	164.58	170.12	164.31	169.81	125.02	129.55	125.06	129.58	125.05	129.57	125.04	129.56
	3 trucks	164.68	170.28	164.67	170.29	164.69	170.31	164.67	170.31	124.98	129.54	124.98	129.54	124.98	129.54	124.99	129.55
4 trucks	164.63	170.24	164.63	170.24	164.62	170.22	164.63	170.24	124.91	129.49	124.91	129.49	124.91	129.49	124.91	129.49	

		OVERALL TRAILER UTILIZATION															
		DEMAND															
TRUCK HUB	FLEET SIZE	E (2)								E (4)							
		SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
		95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High
1 truck	2 trucks	97.51	97.75	98.98	99.15	98.99	99.16	99.03	99.19	91.08	92.60	93.60	94.95	93.52	94.97	94.15	95.42
	3 trucks	97.47	97.71	98.20	98.38	98.09	98.28	98.18	98.35	71.98	74.24	72.45	74.79	72.45	74.75	72.72	75.05
	4 trucks	94.49	94.82	94.85	95.26	94.83	95.24	94.81	95.22	58.26	60.07	58.46	60.22	58.43	60.19	58.52	60.34
	2 trucks	98.83	98.95	99.76	99.83	99.77	99.83	99.79	99.85	59.52	61.89	60.64	62.14	60.42	61.91	61.82	62.46
2 trucks	3 trucks	97.36	97.91	99.09	99.33	99.14	99.37	99.31	99.54	45.02	46.42	46.29	47.97	46.27	47.95	47.11	49.11
	4 trucks	88.82	90.85	94.13	95.94	94.13	95.97	95.89	97.42	38.24	39.33	38.37	39.48	38.36	39.48	38.42	39.55
	2 trucks	98.47	98.74	99.66	99.77	99.65	99.76	99.73	99.82	42.42	44.17	43.71	45.42	43.71	45.42	43.71	45.42
	3 trucks	85.74	88.52	98.49	99.02	98.56	99.09	98.90	99.32	33.04	34.07	34.03	35.30	34.07	35.32	34.73	36.25
4 trucks	66.14	67.91	84.76	88.57	85.61	89.43	93.61	96.17	28.78	29.61	28.89	29.73	28.88	29.73	28.93	29.79	

		OVERALL TRAILER UTILIZATION															
		DEMAND															
TRUCK HUB	FLEET SIZE	E (5)								E (8)							
		SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
		95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High
1 truck	2 trucks	58.71	61.17	59.98	62.64	59.74	62.38	60.32	63.06	42.56	44.36	42.92	44.80	42.96	44.81	43.09	44.98
	3 trucks	44.91	46.60	45.04	46.77	44.98	46.72	45.06	46.79	33.19	34.53	33.22	34.55	33.21	34.55	33.23	34.57
	4 trucks	37.08	38.47	37.07	38.45	37.03	38.41	37.08	38.46	27.67	28.76	27.67	28.76	27.67	28.76	27.68	28.77
	2 trucks	35.10	36.55	37.11	39.18	36.88	38.83	37.98	40.41	25.62	26.69	26.04	27.22	26.04	27.21	26.19	27.42
2 trucks	3 trucks	28.49	29.56	28.61	29.72	28.58	29.68	28.65	29.77	21.24	22.08	21.27	22.12	21.27	22.12	21.28	22.13
	4 trucks	24.73	25.63	24.74	25.64	24.74	25.64	24.75	25.65	18.59	19.30	18.59	19.31	18.60	19.31	18.60	19.31
	2 trucks	25.06	26.08	26.53	28.01	26.42	27.86	27.25	29.15	18.30	19.05	18.61	19.45	18.59	19.42	18.73	19.61
	3 trucks	20.96	21.74	21.05	21.84	21.04	21.83	21.08	21.89	15.65	16.26	15.67	16.29	15.67	16.30	15.68	16.30
4 trucks	18.66	19.33	18.68	19.35	18.67	19.34	18.68	19.35	14.06	14.60	14.06	14.60	14.07	14.60	14.07	14.60	

		OVERALL TRUCK HUB UTILIZATION															
		DEMAND															
TRUCK HUB	FLEET SIZE	E (2)								E (4)							
		SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
		95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High
1 truck	2 trucks	46.72	47.79	46.40	47.61	46.16	47.39	45.59	46.84	45.54	47.00	44.45	45.85	44.69	46.11	43.91	45.35
	3 trucks	58.59	59.73	59.96	61.00	59.84	60.94	59.79	60.91	43.58	45.54	43.74	45.70	43.74	45.73	43.72	45.70
	4 trucks	66.29	67.37	68.34	69.48	68.47	69.56	68.33	69.46	41.06	42.89	41.11	42.91	41.19	43.00	41.21	43.06
	2 trucks	34.26	35.14	26.09	26.87	26.26	27.04	22.81	23.54	20.20	21.27	22.64	23.88	22.47	23.70	22.22	23.20
2 trucks	3 trucks	44.26	45.18	37.82	38.73	37.96	38.85	34.23	35.13	18.67	19.56	18.79	19.70	18.75	19.67	18.88	19.83
	4 trucks	45.90	47.58	45.83	47.13	45.82	47.17	44.52	45.66	18.19	19.04	18.20	19.06	18.18	19.04	18.20	19.06
	2 trucks	25.43	26.14	17.18	17.71	17.20	17.71	14.72	15.20	11.34	11.92	13.08	13.99	13.05	13.98	13.73	14.49
	3 trucks	30.15	31.61	25.77	26.39	25.64	26.30	22.34	22.93	11.01	11.56	11.03	11.57	11.02	11.57	11.03	11.59
4 trucks	25.46	26.52	29.44	30.95	29.54	31.05	28.66	29.58	10.90	11.43	10.89	11.43	10.89	11.42	10.89	11.43	

		OVERALL TRUCK HUB UTILIZATION															
		DEMAND															
TRUCK HUB	FLEET SIZE	E (5)								E (8)							
		SD		EDD		LTIS		SST		SD		EDD		LTIS		SST	
		95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High	95% CI Low	95% CI High
1 truck	2 trucks	28.99	30.66	29.10	30.74	29.02	30.71	29.17	30.85	20.97	22.32	20.96	22.32	20.99	22.35	20.95	22.32
	3 trucks	26.95	28.43	26.99	28.49	26.94	28.46	27.01	28.51	19.95	21.20	19.96	21.23	19.95	21.21	19.96	21.22
	4 trucks	26.14	27.58	26.13	27.57	26.08	27.53	26.13	27.57	19.50	20.71	19.50	20.71	19.50	20.72	19.50	20.72
	2 trucks	12.15	12.88	12.24	12.99	12.20	13.01	12.32	13.11	8.97	9.57	8.98	9.58				