Title

Highway Electrification And Automation Technologies - Regional Impacts Analysis Project: Phase Iii: Impacts Analysis Results

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Publication Date

1993

CALIFORNIA PATH PROGRAM
INSTITUTE OF TRANSPORTATION STUDIES
UNIVERSITY OF CALIFORNIA, BERKELEY

Highway Electrification and Automation Technologies - Regional Impacts Analysis Project: Phase III: Impacts Analysis Results

**Southern California Association of Governments (SCAG),
California Partners for Advanced Transit and Highways
(California PATH)**

UCB-ITS-PRR-93-21

This work was performed as part of the California PATH Program of the University of California, in cooperation with the State of California Business, Transportation, and Housing Agency, Department of Transportation; and the United States Department Transportation, Federal Highway Administration.

NOVEMBER 1993

ISSN 1055- 1425

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November 1993

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FOREWORD

A variety of organizations, too numerous to list on the report cover page, provided valuable service to this project and helped lead to its successful completion.

Phase III of the project consisted of the derivation of the impacts analysis results for each of the two advanced highway technology scenarios. Work was performed primarily by PATH and SCAG. In addition, PATH provided management overview including handling administrative issues and documentation review. Systems Control Technology, Inc., a PATH contractor on a related project and the University of California at Davis also provided technical support.

The following were the principal contributors from each supporting organization:

PATH: Mark Miller, Project Manager
Steven Shladover, PATH Deputy Director

SCAG: Anne Bresnock, Project Coordinator & Senior Planner
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Hong Kim, Principal Planner
Teresa Wang, Senior Planner

Systems Control Technology, Inc.: Edward Lechner, Senior Engineer
Daniel Empey, Senior Engineer
Jill Josselyn, Senior Engineer

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Quanlu Wang, Assistant Research Engineer

A Project Advisory Group was formed at the beginning of the study to provide guidance regarding study goals/objectives, specific methodological approaches, schedule and milestone review, and overall project evaluation. The membership was comprised of individuals from academia, as well as the private and public sectors, with interest in the applications of advanced transportation technologies. The membership list is provided at the end of the report.

Funding for this project was provided by the United States Department of Transportation, Federal Highway Administration, the State of California, Business, Transportation, and Housing Agency, Department of Transportation, and the Southern California Association of Governments.

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6.0 MOBILITY ANALYSIS OF FINAL SYSTEM DESIGNS

This report represents the third, and final, phase of the Highway Electrification and Automation Technologies Regional Impacts Analysis Project (HE&A) which was begun approximately three years ago as a joint research effort by Southern California Association of Governments (SCAG) and the PATH program at the Institute of Transportation Studies, University of California, Berkeley. The focus of the Phase III report is the assessment of regional impacts associated with application of roadway electrification, and automation technologies to selected freeway sections in the Southern California region.

Summary of Phase I and II Reports

The HE&A project's Phase I report included a summary of the assembled data and 2025 baseline (or no advanced technologies) forecasts of transportation demand, utility sector demand, and electric vehicle market penetration. Baseline mobile source emissions data associated with the 2025 transportation demand forecast were reviewed in the HE&A project's Phase II report. Continuing traffic congestion, reliance on fossil fuels, and air quality deterioration indicated in those reports for 2025 are the primary measures targeted for reduction via application of the advanced technologies evaluated in this study.

The Phase II report's primary goal was to develop the modeling frameworks for simulating implementation of the advanced technologies. The report presented the criteria utilized to select the specific configurations for each advanced technology system. Further, physical characteristics underlying the scenario development for these technologies were delineated in the Phase II report. An evaluation of scenario development considerations, such as capital and operating costs, technological availability, fundability, organizational feasibility, ease of implementation, construction phasing, other operations issues, social and political acceptance, and monitoring concerns, were discussed for each technology.

Phase III Coverage

The Phase III report begins with descriptions of the specific advanced technology scenarios that are fundamental to the regional impacts assessment. Section 6.1 identifies the alternative scenario designs for each technology that were derived from the selection of the basic technology scenarios given in the Phase II report. In Section 6.2, modeling considerations related to the transportation assignment methodologies corresponding to each scenario are provided. Section 6.3 contains the assessment of the roadway electrification and highway automation system scenarios' impacts on regional mobility. Although roadway electrification is not expected to have appreciable effects on regional mobility, mobility estimates were developed to determine possible mobility deterioration associated with alternative scenario specifications. In comparison, mobility improvements are presumed to be of primary importance for highway automation. Thus, in addition to presenting highway automation impacts on the region, counties, regional statistical areas, and freeway segments to which the technology was applied, Section 6.4 investigates the effects of highway automation on regional sub-area arterials and freeway ramps adjacent to the automated freeway sections.

Other regional impacts, such as fossil fuel energy consumption and utility demand associated with roadway electrification, and air quality impacts and other environmental issues pertaining to each technology are summarized in Sections 7.0 - 7.4. Section 7.1 specifically provides a comparative analysis of the petroleum and other energy uses for each RPEV scenario with the baseline scenario for different vehicle types. In Section 7.2, baseline emissions are contrasted with the emissions that correspond to each roadway electrification and highway automation scenario. Section 7.3 details the calculations of total electricity demand required for each roadway electrification application. Other environmental issues summarized in Section 7.4 related to roadway electrification include battery disposal and electromagnetic fields considerations.

The economic assessment of roadway electrification is provided in Sections 8.0 - 8.5. An overview of the cost model methodologies utilized to develop the user cost and regional economic cost estimates are given in Section 8.1. Identification of the input parameters and results for the base case user and regional cost models are provided in Section 8.2. A sensitivity analysis of user and regional costs is developed for roadway electrification in Sections 8.3. Comparisons of gasoline vehicle and baseline roadway powered electric vehicle (RPEV) user costs are also included in the sensitivity analysis. Section 8.4 provides a qualitative assessment of the roadway electrification system's impact on the regional economy. Alternative policies to implement the roadway electrification system are analyzed in Section 8.5.

Demonstration opportunities for roadway electrification and highway automation conclude the report in Sections 9.0-9.5 and 10.0-10.5. Section 9.1 identifies several possible applications for roadway electrification while Section 9.2 summarizes the Playa Vista testing and demonstration study. In Section 9.3 freeway and arterial demonstration opportunities are evaluated. Section 9.4 describes *ongoing* RPEV research needs, and Section 9.5 provides guidelines for development of an evaluation plan for future demonstration projects. Section 10.0 contains recommendations concerning feasible timeframes for implementing highway automation. In Sections 10.2 and 10.3 some potential costs and benefits corresponding to implementing the automation technology are presented. Finally, Section 10.4 discusses social and institutional impacts of highway automation, and Section 10.5 gives strategies for demonstrating the automated technology.

6.1 ADVANCED TECRNOLOGY SCENARIO DESCRIPTIONS

In the Phase II report sensitivity analysis of AM-peak trip distribution data were analyzed employing alternative VMT market penetration and network size assumptions to guide selection of the specific configurations for the 2025 roadway electrification and highway automation scenarios. The methodologies which led to the choice of these scenarios incorporated physical characteristics of each technology, and identification of the potential number of trips, and associated VMT, that could be serviced with the technologies. The final freeway network configurations given in that report combined statistical data associated with the distribution of trips, and reviewer comments on our analysis as presented in the draft of the Phase II report.

Hiahwav Automation

The final highway automation scenario encompasses an ambitious freeway network size, approximately 2,165 lane miles, and incorporates a 45% AM-peak VMT market penetration, or 24,268,500 VMT, which represents 19.3% of total AM-peak trips, or 1,047,699 trips. It was assumed that short freeway trips, those less that 4.0 miles in length, would not utilize the automated facility. The choice of an ambitious network size coupled with a 45% market penetration was selected to allow sufficient development of the technology for evaluation purposes. The automation scenario network defined in the Phase II report was accepted without further modification for use in the impacts analysis. Figure 13 repeats the 2025 automation scenario network for ease of exposition in this report. (See also Figure 11, p. 5-25, Phase II Report).

Several design considerations incorporated in the development of the automation scenario are important to review. To ensure maximum safety, automated lanes are modeled as separate facilities throughout the analysis. That is, only trips designated as automated trips are permitted access to the specified automated lane/s. Non-automated, or trips performed by conventional vehicles, travel in mixed flow lanes. Automated vehicles traveling in 15 vehicle platoons at 55 mph are assumed to enable lane capacities to reach 6,000 vehicles per lane per hour. Figure 14 depicts the communication and lateral guidance controls that would be operational in an automated highway system. Automatic braking and headway keeping are additional features of a fully automated system but are not shown in Figure 14.

It was previously asserted that special access and egress facilities, such as additional ramps for automated traffic, would not be modeled in this study. This report expands on the previous work in this area to include two automation scenarios: one without

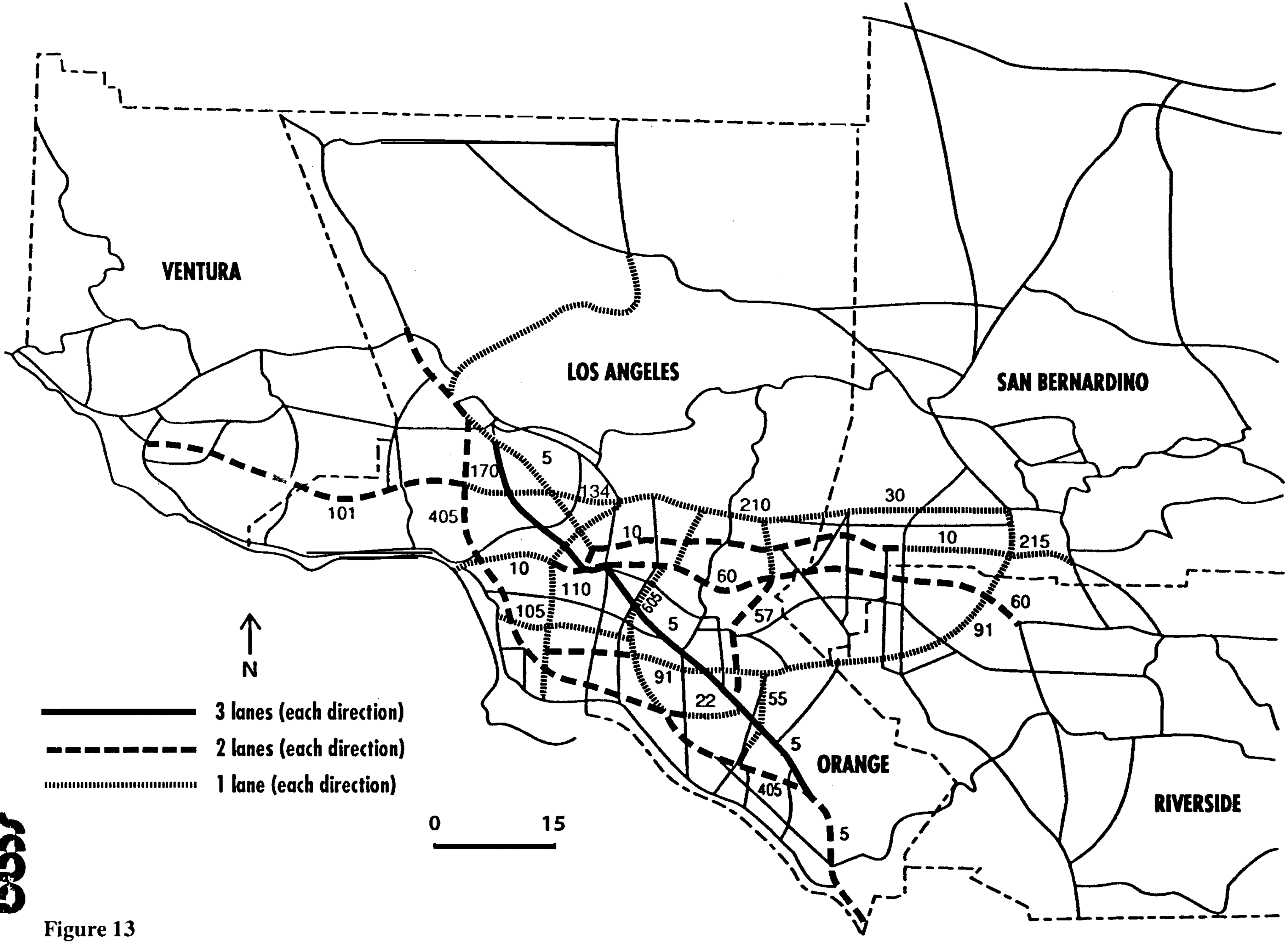


Figure 13
Automation Scenario
2025 Regional Highway Network

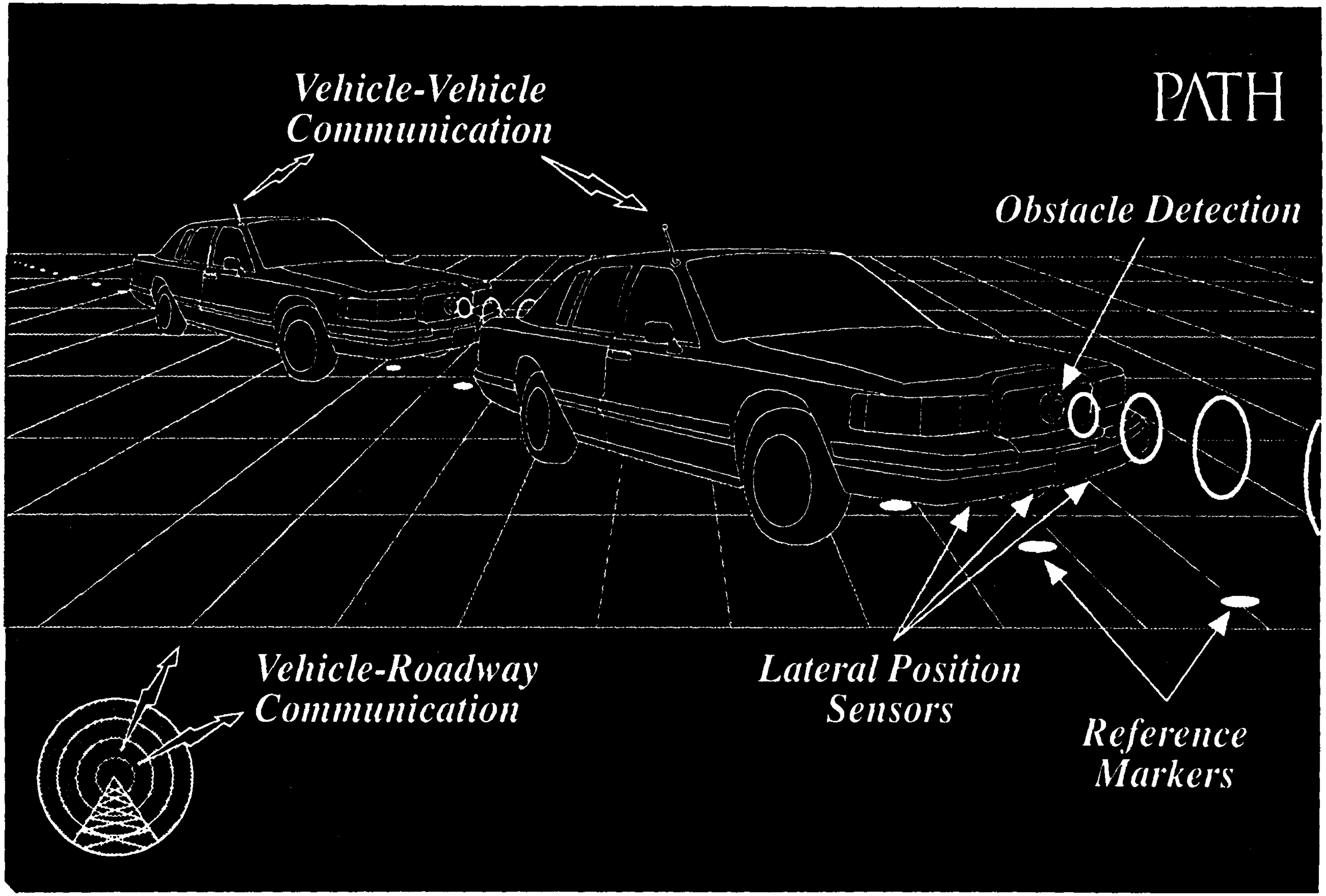


Figure 14 TECHNICAL CONCEPT FOR HIGHWAY AUTOMATION

additional ramp facilities, thus including only those ramps that may be utilized by passage from mixed flow lanes, and a second that incorporates additional ramp facilities to allow automated vehicles to separately exit the freeway to adjacent arterials. In the first scenario, automated vehicles would necessarily merge with mixed flow traffic prior to leaving the freeway system. Such merge points occur at approximately five mile intervals or less and were designed similarly to the merger points described in the roadway electrification scenario. The two automation scenarios are refereed to as the base network ramps and the additional ramp facilities scenarios in all subsequent analysis.

Roadway Electrification

The final roadway electrification scenario includes a modest freeway network size, approximately 1,035 lane miles, and assumes a 15% AM-peak VMT market penetration, or 6,632,400 VMT, which represents 3.28% of total AM-peak trips, or 173,410 trips. High per mile infrastructure cost was the primary concern in selecting the size of the freeway network. Conservative evaluatior of the market penetration of the roadway electrification technology also supported the choice of a small network size. The choice of the number of lanes to which the technology was applied on the RPEV network was determined by analysis of traffic volumes on that freeway network. The complete methodology used for the selection of the number of lanes for each electrified freeway segment is given in the Phase II report.

The number of lanes contained in the roadway electrification network was modified slightly for the final system analysis from that presented in the Phase II report (see Table 5.1, p. 5-9). A reassessment of model output of traffic volumes from the RPEV trip assignment to the regional highway system indicated that some tapering of the number of lanes on certain long freeway segments was warranted. These modifications in the number of lanes are included in the final lane recommendations shown in Table 6.1. For example, lowering the number of lanes on the 5(S) from 3 to 2 lanes at the Jeffrey Road Interchange, and decreasing the number of lanes on the western portion of the 101 freeway from 2 to 1 at Thousand Oaks (Jct. of Rte. 23), were included in the revisions. Appendix M lists the complete breakdown of the freeway sections contained in the roadway electrification scenario, and the total number of lane miles associated with each segment. Figure 15 depicts the RPEV scenario that provides the basis for all subsequent analysis.

In addition to the specifications for the RPEV scenario network given in Table 6.1, it is important to recall a few supplementary design specifications of the RPEV system. The assumption of a derated battery range of 40 miles was imbedded in the development of the RPEV scenario. The derating factor is defined as the ratio between conventional (or total) and derated battery range, and is a function of the daily travel and recharging pattern for each

Table 6.1 Roadway Electrification Scenario: Final Lane Recommendations[a]

Freeway Sections	Number of Lanes[b]
405 (N)	2
405 (S)	2,1
5 (N)	2,1
5 (S)	3,2
110	1
10 (W)	1,2
10 (E)	2,1
105	1
57	1
91	2
101	2,3

[a]Note: = Lane recommendations are revised from those given in the Phase II report, Table 5.1, p. 5-9.

[b] = Some freeway sections have two lane recommendations due to lower volumes on those segments. Also see Appendix M.

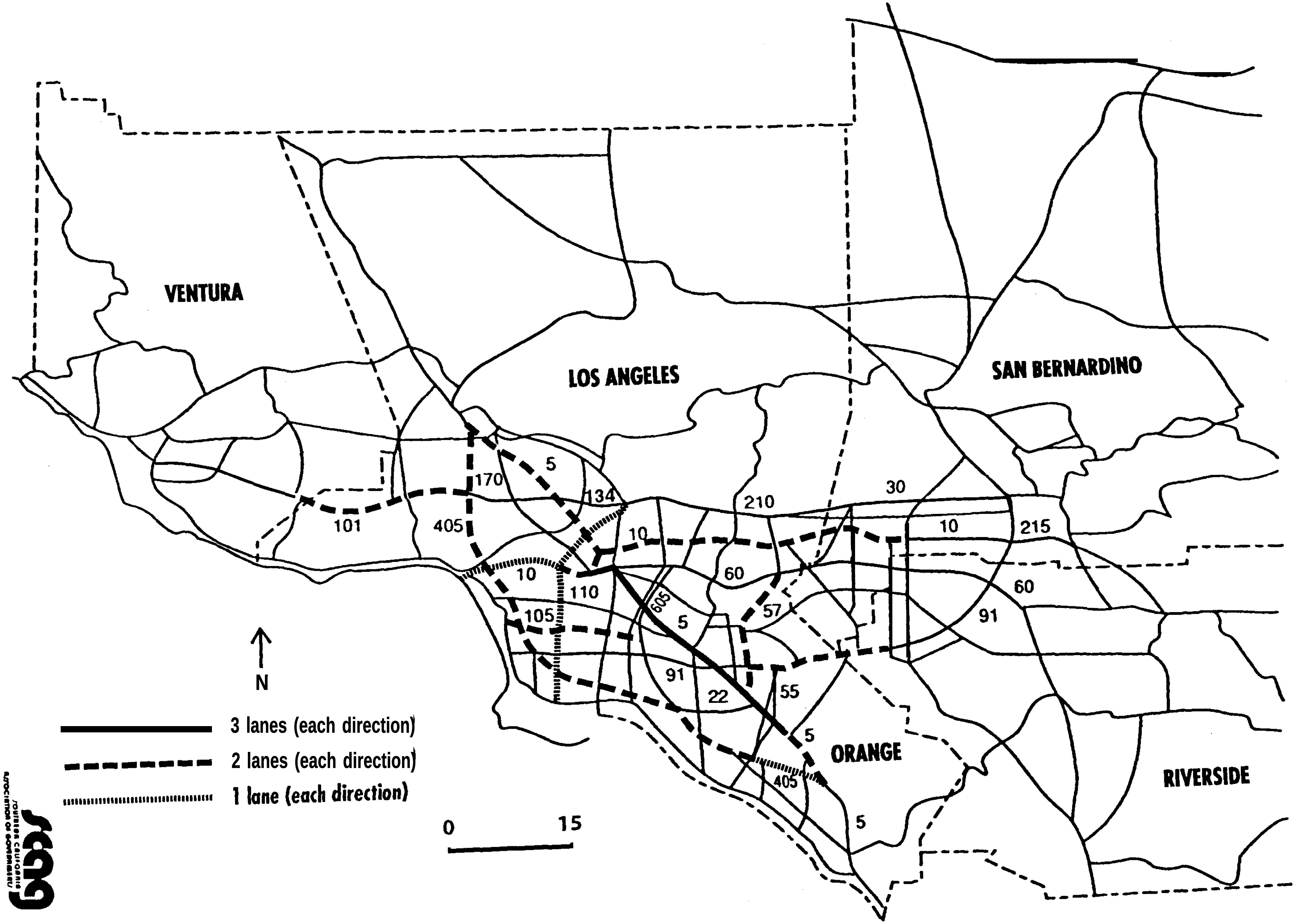


Figure 15
RPEV Scenario
2025 Regional Highway Network

vehicle. The previous sensitivity analysis with respect to alternative battery ranges, and knowledge of battery technology progress suggested this choice for the study.

Lane capacity restrictions were not required for the roadway electrification technology although attention was given to designating an RPEV network that kept volume/capacity ratios as close to one as possible. In cases where V/C ratios were above one, comparisons of V/C ratios on parallel RPEV and mixed flow freeway lanes were compared to determine whether the RPEV facility was of sufficient size to accommodate the demand in those freeway sections. In some cases, relatively high levels of congestion were experienced similarly across all lanes of the freeway sections, i.e. 5(S) between the 10 and the 55, 10(W) between the 110 and La Brea Boulevard.

Special access and egress facilities were not modeled in the applications of roadway electrification to the freeway system, i.e. fly-over ramps connecting RPEVs directly from electrified roadway lanes to adjacent arterials. The RPEV facility configuration does not, however, allow RPEVs access and egress to arterials at all points provided for mixed flow traffic in the base network. The system design requires RPEVs to traverse mixed flow lanes to enter or leave the RPEV facility in order to utilize access and egress opportunities that connect mixed flow lanes to surrounding ramps and arterials. RPEV facility *mergers* with mixed flow traffic occur approximately every five miles or less depending on the number of ramp connectors and the traffic volume on a particular freeway section. For example, on the 10(W) freeway segment between the Route l/Lincoln Boulevard intersection in Santa Monica and the 405(N) intersection, there are three access/egress points for mixed flow traffic -- at Cloverfield/26th Street, Centinela Avenue, and Bundy Drive. RPEVs entering the roadway electrification facility at Route l/Lincoln Boulevard may merge with mixed flow traffic only at Centinela Avenue. Should RPEVs wish to enter or exit the powered roadway lanes at Cloverfield/26th Street or Bundy Drive, they must merge with the mixed flow traffic prior to those entry or exit points so as to utilize the ramp facilities provided from the mixed flow lanes to arterials at those intersections. In this example, the RPEV/mixed flow mergers occur at roughly two mile intervals, whereas on the 101 freeway in the western sections of the San Fernando Valley, or on the eastern portions of the 10 freeway, RPEV/mixed flow merger opportunities were developed at approximately five mile intervals. In selecting the merge points for RPEV and mixed flow traffic, attention was given to the location of concentrated activities, such as airports, business centers, major shopping developments, large sporting or entertainment complexes, etc. Merger points relative to such activity centers were designed to minimize travel inefficiencies, that is, to allow minimal interference of the facility configuration and the travel path of the RPEV trip.

Lane separation facilities between RPEV and mixed flow lanes were not modeling requirements for the RPEV facility design since the technology does not prohibit RPEVs from traveling with conventional traffic. Considerations regarding separation of RPEVs from mixed flow vehicles may, however, assist in connecting roadway costs to users that travel on the powered roadway infrastructure. Although electronic toll collection devices could be utilized to determine RPEV usage of the roadway for user financing purposes, two RPEV scenario assignments were designed to analyze the impacts of separate and non-separate RPEV facilities. The RPEV exclusive scenario allows only trips performed by RPEVs to travel on the RPEV lanes. The RPEV non-exclusive scenario permits all trips to utilize the RPEV lanes to complete their travel plans. These two RPEV scenarios are developed in the assignment stage of the modeling process to examine the results of this consideration on regional impacts.

6.2 TRANSPORTATION TECHNOLOGY ASSIGNMENT METHODOLOGIES

The number of trips served by roadway electrification or automation capabilities were determined in the Phase II report given the market penetration assumptions of each scenario. In sum, the designated percentage of trips to be penetrated by the technology were chosen from a subset of the on- and off-freeway trip length combinations associated with the freeway network selected for each technology. Numerous trips of different origins and destinations are represented by each on- and off-freeway trip length combination. Those trips specified as RPEV or automated trips were randomly chosen from the trips classified in each origin-destination group per-on- and off-freeway trip length combination. This method of trip selection was utilized in the assignment methodologies for both advanced technologies.

The assignment of the RPEV or automated trips and those performed by conventional vehicles encompasses the method of loading trips onto the freeway system specified for each technology. Given restrictions of the available transportation model utilized in the analysis, it was not possible to load mixtures of conventional trips and trips equipped with an advanced technology simultaneously. In other words, trips designated as performed by RPEVs or automated vehicles were assigned separately from those completed by conventional vehicles. Prioritizing trip loading and choosing the amount of trips to be loaded iteratively to the highway system *were* possible modeling options in the trip assignment procedure. Decisions concerning ordered trip loading as well as the selected number of trips loaded in each iteration of the assignment process varied due to scenario assumptions and considerations pertaining to the characteristics of each advanced technology.

Highway Automation

Initial trip assignments were performed to investigate the effects that prioritization of automated trips and conventional trips would have on mobility indicators. The percentage of automated trips out of total AM-peak trips selected to utilize the automation facility was 19.3%. Comparisons of traffic volume statistics on the automated freeway links resulting from loading automated trips first and second showed noticeable differences throughout the automated freeway system. Assigning the automated trips after the conventional vehicle trips was ultimately chosen as the trip loading procedure for the impact analysis since this ordering appeared to be a more realistic representation of expected travel behavior. More specifically, assigning the automated trips after conventional vehicle trips would attach a small time penalty to automated travel that would result from traversing congested conventional traffic in order to *enter* and exit automated lanes.

Due to the technical characteristics of the automation technology, specifically the requirement that the V/C ratio not exceed 1.0 *on* any of the links of the automation facility, it was necessary to develop further refinements to the trip assignment procedure. Initially, the speed-volume relationship defined by the Bureau of Public Roads as

$$\text{Speed} = \text{Speed}, / (1 + .15 (V/C)^4)$$

$$\text{where Speed}, = 55 \text{ m/h},$$

was utilized in modeling trip assignment. After first loading the conventional vehicle trips to the automation scenario network's mixed flow lanes, 30% of the automated trips were assigned to the automation network. A review of link traffic volumes was then performed to determine if congestion had developed on any of the links of the automated facility. Congestion was evident if reported link V/C ratios were above 1.00. For links that indicated

$v/c > 1.00$, Speed = 1 m/h

$v/c < 1.00$, Speed = 55 m/h

These alterations were utilized to prevent trips from entering the congested freeway links and contributing to further mobility deterioration. Trip loading proceeded by loading the remaining automated trips in 10% increments. After each automated trip increment was assigned, V/C ratios *on* each link of the automated facility were studied to determine which links possessed V/C ratios above 1.00. Again, those links indicating V/C ratios greater than 1.00 were assigned speeds equal to 1 mile per hour and those links with V/C ratios less than one were assigned speeds of 55 miles per hour for purposes of subsequent trip loadings. Speeds on all automated network links, including those previously assigned a 1 mph speed for trip loading purposes, were maintained at 55 mph for purposes of calculating mobility statistics. This procedure continued with automated trip loadings in 10% increments until all automated trips had been assigned to the automation scenario network. This method approximates the automation technology concept given current transportation modeling capabilities.

Table 6.2 presents a summary of the V/C ratios that were produced for each automation scenario after the trip assignments were concluded. For the base network ramps scenario, 81.2% of the automated links had V/C ratios below 1.00, where as the additional ramps scenario indicated that 77.5% of the automated links had V/C ratios less than 1.00. Table 6.3 provides closer inspection of the frequency of V/C ratios above 1.00 than remained on the automated links. For the base network ramps scenario 100.0% of the automated links had V/C ratios less than 1.19 while the additional ramps scenario contained V/C ratios less than 1.20 on 98.5% of the automated links. The automation lane capacity definition of 6,000 vehicles per lane per hour was used to compute the V/C ratios in this analysis. Altering this assumption would, of course, change the number of automated links indicating congestion. For example, an automated lane capacity definition of 7,000 vehicles/lane/hour would yield fewer automated links above a V/C of 1.00, whereas a 5,000 v/l/h assumption would generate more automated links with V/C ratio above 1.00. Given transportation modeling limitations that prevented prohibition of V/C ratios from exceeding 1.00 on all automated lanes, which would perfectly capture the automation technology concept, and acknowledging that the automation lane capacity definition is not precisely determined, the results were accepted for further impacts analysis purposes.

A review of the allocation of post-trip assignment VMT associated with the automated trips revealed that 25.6% of systemwide VMT occurred on the automated freeway, or 13,402,185 VMT, in the base network ramps scenario. For the additional ramps scenario, 28.9% of VMT for the regional highway system traveled on the automated lanes, or 15,062,662 VMT. Total regional VMT for the base network ramps and additional ramps scenarios are 52,433,323 and 52,202,568, respectively. The slight VMT difference arises from the difference in the scenarios, Total VMT attributed to the automated vehicles for both on and off-automated network travel were 23,594,995 for the base network ramps scenario, and 23,491,156 for the additional ramps scenario. The automated lanes in the base network ramps scenario carried 56.8% of the assigned VMT while in the additional ramps scenario, automated lanes contained 64.1% of the automated vehicles' VMT. These percentages indicate the portion of automated trips performed on the automated facility, while the remaining VMT driven by the vehicles equipped for automated operation occurred on other highway facilities, i.e. mixed flow lanes, ramps and

TABLE 6.2 2025 HIGHWAY AUTOMATION

FREQUENCY DISTRIBUTION OF AUTOMATED LINK V/C RATIOS

Base Network Ramps[a]

V/C Ratio	Frequency	%	Cumulative Frequency	Cumulative %
0.0000 - 0.2499	375	25.7	375	25.7
0.2500 - 0.4999	271	18.6	646	44.3
0.5000 - 0.7499	298	20.4	944	64.7
0.7500 - 0.9999	240	16.5	1184	81.2
1.0001 - 1.2499	274	18.8	1458	100.0

Additional Ramps[b]

V/C Ratio	Frequency	%	Cumulative Frequency	Cumulative %
0.0000 - 0.2499	234	16.0	234	16.0
0.2500 - 0.4999	309	21.2	543	37.2
0.5000 - 0.7499	261	17.9	804	55.1
0.7500 - 0.9999	326	22.4	1130	77.5
1.0001 - 1.2499	327	22.4	1457	99.9
1.2500 - 1.4999	1	0.1	1458	100.0

Note: a = Base network ramps for the automated facility occur at approximately five mile intervals where access and egress points allow automated traffic to exit the freeway along with mixed flow traffic.

b = Additional ramps for the automated facility (that is, in addition to those in a) occur to enable automated traffic to exit at all other points where ramps exist for mixed flow traffic. These added ramps carry only automated trips.

Table 6.3 2025 HIGHWAY AUTOMATION

FREQUENCY DISTRIBUTION OF AUTOMATED LINKS V/C > 1

Base Network Ramps[a]

V/C Ratio	Frequency	%	Cumulative Freauency	Cumulative %
1.0001 - 1.01	22	8.0	22	8.0
1.0101 - 1.02	32	11.7	54	19.7
1.0201 - 1.03	21	7.7	75	27.4
1.0301 - 1.04	48	17.5	123	44.9
1.0401 - 1.05	16	5.8	139	50.7
1.0501 - 1.06	6	2.2	145	52.9
1.0601 - 1.07	26	9.5	171	‘62.4
1.0701 - 1.08	12	4.4	183	66.8
1.0801 - 1.09	13	4.7	196	71.5
1.0901 - 1.10	12	4.4	208	75.9
1.1001 - 1.11	19	6.9	227	82.8
1.1101 - 1.12	15	5.5	242	88.3
1.1201 - 1.13	14	5.1	256	93.4
1.1301 - 1.14	3	1.1	259	94.5
1,1402 - 1.15	7	2.6	266	97.1
1.1501 - 1.16	0	0.0	266	97.1
1.1601 - 1.17	0	0.0	266	97.1
1.1701 - 1.18	5	1.8	271	98.9
1.1801 - 1.19.	3	1.1	274	100.0

Note: a = See Table 6.2

Table 6.3 2025 HIGHWAY AUTOMATION (Con't.)

FREQUENCY DISTRIBUTION OF AUTOMATED LINKS WITH V/C > 1

Additional Ramps[b]

V/C Ratio	Frequency	%	Cumulative Frequency	Cumulative %
1.0001 - 1.01	36	11.0	36	11.0
1.0101 - 1.02	41	12.5	77	23.5
1.0201 - 1.03	29	8.8	106	32.3
1.0301 - 1.04	31	9.5	137	41.8
1.0401 - 1.05	39	11.9	176	53.7
1.0501 - 1.06	24	7.3	200	61.0
1.0601 - 1.07	19	5.8	219	66.8
1.0701 - 1.08	22	6.7	241	73.5
1.0802 - 1.09	17	5.2	258	78.7
1.0901 - 1.10	12	3.7	270	82.3
1.1001 - 1.11	12	3.7	282	86.0
1.1101 - 1.12	5	1.5	287	87.5
1.1201 - 1.13	8	2.4	295	89.9
1.1301 - 1.14	12	3.7	307	93.6
1.1401 - 1.15	3	0.9	310	94.5
1.1501 - 1.16	0	0.0	310	94.5
1.1601 - 1.17	2	0.6	312	95.1
1.1701 - 1.18	7	2.1	319	97.3
1.1801 - 1.19	1	0.3	320	97.6
1.1901 - 1.20	3	0.9	323	98.5
1.2001 or more	5	1.5	328	100.0

Note; **b** = See description Table 6.3

arterials. The regional impacts described throughout Sections 6.3 and 6.4 are derived from the portion of each automated trip that occurs on the automated facility.

Roadway Electrification

The decision to assign RPEV trips before or after trips performed by conventional vehicles involved assignment tests to review possible differences in mobility statistics resulting from such prioritization. Given the small percentage of trips that were designated as RPEV trips, 3.28% of AM-peak trips, analysis of traffic volume plots on the RPEV freeway network indicated negligible differences in the distributional pattern and magnitude of traffic volumes when comparing the two assignments. For the subsequent impact analysis, we dispensed RPEV trips first and conventional vehicle trips second. This decision is imbedded in the impact results for both RPEV scenarios.

The chosen assignment procedure loads the specified RPEV trips onto the RPEV scenario network first to travel between trip origins and destinations. After the RPEV trips were assigned, the remaining, or conventional vehicle, trips were loaded in an iterative manner. The exclusive scenario assignment precluded conventional trips from being loaded onto the RPEV network and the non-exclusive scenario assignment placed no restrictions on where conventional trips were allowed to travel. The loading procedure allowed these trips to alter their travel plans to adjust for congestion that grew throughout the system as the number of assigned trips increased. Each trip was assumed to be completed utilizing the minimum travel time path between its origin and destination in the presence of traffic congestion.

It is important to note that only a portion of each trip, whether completed by an RPEV or a conventional vehicle, is performed on the freeway. Part of each vehicle trip occurs on arterials and ramps. In the case of the RPEV trips, an additional component of each trip occurs traversing and traveling on mixed flow freeway lanes of the freeway system. The amount of vehicle miles traveled by the RPEVs on the RPEV lanes versus the VMT associated with travel *on* other facility types was recorded after completion of the trip assignment for use in the impact analysis. The results revealed that 2,903,749 VMT was associated with RPEV travel on the RPEV facility out of total VMT attributed to RPEVs of 6,248,000, or 46.5% of all RPEV vehicle miles traveled. (The 6,248,000 VMT represents the VMT associated with RPEVs as a result of modeling the trip assignment. These RPEV vehicle miles traveled correspond to the pre-assignment selection of 6,632,400 VMT designated for market penetration in the previous analysis of the RPEV scenario network's trip length distribution table output. The difference between the two RPEV vehicle miles traveled figures occurs due to the modeling procedures that are used to generate these measures. The trip length distribution tables report zone to zone VMT, whereas the output from the trip assignment reflects the VMT associated with the entire trip path from origin to destination.)

The division of RPEV vehicle miles traveled *on* and off the powered roadway has important implications for the assessed regional' impacts. The effects of electric roadway utilization *on* electricity demand, and corresponding fossil fuel usage by time of day, and costs associated with operation of the powered roadway utilize the on-RPEV facility VMT in their calculations. The effect of RPEVs on air quality, however, are computed with respect to total RPEV vehicle miles traveled since the RPEVs contribute zero mobile *source* emissions whether the trip is completed on *or* off the electrified roadway.

6.3 Regional Mobility Impacts

This section presents the mobility results derived from the application of the advanced technology scenarios to the 2025 regional highway system. The analysis reviews comparisons of vehicle miles traveled (VMT), vehicle hours traveled (VHT), vehicle hours of delay (VHD), and average vehicle speeds for the baseline trip assignment (no advanced technology) versus the alternative automation designs: base network ramps and additional ramp facilities. Mobility indicators were reported for each scenario at the system, county, regional statistical area (RSA), and freeway segment levels. Appendices P and Q contain the complete mobility results for the automation trip assignments.

Analysis of the mobility statistics from the alternative automation scenario assignments was accomplished via three approaches. First, frequency tables presenting tallies of statistical comparisons of mobility indicators for automation's alternative assignments and the baseline assignment were compiled. This procedure condensed the output from the numerous trip assignments and enabled general conclusions to be drawn regarding whether or not the application of automation improved mobility from baseline conditions. An additional comparison of the alternative automation scenarios within each technology type was completed in the same format.

After the frequency tables were reviewed, the extent of the differences in aggregate performance measures among all three pairwise comparisons of the baseline, and the two automation *scenario* designs were analyzed. Principal congestion indicators used were VHD and speed. Average percentage changes in both delay and speed *were* derived at the following levels of aggregation: automation freeway segment, RSA, county, and regional. At the regional level, actual mobility totals for VMT, VHT, VHD, and speed were reviewed across all three scenarios, and facility types.

After the percentage changes between scenarios were reviewed, the appropriate tests for statistical significance of the results were chosen and performed. These tests were utilized to determine whether the patterns of mobility measurement differences developed in the frequency distribution and aggregate percentage change analyses *were* statistically significant or not. The choice *of* each test for statistical significance depended upon the distributional form and sample size of the mobility measurement data. Both parametric and nonparametric statistical tests were conducted since the probability distributions of the data were not precisely understood. In most cases, the number of observations was sufficient to allow assumption of approximately normal probability distributions of the data and subsequent performance of parametric tests for significant differences in the mobility measurements. The choice of applying both parametric and nonparametric testing procedures was, however, accepted as a useful crosscheck to substantiate our findings.

Mobility results were also derived for both roadway electrification designs: -- exclusive and non-exclusive, and may be found in Appendices M, N, and 0. Whereas application of the automation technology would naturally affect congestion levels because of characteristics of the automation technology itself, the roadway electrification technology has no such inherent influence. However, upon analyzing the data in Appendices N and 0, especially with respect to the baseline/RPEV non-exclusive comparison, larger amounts of delay are apparent in the RPEV scenarios than in the baseline. These delay increases were expected because transportation modeling tools placed restrictions on how the technology was represented in the scenario designs. A special facility designation (FT 6) was required to keep track of RPEV designated trips. At merge points between the roadway powered lanes and conventional lanes, identical node numbers were also required for coding purposes. Had merge points been located at all available access and egress points, the equivalency of nodes at these points would have made the distinction between FT 6 and conventional lanes (FT 1) non-existent. In both RPEV scenarios, merge points were positioned at certain locations based on specific criteria (See Section 6.1, page 6-6). However, in an actual application of the non-exclusive scenario, it would be more realistic not only to allow non-RPEV's the choice of which lane to use (electrified or not), but also the choice of weaving in to and out of all lanes, including the electrified lanes, wherever the non-RPEV travelers desired. As a result, added delay attributed not to the technology, but to modeling restrictions accumulated.

Highway Automation: Distributional Mobility Comparisons

Table 6.4 presents a summary of the mobility results reported in Appendix P. For each freeway *segment* to which the automation technology was applied, VMT, VHT, VHD and speeds were collected for the AM-peak period for the baseline (no technology), base network ramps and additional ramps automation trip assignments to the regional highway system. These mobility outputs were calculated

Table 6.4 2025 HIGHWAY AUTOMATION MOBILITY STATISTICS:

ALTERNATIVE SCENARIO DISTRIBUTIONAL COMPARISONS

Automation Network Freeway Segments

Mobility Measures (Per Lane)	Baseline > Base Ramps (%)[a]	Baseline > Added dRamps (%)[b] e	Base Ramps > d Ramps (%)[c]
VMT			
FT 1	90.0	96.7	100.0
FT7	N/A	N/A	10.0
VHT			
FT 1	83.3	96.7	96.7
FT 7	N/A	N/A	10.0
VHD			
FT 1	80.0	100.0	96.7
FT 7	N/A	N/A	0.0
SPEED			
FT 1	20.0	13.3	3.3
FT 7	N/A	N/A	3.3

Note: a = Percentage of mobility measurements for baseline (no technology) assignment greater than automated assignment with base network ramp facilities (see a, Table 6.1).

b = Percentage of mobility measurements for baseline assignment greater than automated assignment with additional network ramps (see Table 6.1).

c = Percentage of mobility measurements for automated assignment with base network ramp facilities greater than automated assignment with additional network ramp facilities.

FT 1 = Mixed flow lanes parallell to automated lane/s
FT 7 = Automated lanes
N/A = Not applicable

for the mixed flow lanes of the freeway segments located parallel to the automation facility, and the automation facility lane/s. The freeway segments are shown in Figure 13 and are described in Appendix P. (See also, Phase II Report, Appendix J, for specific definitions of each chosen freeway segment).

Table 6.4 shows the percentage of mobility measurements from the baseline assignment that were greater than those determined for the automation base ramps assignment in column two, and the automation additional ramp facilities assignment in column three. Because mobility indicators for the baseline and both automation assignment scenarios for the non-automated lanes (FT 1) were based on different numbers of lanes, all percentages were calculated on a per lane basis to insure the validity of the comparison among the scenarios. As indicated, for 80% to 100% of the automated network freeway segments' mixed flow lanes, the baseline assignment's VMT, VHT, and VHD were greater than similar mobility measurements associated with each automation scenario assignment. Similarly, for approximately 80% to 87% of these lanes the baseline assignment's speed was less than speeds of both automation assignment scenarios. These results suggest that the automation technology in both applications is correlated with mobility improvement on the mixed flow lanes.

Column four in Table 6.4 presents the *per* lane comparison of the percentage of mobility measurements from the automation base ramps assignment that exceeded those determined in the automation additional ramps assignment. The base ramps network indicates higher VMT, VHT, VHD and lower speeds for the mixed flow lanes compared with the results for the automation assignment with additional ramps. Obviously, constructing more ramps to enable automated traffic to directly enter and exit the automation facility yields greater mobility benefits for mixed flow traffic. In the base ramps automation assignment, automated trips must traverse the mixed flow lanes in order to enter or exit the automated facility. Column four also indicates that the automation additional ramps assignment carries a larger percentage of VMT and VHT at higher speeds than the automation base ramps assignment.

Table 6.5 shows analogous results to those in Table 6.4 at the RSA level of analysis. (See Figure 16). However, at the RSA level comparisons across scenarios were made for mobility measurements of FT 1 plus FT 7 instead of for FT 1 alone to insure the validity of the comparison. The general conclusions drawn from Table 6.4 are in agreement with the comparative analysis of Table 6.5. (Appendix Q provides the detailed mobility measurements that are summarized in Table 6.5). Again, the automation additional ramps assignment offers mobility advantages compared to the automation base ramps assignment.

Table 6.5 2025 HIGHWAY AUTOMATION MOBILITY STATISTICS: ALTERNATIVE SCENARIO DISTRIBUTIONAL COMPARISONS

	Regional Statistical Areas		
Mobility Measures	**Baseline >** Added **Ramps (%)**[a]	**Baseline >** **Added Ramps (%)**[b]	**Base Ramps >** **Added Ramps (%)**[c]
VMT			
FT 1 + FT 7	22.7	22.7	56.8
FT 3	93.5	93.5	78.3
FT 4	95.0	90.0	47.5
FT 5	38.6	31.8	20.5
FT 7	N/A	N/A	8.6
VHT			
FT 1 + FT 7	81.8	90.9	90.9
FT 3	87.0	87.0	63.0
FT 4	92.5	85.0	40.0
FT 5	36.4	31.8	18.2
FT 7	N/A	N/A	8.6
VHD			
FT 1 + FT 7	88.6	93.2	86.4
FT 3	69.6	71.7	56.5
FT 4	72.5	70.0	35.0
FT 5	9.1	29.5	45.5
FT 7	N/A	N/A	0.0
SPEED			
FT 1 + FT 7	6.8	2.3	11.4
FT 3	41.3	41.3	39.1
FT 4	30.0	15.0	51.3
FT 5	50.0	25.0	20.5
FT 7	N/A	N/A	31.4

Note; a = See Table 6.4
b = See Table 6.4
c = See Table 6.4

FT 1 = Mixed flow lanes
FT3 = Major arterials
FT 4 = Minor arterials

FT 5 = **Ramps**
FT 6 = Automated lanes
N/A = Not applicable

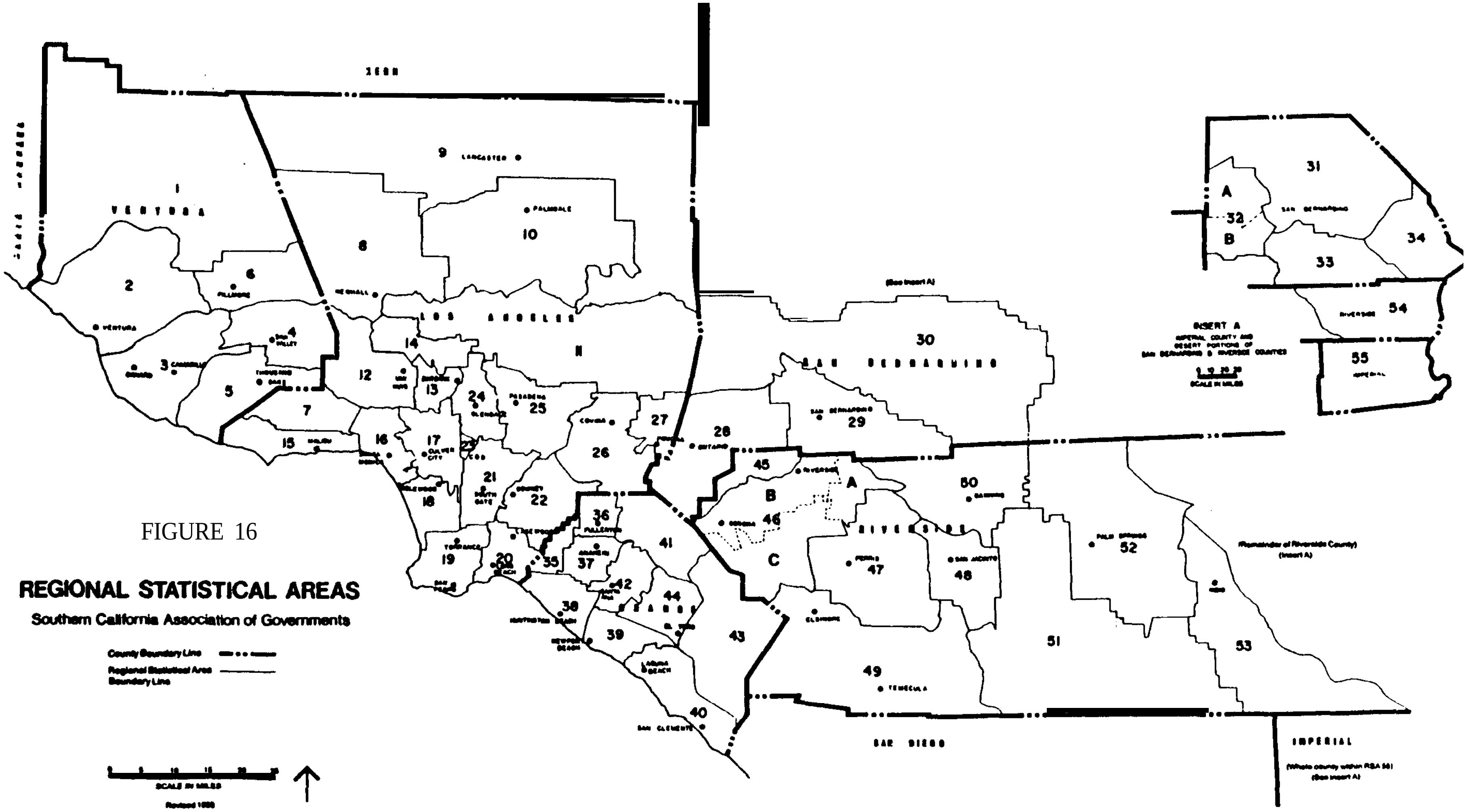


FIGURE 16

REGIONAL STATISTICAL AREAS

Southern California Association of Governments

scag
SOUTHERN CALIFORNIA ASSOCIATION OF GOVERNMENTS

Highway Automation: Aggregate Mobility Comparisons

Mobility results were compiled with respect to the highway automation technology for all three scenarios (baseline, automation base ramp, automation additional ramp facilities), for several facility types (automated lanes, mixed flow lanes, major and minor arterials), and various levels of aggregation (automated freeway corridor, regional statistical area (RSA), county, regional). The performance measures reported consisted of VMT, VHT, VHD, and speed. Of these measures, VHD and speed are the appropriate indicators of congestion and Table 6.6 reports the average percentage change in VHD and speed at different levels of aggregation, for different facility types, and all three pairwise scenario comparisons (baseline versus automation base ramp, baseline versus automation additional ramp facilities, automation base ramp versus automation additional ramp facilities). Table 6.7 summarizes actual regional totals for all relevant performance measures, over all facility types and all three scenarios.

Table 6.6 reports changes in congestion levels on a per lane basis. Note also that for RSA, county, and regional results, "FT1+FT7" refers to all freeway lanes contained within the specific area. Findings indicate congestion reduction almost uniformly across all aggregation levels, facility types, and pairwise scenario comparisons. The level of congestion mitigation increases relative to the baseline from automation base ramp to automation additional ramp facilities scenarios. This result is expected because the latter automation scenario offers more access and egress opportunities to the automated vehicle. While precise levels of congestion reduction depend on the automated lane hourly capacity, market penetration, and size of the automated network chosen for the two automation scenario designs, the mobility statistics depicted in Table 6.6 exhibit tangible evidence of congestion relief as a result of the application of the automation technology.

Congestion mitigation on arterials suggest that vehicle trips are drawn to the automated freeway lane/s, as well as mixed flow lanes, from the arterials when trips equipped with automation technology enable freeway mobility conditions to improve. That is, a larger portion of trips may now travel faster on the automated freeway lanes, as well as on the mixed flow lanes, than in the assignment without application of the automation technology. Fewer trips remain on the arterials when the option to travel with automation enhancements is present. A more detailed analysis of arterial congestion reduction is discussed in Section 6.4 below.

Table 6.7 depicts actual performance measurement totals across scenarios, and facility types. In addition to the facility types previously discussed, performance measures for freeway on- and off-ramps (FT 5) are depicted. There are mixed results across automation scenarios. Overall regional ramp congestion increases for the base ramp assignment scenario, and decreases for the

TABLE 6.6 HIGHWAY AUTOMATION MOBILITY COMPARISONS (Average Percentage Change)

	Baseline vs Base Ramps		Baseline vs Added Ramps		Base Ramp vs Added Ramps	
CC	**VHD**	SPD	**VHD**	SPD	**VHD**	SPD
FT 1	-21.6	+13.1	-45.0	+28.0	-29.7	+13.3
FT 1 + FT 7	-50.5	+63.7	-64.3	+79.7	-29.7	+ 9.5
RSA	**VHD**	SPD	**VHD**	SPD	**VHD**	SPD
FT 1 + FT 7	-39.6	+29.1	-54.5	+40.1	-25.3	+ 8.2
FT 3	-26.7	+ 4.4	-27.4	+ 4.7	- 1.9	+ 0.2
FT 4	-22.2	+ 7.1	-21.3	+ 6.4	+ 5.1	- 0.2
COUNTY	**VHD**	*SPD*	**VHD**	SPD	**VHD**	SPD
FT 1 + FT 7	**-47.0**	+26.0	-59.0	+34.2	-23.0	+ 6.2
FT 3	**-13.5**	- 2.2	-14.0	- 1.7	- 0.6	+ 0.5
FT 4	**-15.3**	+ 8.7	-17.1	+ a.5	- 1.0	-0.02
REGIONAL	**VHD**	SPD	**VHD**	SPD	**VHD**	SPD
FT 1 + FT 7	**-47.7**	+35.6	-62.3	+47.5	-27.9	+ 8.8
FT 3	**-22.9**	+ 1.1	-23.6	+ 0.5	- 1.0	- 0.5
FT 4	**-28.0**	+10.0	-27.7	+10.0	+ 0.5	0.0
ALL FACILITIES	-33.8	+21.8	-40.2	+25.9	- 9.7	+ 3.4

NOTE:

FT 1 = Mixed flow lanes
FT 3 = Major arterials
FT 4 = Minor arterials
FT 7 = Automated lanes

TABLE 6.7 HIGHWAY AUTOMATION
2025 REGIONAL HIGHWAY NETWORK
(AM PEAK)

PERFORMANCE MEASUREMENT TOTALS

		Automation Scenarios			
Baseline		Base Network Ramp Facilities*		Additional Ramp Facilities**	
FT	VMT	FT	VMT	FT	VMT
1	27,175,266	1 3	17,823,585 18,419,181	1	16,805,344
3	22,919,614			3	17,522,639
4	2,369,025	4	2,031,826	4	2,021,679
5	611,580	5	644,153	5	677,852
7	n.a.	7	13,402,185	7	15,062,662
Total	53,188,229	Total	52,433,323	Total	52,202,568
FT	VHT	FT	VHT	FT	VHT
1	940,352	1	568,178	1	
3	1,261,873	3	970,710	3	473,732 956,641
4	181,674	4	141,866	4	141,849
5	30,763	5	32,475	5	33,965
7	n.a.	7	243,643	7	273,827
Total	2,416,722	Total	1,958,924	Total	1,882,066
FT	VHD	FT	VHD	FT	VHD
1		1	233,300	1	168,190
3	446,283 516,465			3	
4	102,246	7	398,294 73,612	4	394,483 73,972
5	184	5	267	5	73
7	n.a.	7	0	7	0
Total	1,065,177	Total	705,473	Total	636,718
FT	SPEED	FT	SPEED	FT	SPEED
1		1			
3	28.90 18.16	3	32.42 18.36	3	35.47 18.32
4	13.04	4	14.32	4	14.25
5	19.88	5	19.84	5	19.96
7	n.a.	7	55.01	7	55.01
Total	22.00	Total	26.77	Total	27.74

additional ramp facilities scenario. A more detailed analysis of ramp congestion changes is discussed in Section 6.4 below. Also, note that the **"Total"** for VMT, VHT, and VHD across all scenarios are sums over all facility types **(FT's)**, while the **"Total"** under speed is the average overall speed derived from total VMT and total VHT (Total **VMT/Total VHT)**. The most striking impact on mobility displayed in Table 6.7 is the considerable decrease in VHD as a result of automation, ranging from a 34% to 40% decrease. There is a savings of 359,704 hours and 428,459 hours for the base ramp network and additional ramp scenarios, respectively.

Highway Automation: **Statistical Test Results**

Parametric and nonparametric tests for statistical significance were performed at the individual automated freeway corridor and RSA levels utilizing the VHD measurements reported for the baseline, automation base network ramps, and automation additional ramps assignments. Although parametric tests were sufficient in those tests that utilized large numbers of observations, uncertainty as to shape and location of the probability distributions of VHD suggested utilization of the appropriate nonparametric tests to validate the mobility results.

The appropriate parametric test for statistically significant differences pairs the VHD measurements across two assignments, i.e. baseline and automation base network ramp, and analyzes the differences in VHD between these assignments. The paired VHD observations were utilized to test the null hypothesis of no significant difference between **VHD** across the two assignments, against the alternative hypothesis that the VHD of one assignment was greater than the VHD of the other assignment. A statistical t test was then developed to determine whether the null hypothesis is accepted or rejected at a specified level of significance. The tabulated t statistic was recorded for the .05 level of significance and degrees of freedom. Calculated t values were constructed from the paired VHD measurement differences and compared with the tabulated t values in each test. Calculated t values exceeding tabulated t values indicated that the differences in VHD were statistically significant at the .05 level. These statistical difference results are presented in the top portions of Tables 6.8 and 6.9.

Nonparametric test formulation employed the **Wilcoxon** signed rank test for paired differences. This test is used to compare two probability distributions when a paired difference test design is appropriate, and the shapes and variances of the probability distributions are not known. This test ranks the differences in VHD between the two assignments, for a particular facility type by freeway segment or RSA, and utilizes these ranks to develop the calculated T statistic. The null hypothesis in this test stipulates that the probability distributions of the VHD measurements for both assignments are identical, **whereas the**

TABLE 6.8 2025 HIGHWAY AUTOMATION

PER LANE VHD STATISTICAL TEST RESULTS

Parametric Test Statistics: Automation Network Mixed Flow Lanes

		Calculated t		
Tabulated t	n	Case 1	Case 2	Case 3
1.70	30	3.33	5.78	4.73

Non-Parametric T Automation Network Mixed Flow Lanes

		Calculated T		
Tabulated	n	Case 1	Case 2	Case 3
152	30	80	0	3

Note:

case1 = Significance test results for comparison of baseline assignment VHD greater than automated assignment VHD with base network ramp facilities.

Case 2 = Significance test results for comparison of baseline assignment VHD greater than automated assignment VHD with additional network ramp facilities.

Case 3 = Significance test results for comparison of automated assignment VHD with base network ramp facilities greater than automated assignment VHD with additional ramp facilities.

TABLE 6.9 2025 HIGHWAY AUTOMATION

VHD STATISTICAL TEST RESULTS

Regional Statistical Areas

Parametric Test Statistics

			Calculated t		
Facility Type	**Tabulated t**	**n**	**Case 1**	**Case 2**	**Case 3**
1+7	1.68	44	5.90	6.67	6.54
3	1.68	46	4.28	4.28	1.17
4	1.68	40	2.45	2.52	-0.48

Non-Parametric Test Statistics

			Calculated T		
Facility Type	**Tabulated T**	**n**	**Case 1**	**Case 2**	**3**
1+7	336 (319)	43 (42)	31'	(8)	(31)
3	353	44	151	152	331
4	228 (214) (188)	36 (35) (33)	79	(74)	{246}

Note:

Case 1 = Se-e Table 6.8
Case 2 = See Table 6.8
Case 3 = See Table 6.8
FT 1 = Mixed Flow lanes
FT3 = Major arterials
FT 4 = Minor arterials
Numbers in ( ) are comparable due to adjustments in n.
Numbers in { } are comparable due to adjustments in n.

alternative hypothesis indicates that the probability distribution of the VHD for one assignment has shifted to the right, or contains measurements of larger value than the probability distribution of the VHD for the other assignment.

The statistical test criterion utilized in our comparisons states that if the calculated T statistic is greater than or equal to the tabulated T statistic, the null hypothesis is accepted. Therefore, the smaller the value of the calculated T, the greater will be the evidence to indicate that one probability distribution contains VHD measurements that are larger than those found in the other distribution.

In Table 6.8, both parametric and nonparametric test results reveal statistical significance for all tests. More specifically, baseline assignment VHD is greater than both automation assignment's VHD at the .05 level of significance for the mixed flow facility. In addition, the VHD associated with the base ramp automation assignment is greater than the VHD for the additional ramps assignment at the 5% level for the mixed flow lanes. These results are confirmed at the freeway segment and RSA levels of analysis.

In Table 6.9 our results indicate'that baseline assignment VHD on major and minor arterials was significantly greater than the VHD that occurred on these facilities when the automation trip assignments were deployed. These findings suggest that vehicle trips are drawn to the automated freeway lane/s, as well as mixed flow lanes, from the arterials when trips equipped with automation technology enable freeway mobility conditions to improve. That is, a larger portion of trips may now travel faster on the automated freeway lanes, as well as on the mixed flow lanes, than in the assignment without application of the automation technology. Fewer trips remain on the arterials when the option to travel with automation enhancements is present.

The statistical test results for comparisons of the automation technology assignments for arterials at the RSA level were insignificant and/or conflicting when parametric and nonparametric tests were performed. Findings pertaining to the statistical significance of mobility impacts corresponding to the alternative automation assignments on the arterials throughout each RSA, however, could dilute the immediate VHD associated with arterials adjacent to the freeway segments to which the automation technology was applied. The mobility impacts related to linkages between the automation enhanced freeway lanes, and the arterials and ramps in close proximity to these lanes, are somewhat reduced when the broader RSA level of analysis is evaluated. For this reason further statistical investigations were developed to study the impacts of the automation scenarios on arterials and ramps within approximately one mile distances of each side of the freeway segments to which the automation technology was applied. This analysis was conducted for selected geographical sub-areas of the regional highway system. Section 6.4 presents the research concerning this refinement of the automation mobility impacts.

Overall our analysis indicates that mobility improvement as indicated in Table 6.6 is statistically significant in both automation scenario assignments when compared to the baseline, no technology, assignment. The automation additional ramps assignment offers further mobility benefits to travel throughout the regional highway system's mixed flow facilities when contrasted with the automation base ramps assignment.

6.4 Automation **Sub-Area** Assessment

This section summarizes the findings of investigations concerning the automation mobility impacts on facilities connected to the automation scenario network. Six geographically diverse sub-areas of the SCAG region were selected for this analysis. Figure 17 depicts the chosen sub-areas which cover approximately 103 square mile areas each, with the exception of the Los Angeles central business district sub-area, LA CBD, which spans 25 square miles. The approximate locations of the six sub-areas are: Claremont, El Toro, LA CBD, Long Beach, Riverside/San Bernardino, and the San Fernando Valley.

Analysis of the mobility results began with compilation of the V/C ratios for each arterial link located within approximately one mile of the automated facility. For each sub-area the link V/C ratios were assembled in frequency distribution tables and graphs for the baseline, automation base ramps, and automation additional ramp facilities trip assignments. Tables 6.10 - 6.15 and the corresponding Figures 18 - 23 report these findings. In general, a larger percentage of V/C ratios fall below 1.0 in both automation assignment frequency distributions when compared with the baseline assignment frequency distributions. These results indicate that arterial travel is less congested when automation technology is applied than when it is not utilized. For example, in Table 6.10 for the Claremont sub-area, 79.81% of the arterial link V/C ratios are less than 1.0 compared to 85.71% and 83.65% for the automation base network ramps and automation additional ramp facilities assignments respectively. Figure 18 illustrates this finding with the upward, **leftward** shift of the automation assignment cumulative arterial link V/C ratio frequency distributions. The figure shows larger amounts of arterial link V/C ratios occurring at lower V/C ratio levels. These results are found for each sub-area although the degree of mobility improvement revealed in this manner varies across sub-areas. The conclusion that the presence of automation freeway lanes tended to reduce congestion on arterials adjacent to these lanes is supported with the cumulative frequency reports.

In addition to the data on arterial V/C ratios, individual link

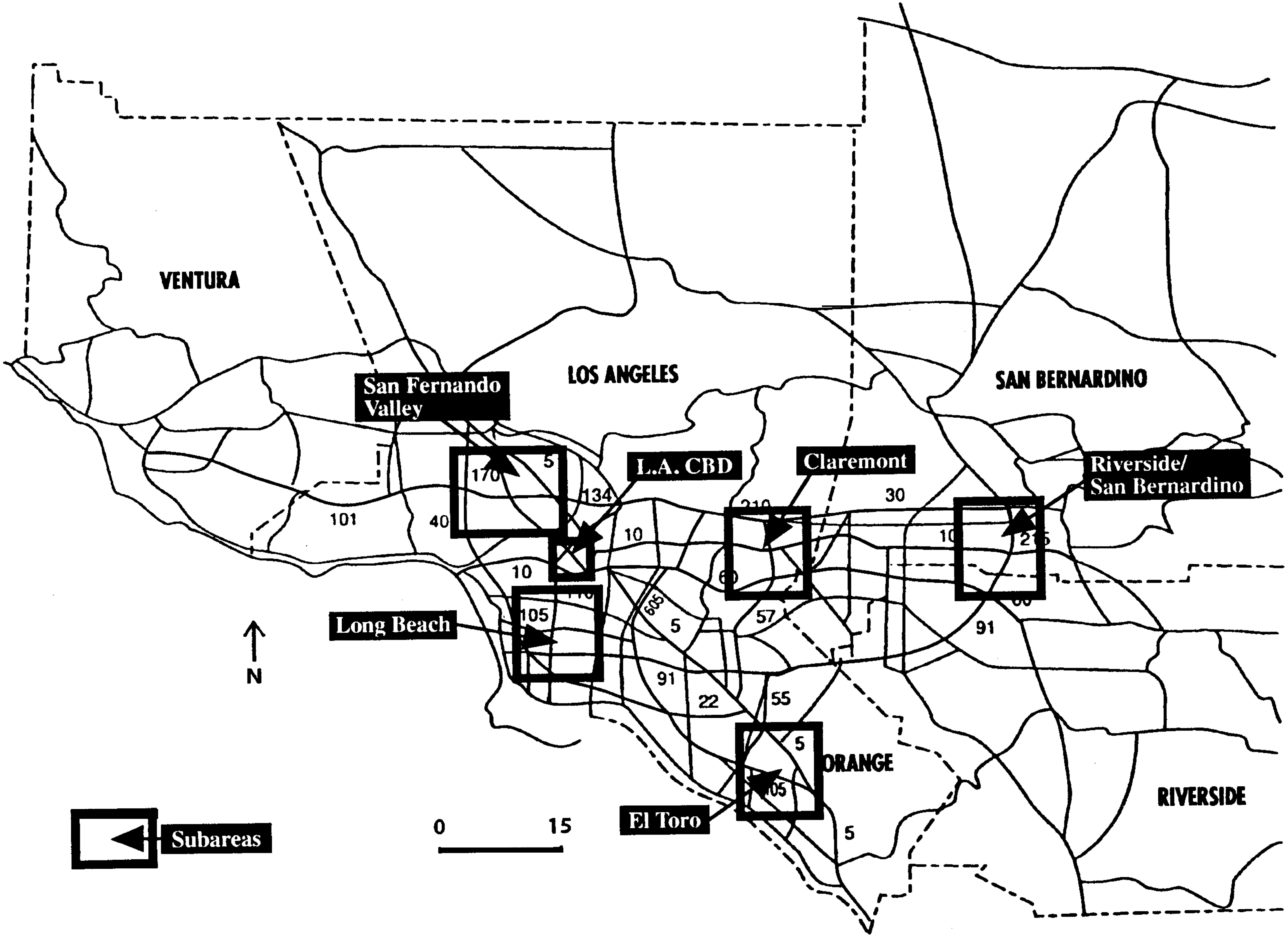


Figure 17
2025 Regional Highway Network

Table 6.10 2025 HIGHWAY AUTOMATION

V/C RATIO DISTRIBUTION ON ARTERIALS ADJACENT TO AUTOMATED FACILITIES

Claremont Sub-Area

	Alternative Scenarios Cumulative Frequency Distributions (%)		
V/C Ratio	Baseline	Base Network Ramp Facilities[a]	Additional Ramp Facilities[b]
0.1	0.96	14.29	15.38
0.2	11.54	20.00	22.12
0.3	17.31	35.24	32.69
0.4	22.12	43.81	42.31
0.5	29.81	49.52	50.96
0.6	39.42	57.14	58.65
0.7	47.12	65.71	66.35
0.8	54.81	73.33	71.15
0.9	71.15	76.19	76.92
1.0	79.81	85.71	83.65
1.1	86.54	89.52	88.46
1.2	89.42	90.48	91.35
1.3	92.31	93.33	94.23
1.4	95.19	95.24	95.19
1.5	97.12	97.14	95.19
1.6	97.12	98.10	97.12
1.7	97.12	98.10	98.08
1.8	99.04	99.05	100.00
1.9	100.00	100.00	100.00

Note: a = See Table 6.2
b = See Table 6.2

Figure 18: HIGHWAY AUTOMATION
CUMULATIVE V/C RATIO FREQUENCY DISTRIBUTION

Claremont Subregion

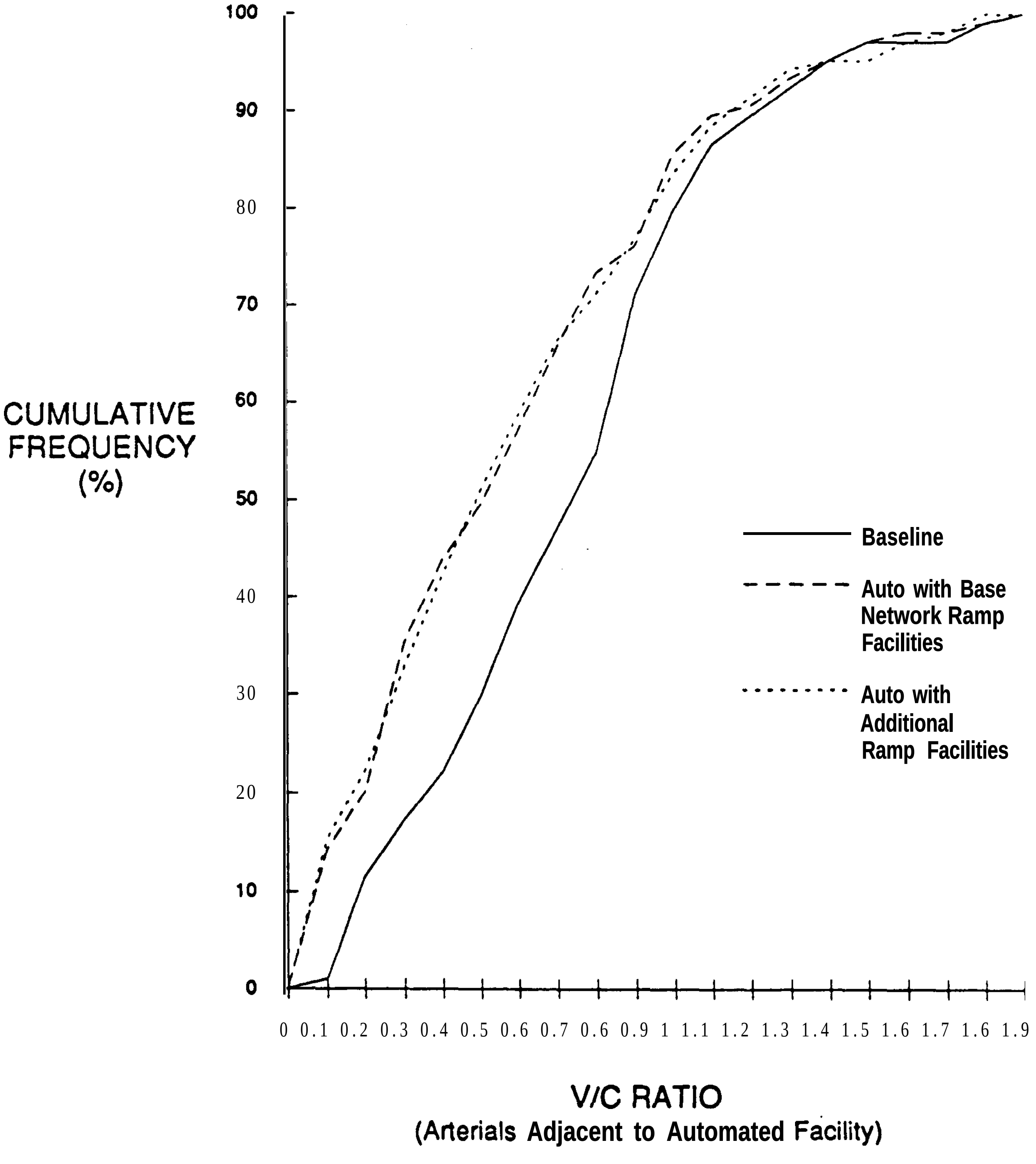


Table 6.11 2025 HIGHWAY AUTOMATION

V/C RATIO DISTRIBUTION ON ARTERIALS ADJACENT TO AUTOMATED FACILITIES

El Toro Sub-Area

Alternative Scenarios Cumulative Frequency Distributions (%)

V/C Ratio	Baseline	Baseline Network Ramp Facilities [a]	Additional Ramp Facilities[b]
0.1	0.00	0.74	0.75
0.2	0.75	2.21	3.73
0.3	4.51	2.94	9.70
0.4	5.26	8.09	14.18
0.5	7.52	16.91	17.91
0.6	9.02	22.06	28.36
0.7	18.80	29.41	31.34
0.8	24.81	33.82	36.57
0.9	33.08	41.91	45.52
1.0	39.85	50.74	49.25
1.1	48.87	56.62	55.22
1.2	54.89	67.65	64.93
1.3	62.41	74.26	70.15
1.4	68.42	80.88	77.61
1.5	76.69	86.03	82.09
1.6	82.71	88.97	85.82
1.7	87.97	91.18	88.81
1.8	92.48	92.65	91.04
1.9	93.23	95.59	93.28
2.0	94.74	95.59	95.52
2.1	95.49	96.32	97.01
2.2	96.24	97.06	97.01
2.3	96.99	97.79	97.76
2.4	96.99	97.79	99.25
2.5	97.74	97.79	99.25
2.6	97.74	99.26	99.25
2.7	99.25	99.26	99.25
2.8	100.00	99.26	99.25
2.9	100.00	100.00	100.00

Note: a = See Table 6.2 b = See Table 6.2

Figure 19: HIGHWAY AUTOMATION CUMULATIVE V/C RATIO FREQUENCY DISTRIBUTION

El Toro Subregion

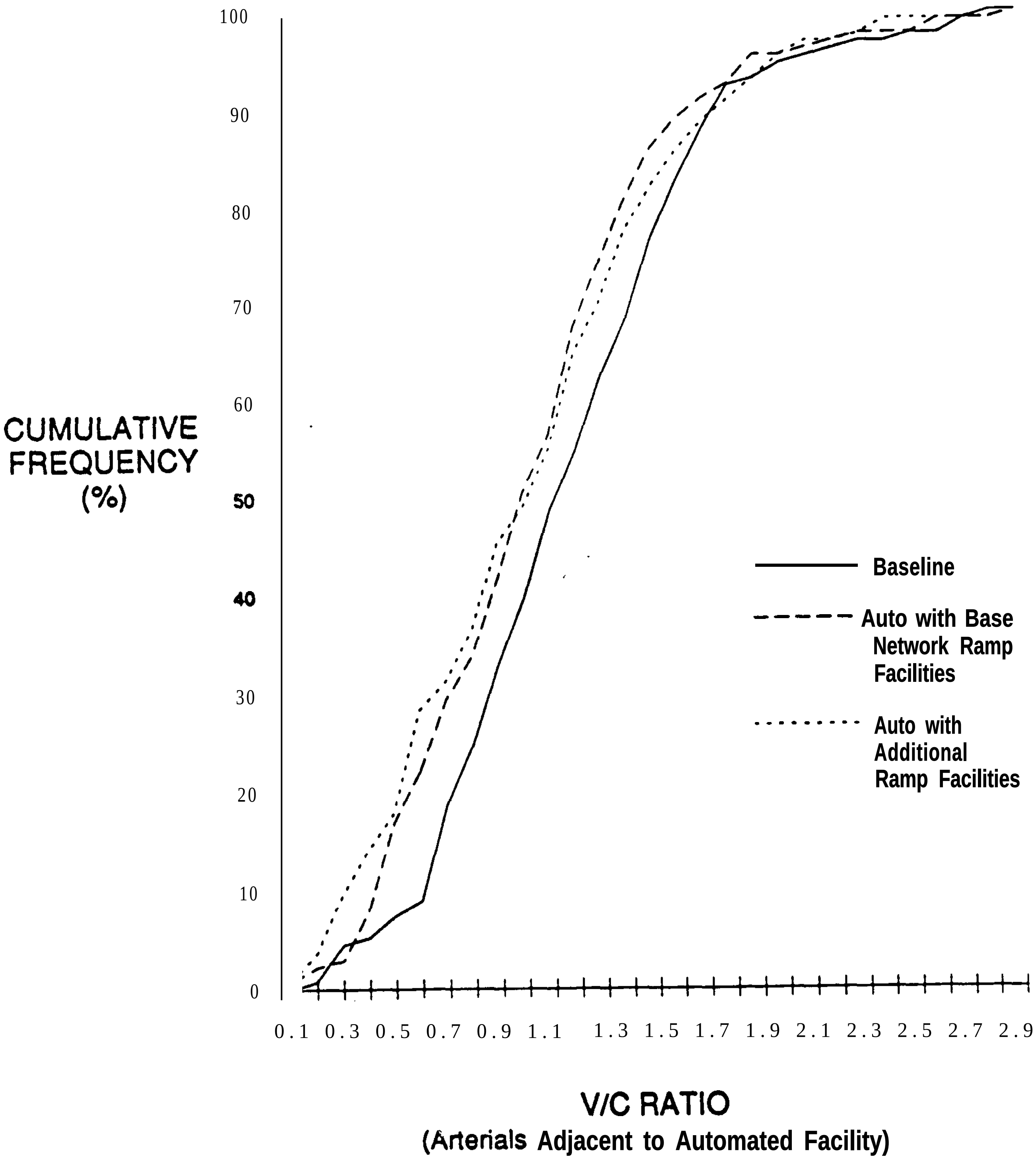


Table 6.12 2025 HIGHWAY AUTOMATION

V/C RATIO DISTRIBUTION ON ARTERIALS ADJACENT TO AUTOMATED FACILITIES

Los Angeles CBD Sub-Area

Alternative Scenarios Cumulative Frequency Distributions (%)

V/C Ratio	Baseline	Nasevork Ramp Facilities [a]	Additional mp Facilities [b]
0.1	9.30	20.63	20.63
0.2	18.60	38.10	37.30
0.3	28.68	50.79	53.17
0.4	37.98	62.70	65.87
0.5	55.04	71.43	74.60
0.6	67.44	79.37	79.37
0.7	71.32	87.30	85.71
0.8	77.52	88.89	90.48
0.9	82.17	92.06	94.44
1.0	87.60	93.65	96.83
1.1	94.57	95.24	96.83
1.2	98.45	96.03	97.62
1.3	98.45	99.21	98.41
1.4	99.22	99.21	99.21
1.5	99.22	100.00	100.00
1.6	99.22	100.00	100.00
1.7	100.00	100.00	100.00

Note: a = See Table 6.2
b = See Table 6.2

Figure 20: HIGHWAY AUTOMATION CUMULATIVE V/C RATIO FREQUENCY DISTRIBUTION

Los Angeles CBD Subregion

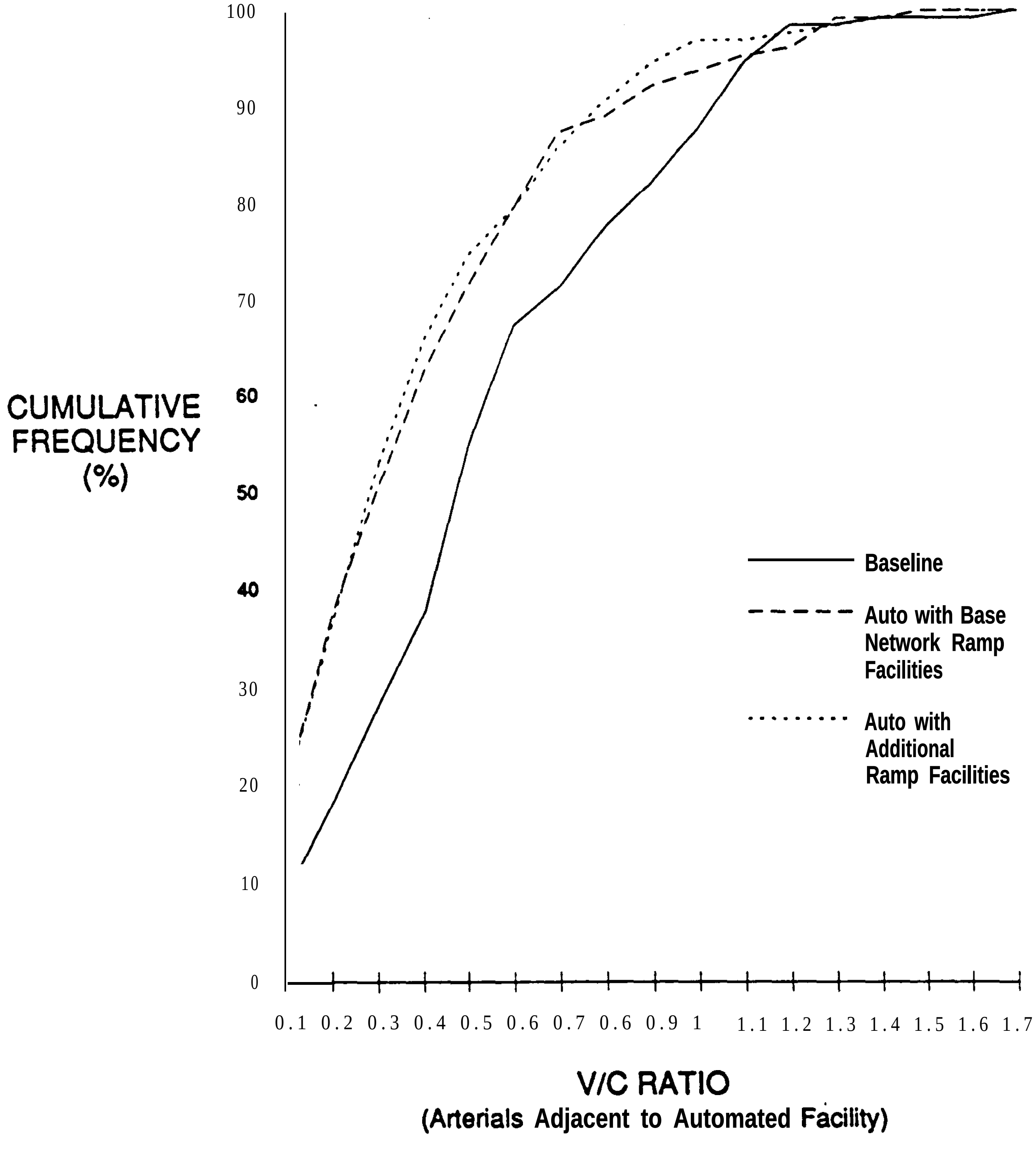


Table 6.13 2025 HIGHWAY AUTOMATION

V/C RATIO DISTRIBUTION ON ARTERIALS ADJACENT TO AUTOMATED FACILITIES

Long Beach Sub-Area

	Alternative Scenario Cumulative Frequency Distributions (%)		
V/C Ratio	Baseline	Base Network Ramp Facilities [a]	Additional Ramp Facilities [b]
0.1	0.00	9.73	11.29
0.2	2.16	23.78	25.81
0.3	5.41	38.38	39.78
0.4	10.81	52.43	54.84
0.5	23.78	64.86	67.74
0.6	34.05	72.97	74.73
0.7	50.27	79.46	80.65
0.8	63.24	84.86	86.02
0.9	76.76	88.65	89.78
1.0	83.78	92.43	94.09
1.1	88.11	96.76	96.77
1.2	92.43	98.92	97.85
1.3	97.30	98.92	98.92
1.4	99.46	100.00	99.46
1.5	99.46	100.00	99.46
1.6	100.00	100.00	100.00

Note: a = See Table 6.2
b = See Table 6.2

Figure 21: HIGHWAY AUTOMATION CUMULATIVE V/C RATIO FREQUENCY DISTRIBUTION

Long Beach Subregion

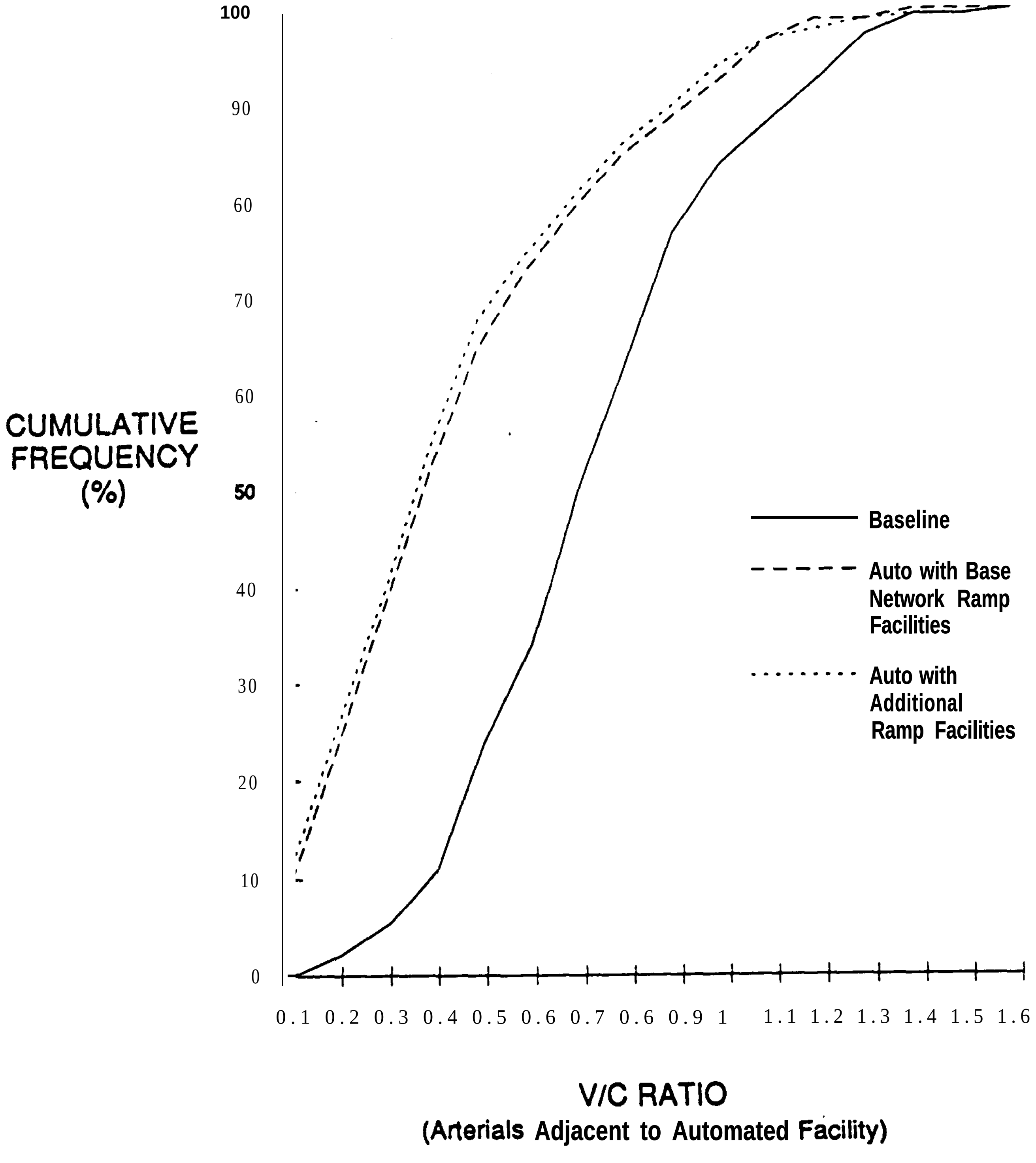


Table 6.14 2025 HIGHWAY AUTOMATION

V/C RATIO DISTRIBUTION ON ARTERIALS ADJACENT TO AUTOMATED FACILITIES

Riverside/San Bernardino Sub-Area

Alternative Scenarios Cumulative Frequency Distributions (%)

V/C Ratio	Baseline	Base Network Ramp Facilities [a]	Additional Ramp Facilities [b]
0.1	0.00	8.70	8.76
0.2	6.52	22.46	22.63
0.3	15.94	36.23	35.04
0.4	28.99	42.03	38.69
0.5	41.30	55.07	53.28
0.6	53.62	63.77	65.69
0.7	63.04	71.74	71.53
0.8	74.64	78.99	78.83
0.9	84.06	87.68	86.86
1.0	91.30	95.65	94.89
1.1	94.20	97.10	96.35
1.2	98.55	97.83	97.81
1.3	99.28	98.55	98.54
1.4	100.00	99.28	100.00
1.5	100.00	100.00	100.00

Note: a = See Table 6.2
b = See Table 6.2

Figure 22: HIGHWAY AUTOMATION CUMULATIVE V/C RATIO FREQUENCY DISTRIBUTION

Riverside/San Bernardino Subregion

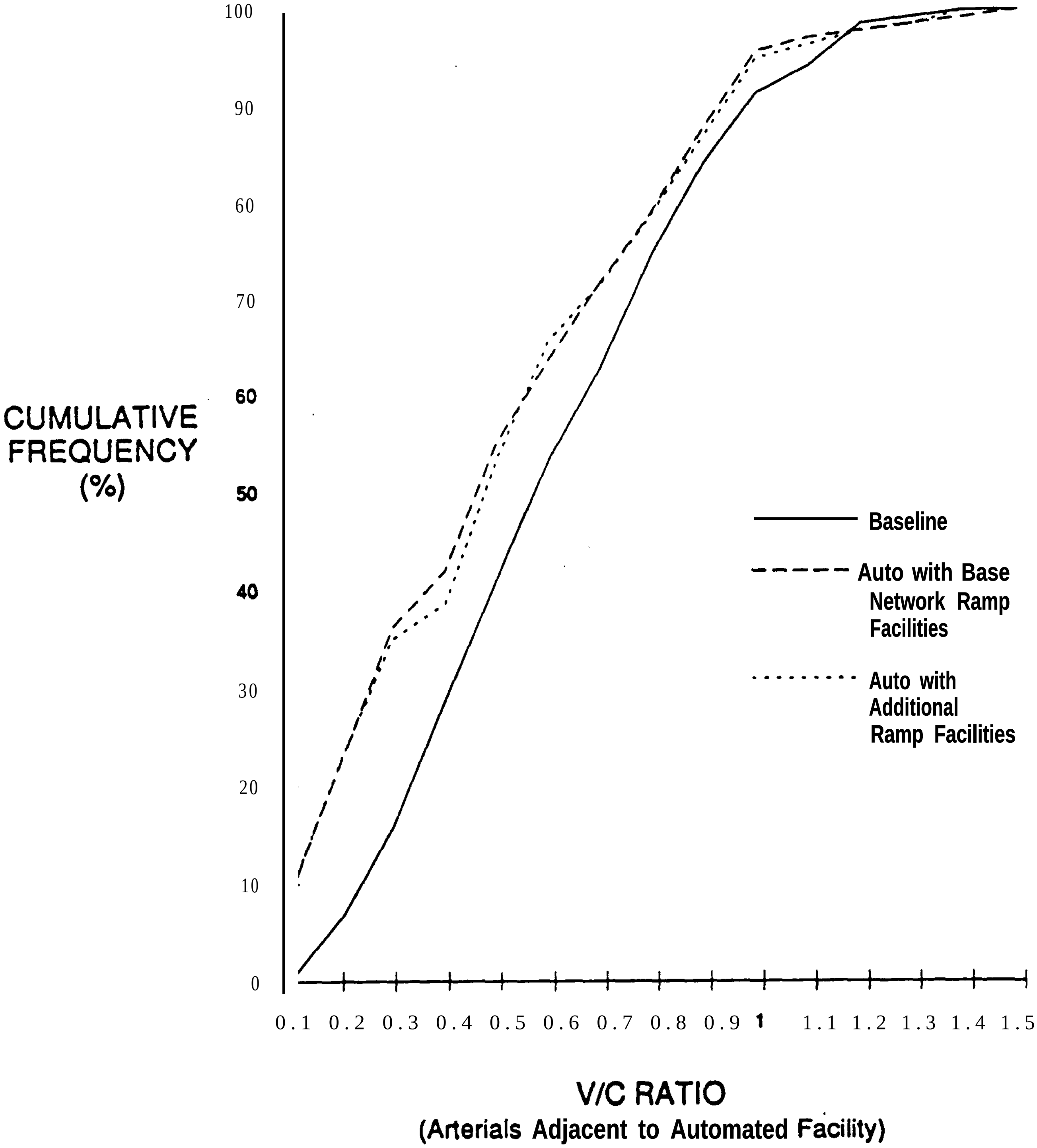


Table 6.15 2025 HIGHWAY AUTOMATION

V/C RATIO DISTRIBUTION ON ARTERIALS ADJACENT TO AUTOMATED FACILITIES

San Fernando Valley Sub-Area

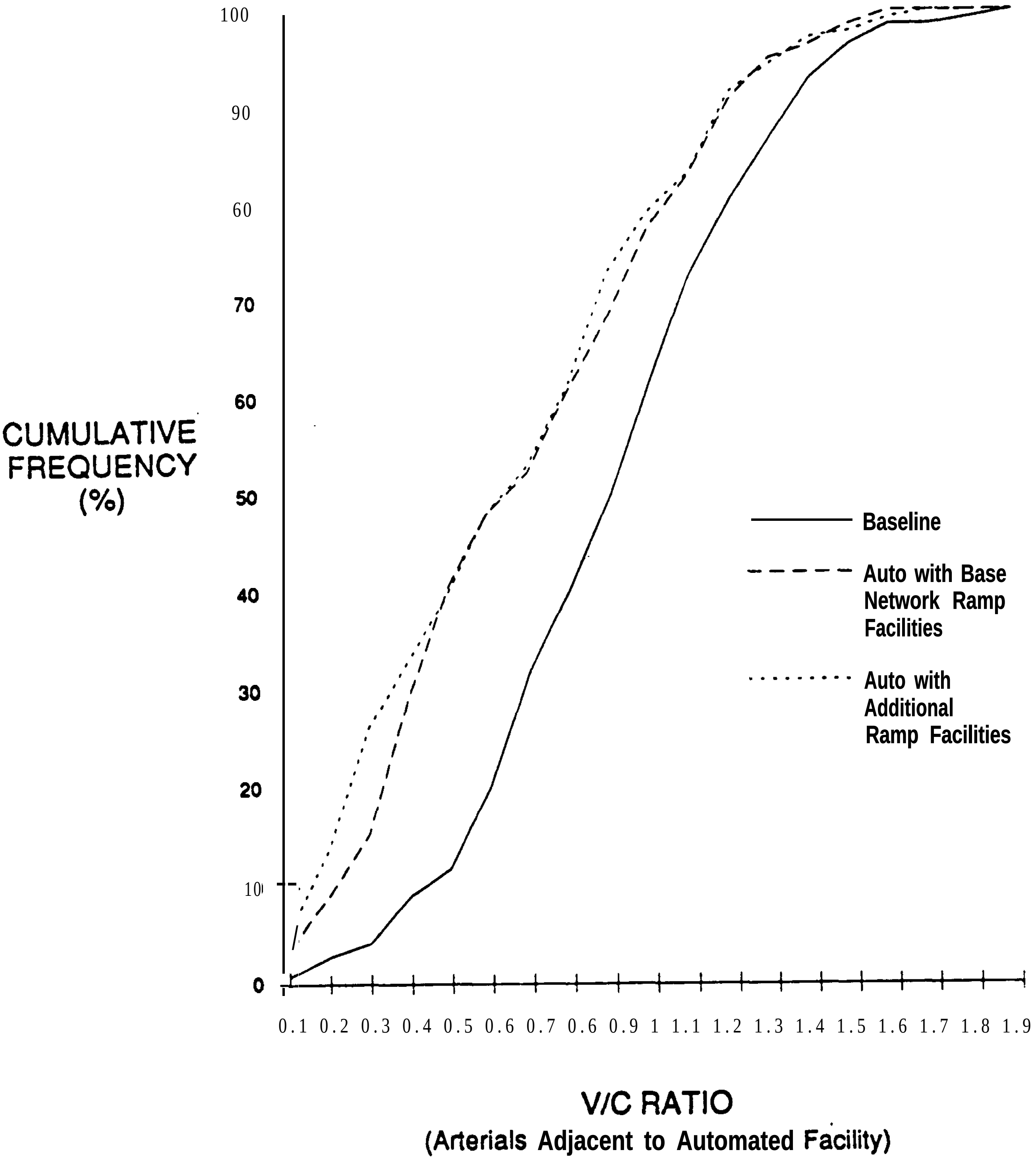
Alternative Scenarios Cumulative Frequency Distributions (%)

V/C Ratio	Baseline	Base Net work Ramp Facilities •	Additional Ramp Facilities [b]
0.1	🗀📭⌛☎	3.50	5.52
0.2	2.78	9.09	13.79
0.3	4.17	15.38	26.21
0.4	9.03	29.37	33.10
0.5	11.81	40.56	40.00
0.6	20.14	48.25	48.28
0.7	31.94	52.45	53.10
0.8	40.28	60.84	61.38
0.9	50.00	68.53	73.10
1.0	61.81	77.62	79.31
1.1	72.92	83.22	83.45
1.2	80.56	90.91	91.72
1.3	86.81	95.10	94.48
1.4	93.06	96.50	97.24
1.5	96.60	98.60	97.93
1.6	98.61	100.00	99.31
1.7	98.61	100.00	100.00
1.8	99.31	100.00	100.00
1.9	100.00	100.00	100.00

Note: **a =** See Table 6.2
b = See Table 6.2

Figure 23: HIGHWAY AUTOMATION CUMULATIVE V/C RATIO FREQUENCY DISTRIBUTION

San Fernando Valley Subregion



traffic volumes were compiled for all three scenarios for adjacent arterial links and freeway on- and off-ramp links. For the arterial link case, the average percentage change in both Vehicle Hours of Delay (VHD) and speed across scenarios for each sub-area were derived. For the case of ramp links, the average percentage change in traffic volume across scenarios was derived. These results are presented in Tables 6.16 and 6.17, respectively.

The ranges in the average percentage reduction in VHD across sub-areas on arterials comparing the baseline to the automation base ramp scenario and the baseline to the automation additional ramp facilities scenario are approximately 35%-75%, and 30%-75%, respectively. The analogous ranges in the average percentage increase in speed are 1%-8%, and 1%-7%, respectively. The comparison of the two automation scenarios show much less change in both VHD and speed. The range in the average percentage change in VHD across sub-areas comparing the base ramp to additional ramp facilities scenario is -19% to +5%. The corresponding range in average percentage change in speed is approximately -1% to +1%. These results further support the earlier conclusions that arterial travel is considerably less congested when automation technology is applied than when it is not.

The ranges in the average percentage increase in traffic volumes on ramps across sub-areas comparing the baseline to the automation base ramp scenario and the baseline to the automation additional ramp facilities scenario are 5%-33%, and 10%-47%, respectively. The range in the average percentage increase in traffic volume across sub-areas comparing the two automation scenarios is approximately 2%-10%. Because the number of ramps available to all vehicles in both the automation base ramp scenario and the baseline were the <u>same</u>, these results suggest that automated freeway ramps become more congested when automation technology (in base ramp scenario) was applied than when it was not. However, for the additional ramp facilities scenario, even though traffic volume increased, ramp congestion (VHD) <u>decreased</u> on a regional basis relative to the baseline since automated and non-automated vehicles utilized distinct sets of ramps. While the impact on ramp congestion in the more immediate vicinity of the automated facilities is not precisely known in terms of vehicle hours of delay, these results still suggest a decrease in congestion since traffic volume increased between 10% and 47%, while the number of available ramps, doubled in number. A detailed analysis of ramp link volume data was performed to determine the statistical significance of these results. The larger the percentage increases in traffic volume, the more likely the results were statistically significant. The sub-areas showing the three largest percentage increases in volume comparing the baseline to the automation scenarios (L.A. CBD, Long Beach, Riverside/San Bernardino) had statistically significant ramp link volume increases. The other three sub-areas had much lower percentage increases and these results were not statistically significant. Even though only half the sub-areas showed statistically significant increases in traffic volume when standard statistical tests were applied, the general trend indicates that ramp traffic adjacent to automated facilities would become slightly to moderately more congested. The slight increases in traffic volume across the automation scenarios were not statistically significant.

This analysis does not, however, determine whether such tendencies are statistically significant or not. In order to test for statistically significant differences in mobility conditions on the facilities immediately surrounding the automation scenario network, the appropriate statistical tests were chosen and performed. These tests compared the traffic volume associated with the baseline and alternative automation assignments for ramps and arterials adjacent to the automation scenario network in each sub-area.

The choice of parametric test for the arterial link level traffic volume comparisons utilized the analysis of variance, **ANOVA**, block design. The **ANOVA** test was selected for the link level analysis rather than the paired difference test since the independence of traffic volume measurements within an assignment could not be assumed. That is, traffic volume measurements across arterial links are likely to be highly correlated, or dependent, thereby invalidating the paired difference test procedure.

The **ANOVA** test utilizes matched sets, or blocks, of traffic volume measurements to test the null hypothesis that the average traffic volume from each of two assignments, i.e. baseline and automation base ramps, are equal. The alternative hypothesis is that the average traffic volume for each assignment are different, in this case larger for one assignment compared to another given the specific organization of our data. The F ratio is used to determine whether the null hypothesis is accepted or rejected. The tabulated F statistic was determined for the .05 level of significance and degrees of freedom. Calculated F values were constructed from the blocks of traffic volume and compared with the tabulated F values in each test. Calculated F values exceeding tabulated F values indicate that the differences in traffic volume are statistically significant at the .05 level. The findings from these tests are contained in the top portions of Tables 6.18 and 6.19 for arterial and ramp links respectively in close proximity to the automation facilities.

In Table 6.18, comparison of the calculated and tabulated F statistics -indicates that differences in baseline and automation base ramp assignment traffic volumes were significant as well as those between the baseline and automation additional ramps assignment. These results convey significantly higher traffic volumes on arterial links when the automation technology is not present on the neighboring freeway. In four of the six subareas the base network ramps assignment did not produce statistically significant traffic volumes arterial link differences when compared

TABLE 6.16 HIGHWAY AUTOMATION ARTERIAL HOBILITY COMPARISONS
(Average Percentage Change)

ARTERIAL Sub-Arsa	**Baseline vs** Base Ramps		**Baseline vs** Added Ramps		Base Ramp vs Added Ramps	
	VHD	SPD	**VHD**	SPD	**VHD**	SPD
Clarmont	-42.4	+ 2.2	-41.3	+ 2.2	- 2.0	0.0
El Toro	-34.7	+ 7.7	-31.3	+ 6.3	+ 5.3	-1.3
LACBD	-57.7	+ 1.6	-65.5	+ 2.1	-18.5	**+0.5**
Long Beach	-74.4	+ 4.3	-76.4	+ 4.3	- 7.6	0.0
Riverside/San Bernardino	-36.4	+ 1.0	-35.2	+ 1.0	- 2.0	0.0
San Fernando Valley	-57.9	+ 6.1	-60.5	+ 6.5	- 6.2	**+0.4**

TABLE 6.17 **HIGHWAY** AUTOMATION RAMP MOBILITY COMPARISONS
(Average Traffic Volume Percentage Change)

RAMPS Sub-Area	**Baseline vs Base Ramps**	**Baseline vs Added Ramps**	**Base Ramp vs Added Ramps**
Claremont	+ 5.3	**+ 9.7**	+ 4.2
El Toro	+ 5.5	**+13.6**	+ 7.6
LACBD	**+32.8**	**+46.5**	**+10.4**
Long Beach	**+14.4**	**+19.9**	+ 4.8
Riverside/San Bernardino	**+20.5**	**+22.6**	+ 1.7
San Fernando Valley	+ 9.6	**+13.1**	+ 3.3

to the additional ramp facilities assignment. For the Long Beach and San Fernando Valley sub-areas, significant differences in traffic volume were found when base ramps and additional ramp facilities automation assignments were contrasted. Thus, there may be limited evidence that the additional ramp facilities reduce traffic volume on adjacent arterial links.

The top portion of Table 6.19 shows mixed results from the parametric tests concerning traffic volume differences on ramp links that are in close proximity to the automated facilities in the selected sub-areas. For example, the LA CBD, Long Beach, and Riverside/San Bernardino sub-area statistical rests indicate that differences in traffic volume are significant for the baseline versus automation base ramps assignment. Given that the data was organized in a manner so that these differences may be interpreted as baseline traffic volume less than automation base ramps traffic volume, statistical significance suggests that ramp traffic is increased in these subareas when the automation technology is applied in this manner. Similar increases in traffic volume occur for the additional ramp facilities assignment with the inclusion of the El Toro sub-area to those with significantly less traffic volume on ramp links prior to the automation technology utilization. However, since the number of ramps increases for the additional ramp facilities relative to the base ramp network, statistically significant traffic volume increases may still co-exist with decreases in ramp delay in the vicinity of the automated facilities. The comparison of ramp link traffic volume between the two automation assignments did not yield statistically significant results.

The nonparametric test results, which utilized the **Wilcoxon** signed rank test previously described, for the arterial link level traffic volume assignment comparisons were identical to the findings of the parametric test equivalents. These results are found in the lower portion of Table 6.18. The **z** statistic rather than the T statistic was utilized since the large number of observations allowed the test to be approximated with a normal distribution test statistic. A calculated **z** statistic exceeding the tabulated **z** statistic confirms statistically significant differences in traffic volume.

The bottom portion of Table 6.19 indicates mixed results from the nonparametric tests related to traffic volume differences on ramp links adjacent to the automated facilities in the selected areas. In the majority of sub-area tests, baseline assignment traffic volume appears to be significantly less than both automation assignment's traffic volume for ramp links. The a priori expectation that automation would contribute to increased ramp congestion was confirmed in the majority of sub-area tests for the base ramp network automation scenario. The nonparametric and parametric test results for this comparison were found to be in general agreement on this point. These results seem to indicate that mobility benefits are forthcoming from the automation scenario

TABLE 6.18 2025 HIGHWAY AUTOMATION

TRAFFIC VOLUME STATISTICAL TEST RESULTS

Parametric Test Statistics: Arterials

			Calculated F		
Sub-Area	Tabulated F	d.f.	Case 1	Case 2	Case 3
Claremont	3.94	1/105	4.02	4.27	0.01
El Toro	3.91	1/135	30.24	44.51	1.88
LA CBD	3.91	1/135	45.46	47.64	0.39
Long Beach	3.89	1 /222	202.48	221.68	12.51
Riverside/San Bernardino	3.91	1/152	47.56	52.62	0.26
San Fernando Valley	3.90	1/161	112.86	120.96	4.46

Non-Parametric Test Statistics: Arterials

		Calculated Z		
Sub-Area	Tabulated Z	Case 1	Case 2	Case 3
Claremont	1.645	5.27 (105)	5.25 (105)	1.26 (92)
El Toro	1.645	5.37 (136)	6.46 (136)	1.28 (132)
LA CBD	1.645	6.63 (136)	6.80 (136)	2.24 (132)
Long Beach	1.645	10.87 (222)	10.98 (223)	3.86 (216)
Riverside/San Bernardino	1.645	6.88 (153)	6.90 (153)	1.28 (134)
San Fernando Valley	1.645	8.50 (162)	8.76 (161)	2.46 (160)

Note:

Case 1 = Significance test results for comparison of baseline assignment traffic volume greater than automated assignment traffic volume with base network ramp facilities.

Case 2 = Significance test results for comparison of baseline assignment traffic volume greater than automated assignment traffic volume with additional network ramp facilities.

Case 3 = Significance test results for comparison of automated assignment traffic volume with base network ramp facilities greater than automated assignment traffic volume with additional ramp facilities.

Numbers in ( ) are sample sizes.

Table 6.19 2025 HIGHWAY AUTOMATION TRAFFIC VOLUME STATISTICAL TEST RESULTS

Parametric Test Statistics: Ramps

			Calculated F		
Sub-Area	Tabulated F	d.f.	Case 1	Case 2	Case 3
Claremont	4.16	1/31	0.35	1.71	1.32
El Toro	4.18	1/29	0.86	5.22	1.44
LA CBD	4.10	1/38	13.80	18.30	2.40
Long Beach	4.00	1/62	6.81	13.50	2.29
Riverside/San Bernardino	4.07	1/43	19.79	20.57	0.62
San Fernando Valley	5.39	1/44	2.78	3.88	0.72

Non-Parametric Test Statistics: Ramps

		Calculated T		
Sub-Area	Tabulated T	CCase 2		Case 3
Claremont	175	215 (32)	183 (32)	197 (32)
El Toro	152	183 (30)	124 (30)	202 (30)
LA CBD	271	146 (39)	106 (39)	306 (39)
Long Beach	768	556 (63)	408 (63)	690 (63)
Riverside/San Bernardino	353	149 (44)	141 (44)	422 (43)
San Fernando Valley	371	362 (45)	321 (45)	427 (44)

Note:

Case 1 = Significance test results for comparison of baseline assignment traffic volume less than automated assignment traffic volume with base network ramp facilities.

Case 2 = Significance test results for comparison of baseline assignment traffic volume less than automated assignment traffic volume with additional network ramp facilities.

Case 3 = Significance test results for comparison of automated assignment traffic volume with base network ramp facilities automated assignment traffic volume with less than additional ramp facilities.

Numbers in ( ) are sample sizes.

7.0 OTHER REGIONAL IMPACTS OF FINAL SYSTEM DESIGNS

In this chapter major regional impacts of the final system designs other than mobility impacts are discussed, with the focus on energy and environmental issues. In section 7.1, energy conservation is evaluated for both roadway electrification scenarios (exclusive, and non-exclusive). Energy conservation impacts are determined for petroleum and natural gas. For each of these two cases, energy consumption is analyzed for both AM peak and daily travel; for travel both on and off the electrified network; and, for the on-network portion of this travel. Section 7.2 documents the emissions impacts for all four scenarios (RPEV exclusive and non-exclusive, automation with base network ramp facilities and automation with additional ramp facilities). The emissions analysis is performed for the AM peak only, and emphasis is on the two roadway electrification scenarios. Section 7.3 documents the impact of both RPEV scenarios on the demand for electricity from the utilities in the SCAG region for the AM peak, PM peak, and daily time periods. For sections 7.1 through 7.3, the analysis is performed for the two major vehicle types, light duty auto (LDA) and light duty truck (LDT). Together these two vehicle types comprise approximately 94% of the forecasted vehicle fleet in 2025 for the SCAG region. For sections 7.1 and 7.3, in which results were derived for time periods other than the AM peak, estimates of electrified network vehicle miles of travel (VMT) were made for these alternate time periods. Finally, in section 7.4, additional issues of importance to the roadway electrification technology are discussed such as (1) battery recycling and disposal, (2) electromagnetic field interference, and (3) acoustic noise.

7.1 FOSSIL FUEL ENERGY CONSUMPTION

This section analyzes the impact of both roadway electrification scenarios on fossil fuel energy usage in the production of electricity compared to fossil fuel usage in the baseline scenario. The energy sources under scrutiny in this analysis are petroleum and natural gas. Coal, another fossil fuel, was excluded from the analysis since it only contributes a very small amount (1) in the petroleum-based production process of gasoline, and (2) in the natural gas-based generation of electricity. Coal-based production of electricity is estimated to account for approximately 3% of total electricity supply for the region in 2025, all of which would originate out-of-basin.

An analysis of petroleum usage alone is performed because of its large usage in the U.S. transportation sector, and the dependence of the U.S. on foreign sources of oil. An analysis of natural gas consumption is performed since it is forecasted to be the fuel feedstock source for approximately 81% of electricity generated for the region in 2025. The analysis is performed for both **LDA's, LDT's,** and for these two vehicle types aggregated. Total RPEV driving (on and off the network) is presented as well as on-network only, for two time periods: AM peak and daily.

For both types of fossil fuel cases (petroleum-only and natural gas-only), the total RPEV network consumption for each scenario *in* the AM peak refers to the total fossil fuel consumption for the RPEV driving occurring during the AM peak. However, the processing of all that energy does not occur during the AM peak because part of that energy consumption results from the battery driven portion of the vehicles off the powered roadway. It is assumed that all battery recharging occurs overnight. Even if midday opportunity recharging were to occur, energy consumption and actual RPEV driving would occur during different times. The on-network portion energy consumption comparison restricts the energy consumption and actual driving to the same time period. The methodology used in the estimation of fossil fuel energy consumption was developed by Wang et al. (1992). A summary of the methodological approach is presented in the next section,

Petroleum Consumption Analysis

The baseline scenario vehicle fleet is assumed to consist entirely of gasoline **ICEV's.** There are two sources of petroleum consumption for these **ICEV's,** namely, vehicle gasoline consumption and the use *of* petroleum-derived fuels used in the earlier phases of the gasoline production cycle, such as gasoline, diesel, and fuel oil. While the focus is on the use of petroleum-based products in all phases of the fuel cycle, it should be noted that other energy sources, both primary and secondary are used in the gasoline production process. These other energy sources are discussed when all fossil fuel primary energy sources are analyzed.

The formula for calculating ICEV petroleum consumption in units of million British thermal units (mbtu) is the following:

$$PC_{icev} = 125{,}000*VMT/(MPG*10^6)*(1+PEU_g*PPEU_g)$$

PC_{icev} is the petroleum consumption of gasoline **ICEV's** in mbtu; VMT is the total vehicle miles traveled for the specific scenario and time period under investigation; MPG is the fuel economy (miles per gallon) of **ICEV's;** 125,000 is the heating value of gasoline in btu per gallon; PEU_g is the process energy use in btu per btu of gasoline output; and $PPEU_g$ is the percent process energy that is petroleum. VMT for both time periods for the baseline scenario was derived from the transportation model run output. For the two **RPEV** scenarios during the AM peak, VMT for all vehicles **(ICEV's** and **RPEV's)** and **RPEV'S-only** were output from the model. The ICEV portion of this was derived by subtracting total VMT attributed to the **RPEV's (6,248,000).** For daily VMT, an estimate of the total VMT for all trips and for RPEV-only trips for each RPEV scenario is estimated first, and then the RPEV associated trip **VMT** is subtracted from the total VMT to derive total daily VMT for the **ICEV** trip portion. MPG data was obtained for each vehicle type (LDA and LDT) from Direct Travel Input Model (DTIM) model output. **PEU_g** and **$PPEU_g$** data is taken directly from Wang et al (1992). Petroleum consumption estimates for each of the two major vehicle types are estimated by weighing the total petroleum consumption for gasoline **ICEV's** by the relative percentage of **LDA's** and **LDT's** in the fleet.

Petroleum consumption for **RPEV's** is also derived from two sources. Analogous to the ICEV case, those two ***sources*** are the use of petroleum for electricity generation and the use of petroleum products for processing other fuels such as coal and natural gas.

The formula for calculating **RPEV** petroleum consumption in units of mbtu is the following:

$$PC_{rpev} = EC*3412*VMT/10^6*[\sum_{i}(P_i*PEU_i*PPEU_i/CE_i) + P_{oil}*(1 + PEU_{oil}*PPEU_{oil})/CE_{oil}]$$

PC_{rpev} is the petroleum consumption of **RPEV's** in mbtu, EC is the RPEV electricity consumption in kwh per mile including (1) distribution losses between the power plant and the wall outlet or the roadway inductor, and (2) battery, battery charger and battery overcharging efficiencies for off-network travel or inductive coupling system efficiencies for on-network travel. A weighted average of electricity consumption is used when petroleum consumption estimates are derived for both on- and off-network travel. The weights for **on-** and off-network travel are estimated from AM peak period modeling results (Wang et al 1992, Systems Control Technology, Inc. 1993). VMT for the AM peak period is **6,248,000.** The daily equivalent of this total was estimated to be **63,970,242** and is derived by computing the ratio of regional on-freeway AM peak VMT to regional on-freeway daily VMT. It was assumed that this ratio is preserved when considering on-RPEV network VMT instead of regional on-freeway **VMT.** Thus, the estimate for daily on-RPEV network VMT is the AM peak on-RPEV network VMT **(2,903,749)** divided by this ratio **(15,085,000/154,448,000).** The last step is to convert this on-RPEV network daily VMT into total RPEV daily **VMT.** It is assumed that the on-network/off-network percentage split for daily equals the percentage split for the AM peak. This latter ratio is 0.4647485 **(2,903,749/6,248,000).** The estimate for daily VMT on- and **off-** the RPEV network equals **63,970,242.** **P_i** is the percentage of electricity produced from fuel source i, other than oil (i = 1: coal; i = 2: natural gas). Of all other fuel feedstock sources used for electricity production, the use of uranium in nuclear power plants would also utilize petroleum in the electricity generation process. However, not all required data is available and so the total petroleum consumption cannot be estimated for nuclear power. Yet because only about 2% of electricity is estimated to be produced via nuclear power in 2025, the loss is considered acceptably small. PEU_i is the process energy usage for one unit of energy output, expressed in btu per btu of energy output from fuel source i input into the power plants. $PPEU_i$ is the petroleum percentage of energy usage for fuel source i, out of total energy use. CE_i is the power plant conversion efficiency when fueled by fuel source i. P_{oil} is the percentage of electricity produced from oil. PEU_{oil} is the process energy usage for one unit of energy output, in btu per btu of energy output from oil input into the power plant. PPEU, is the petroleum percentage of energy usage for oil out of total energy use. Wang et al provided data for PEU_i, $PPEU_i$, CE_i, PEU_{oil}, and $PPEU_{oil}$. Data for P_i and P_{oil} were derived from information in the Phase I Report on the 2025 baseline utility forecast.

The results for the petroleum consumption analysis appear in Tables 7.1 through 7.4 below. Analysis was done for both the AM peak and daily and for all RPEV traffic (on- and off-network), as well as considering on-network traffic only.

TABLE 7.1

2025 ROADWAY ELECTRIFICATION

AM PEAK PETROLEUM CONSUMPTION (mbtu): ON & OFF NETWORK

	Baseline	Exclusive RPEV		Non-Exclusive RPEV	
LDA	173,694	153,677	(-11.52)	153,430	(-11.67)
LDT	61,189	54,141	(-11.52)	54,054	(-11.66)
Total	**234,883**	207,818	(-11.52)	207,483	(-11.67)

Note: Numbers in parentheses represent percentage changes relative to the baseline.

TABLE 7.2

2025 ROADWAY ELECTRIFICATION

AN PEAR PETROLEUM CONSUMPTION (mbtu): ON NETWORK

	Baseline	Exclusive RPEV		Non-Exclusive RPEV	
LDA	173,694	153,669	(-11.53)	153,421	(-11.67)
LDT	61,189	54,136	(-11.53)	54,049	(-11.67)
Total	234,883	207,805	(-11.53)	207,470	(-11.67)

Note: Numbers in parentheses represent percentage changes relative to the baseline.

TABLE 7.3

2025 ROADWAY ELECTRIFICATION

DAILY PETROLEUM CONSUMPTION (mbtu): ON & OF? NETWORK

	Baseline	Exclusive RPEV		Non-Exclusive RPEV	
LDA	**1,357,531**	**1,151,687**	(-15.16)	**1,149,754**	(-15.31)
LDT	478,233	405,750	(-15.16)	405,069	(-15.30)
Total	**1,835,764**	**1,557,437**	(-15.16)	**1,554,823**	(-15.30)

Note: Numbers in parentheses represent percentage changes relative to the baseline.

TABLE 7.4

2025 ROADWAY ELECTRIFICATION

DAILY PETROLEUM CONSUMPTION (mbtu): ON NETWORK

	Baseline	Exclusive RPEV		Non-Exclusive RPEV	
LDA	**1,357,531**	**1,151,600**	(-15.17)	**1,149,667**	(-15.31)
LDT	**478,233**	405,702	(-15.17)	405,021	(-15.31)
Total	**1,835,764**	**1,557,301**	**(-15.17)**	**1,554,688**	(-15.31)

Note: Numbers in parentheses represent percentage changes relative to the baseline.

The results show that for each time period and scenario comparison, the differences between total RPEV driving and on-network results are negligible. The reason for this is that the market penetration for both RPEV scenarios is small and the internal combustion engine vehicle (ICEV) component dominates the **RPEV** component. The **on-network** component is approximately half of the total on- and **off-network** fossil fuel consumption.

The percentage petroleum consumption savings in the AM peak period for both RPEV scenarios and for both all-RPEV traffic and **on-network** RPEV traffic only is approximately 12%. Only very small differences exist between the all-RPEV traffic and on-network only for a given vehicle type and RPEV scenario because the market penetration for the **RPEV's** is small, yielding an extremely small petroleum consumption **(mbtu)** relative to the total scenario petroleum consumption (0.01%). Restricting all RPEV traffic to just the on-network portion, that is, reducing the VMT by a factor of about 0.465 will simply make an already small number (RPEV contribution to total scenario petroleum consumption) even smaller. For a given vehicle type and type of RPEV traffic (total or **on-only),** there is a slight difference between the total petroleum consumption and hence also for the percentage savings from the baseline because the total VMT for the **AM** peak period for the two RPEV scenarios were slightly different due to the' scenario differences.

The petroleum consumption savings for the daily time period and both RPEV scenarios and both all-RPEV traffic and on-network RPEV traffic only is approximately 15%. Observations for this case may be made analogous to the AM peak period. The difference in results between the two time periods is a function of the estimate used for total daily RPEV VMT, and how it was calculated. These differences would have been negligible had it been calculated by preserving the ratio of total RPEV VMT **(6,248,000)** to total regional VMT for each scenario. For example, for the RPEV exclusive scenario, the total regional VMT is **53,301,809,** and so the ratio would be 0.1172. This method was rejected because it included data on all facilities, and it was felt that concentrating on freeways only would be more appropriate because the **RPEV** network consisted only of freeways.

Natural Gas Consumption Analysis

The other fossil fuel feedstock examined was natural gas. Even though the **RPEV** market penetration was relatively small, 81% of **electricity produced** for the **RPEVs** was derived from natural gas as the primary energy source. Natural gas was, in fact, the only **in-basin** fuel feedstock source used.

An assessment of fossil fuel primary energy consumption was performed in which petroleum and natural gas were the primary energy sources considered and the entire energy production process stream was analyzed. It is assumed that gasoline for **ICEV's** is provided entirely by petroleum. In addition to excluding coal from the analysis, all non-fossil fuel primary energy sources, such as biomass, were also excluded. For the biomass case, approximately 3% of electricity generated in the SCAG region for 2025 is forecasted to come from this material. However, trace amounts of such non-fossil fuels as well as coal were included *in* the primary energy consumption derivation for ICEVs and **RPEVs** because all downstream energy sources were considered in the natural gas-based electricity generation process and the petroleum-based gasoline production process. Thus even though the baseline scenario consists of gasoline powered ICEVs and the primary energy source is petroleum, other energy sources such as natural gas are consumed in the whole process of gasoline production. Based on the results of this analysis and the petroleum consumption previously discussed, natural gas-only usage was derived. It was assumed, based on best professional judgment, that approximately 90% of the difference between total ICEV petroleum-based *energy* consumption (petroleum, natural gas, etc.) and total ICEV petroleum consumption would comprise the amount of natural gas consumption in the baseline scenario as well as in the ICEV portion of each RPEV scenario. In each RPEV scenario, consumption of natural gas for the RPEV portion was based solely on the difference between total **RPEV** natural gas-based energy consumption (natural gas, petroleum, etc.) and RPEV petroleum consumption. All other consumption sources, e.g. biomass were assumed negligible in size.

The formula for calculating ICEV primary energy consumption in units of mbtu is the following:

$$\mathbf{PEC_{icev} = 125{,}000*VMT/(MPG*10^6)/PEE}$$

PEC,, is the primary energy consumption of ICEVs in mbtu, VMT and MPG are described in the previous section on petroleum consumption. PEE is the process energy efficiency from primary source recovery to gasoline in service stations.

The formula for calculating RPEV primary energy consumption in units of mbtu is the following:

$$\mathbf{PEC_{rpev} = 3412*EC*VMT/(PEE*10^6)}$$

EC is described in the previous section on petroleum consumption. The results for the natural gas consumption appears *in* Tables 7.5 through 7.8 below. Analysis was performed for both the AM peak and daily and for all RPEV traffic (on- and off-network), and on-network traffic only.

TABLE 7.5

2025 ROADWAY ELECTRIFICATION

AN PEAR NATURAL OAS CONSUMPTION FOR TRANSPORTATION (mbtu)

ON & OFF NETWORK

	Baseline	Exclusive RPEV		Non-Exclusive RPEV	
LDA	23,326	32,300	(+38.47)	32,267	(+38.33)
LDT	8,217	13,689	(+66.59)	13,678	(+66.46)
Total	31,543	45,989	(+45.80)	45,945	(+45.66)

<u>**Note**</u>: Numbers in parentheses represent percentage changes relative to the baseline.

TABLE 7.6

2025 ROADWAY ELECTRIFICATION

AM PEAR NATURAL OAS CONSUMPTION FOR TRANSPORTATION (mbtu)

ON NETWORK

	Baseline	Exclusive RPEV		Non-Exclusive RPEV	
LDA	23,326	26,013	(+11.52)	25,980	(+11.38)
LDT	8,217	10,223	(+24.41)	10,212	(+24.28)
Total	31,543	36,236	(+14.88)	36,192	(+14.74)

<u>**Note**</u>: Numbers in parentheses represent percentage changes relative to the baseline.

TABLE 7.7

2025 ROADWAY ELECTRIFICATION

DAILY NATURAL GAS CONSUMPTION FOR TRANSPORTATION (mbtu)

ON & OF? NETWORK

	Baseline	Exclusive RPBV		Non-Exclusive RPEV	
LDA	**182,307**	274,069	(+50.33)	273,810	(+50.19)
LDT	64,223	120,211	(+87.18)	120,120	(+87.04)
Total	246,530	394,280	(+59.93)	393,930	(+59.79)

<u>Note</u>: Numbers in parentheses represent percentage changes relative to the baseline.

TABLE 7.8

2025 ROADWAY ELECTRIFICATION

DAILY NATURAL GAS CONSUMPTION FOR TRANSPORTATION (mbtu)

ON NETWORK

	Baseline	Exclusive RPEV		Non-Exclusive RPEV	
LDA	182,307	209,701	(+15.03)	209,442	(+14.88)
LDT	64,223	84,724	(+31.92)	84,633	(+31.78)
Total	246,530	294,425	(+19.43)	294,075	(+19.29)

Note: Numbers in parentheses represent percentage changes relative to the baseline.

Because natural gas was the primary energy source for 81% of generated electricity, large increases in natural gas usage relative to the baseline occurred. Moreover, there were sizeable differences in the magnitude of the increase in natural gas consumption relative to the baseline for daily versus AM-peak period travel and total RPEV network versus on-RPEV network travel. Although the baseline scenario consisted of gasoline powered ICEVs, and the primary energy source was petroleum, other energy sources such as natural gas were consumed in the whole process of gasoline production. Tables 7.5 through 7.8 depict the amount of this source of natural gas consumption.

Total daily natural gas usage was forecast to increase about 60% for each RPEV scenario for the aggregation of LDAs and LDTs. While the forecast daily petroleum consumption percentage decrease (15%) was considerably smaller than the analogous natural gas usage percentage increase (about 60%) for the aggregation of LDAs and LDTs, in terms of actual consumption, petroleum usage decreased 278,327 mbtu, and natural gas consumption increased approximately 147,500 mbtu. As in the case for petroleum consumption analysis, the relatively minor differences between scenarios for a given vehicle type, time period, and type of RPEV traffic was due to VMT differences between these two scenarios. The increase in daily natural gas consumption aggregated over both vehicle types for both scenarios for travel on and off the network was approximately 0.148 trillion btu (tbtu) (Table 7.7). Total annual end use demand of natural gas for California in 2025 was projected to be approximately 1,500 (tbtu) (CEC, 1989). The SCAG region proportion of this amount is about 50%, that is, 750 tbtu, based on the region's population relative to the whole state. Thus the average daily volume of natural gas demand in the SCAG region for 2025 (baseline) was forecast to be approximately 2.055 tbtu. Thus, total incremental natural gas consumption for either of the RPEV scenarios (0.148 tbtu) would cause an increase of approximately 7.2% relative to the baseline.

The projected average daily percentage increase in natural gas demand for the SCAG region between 1990 (1.97 tbtu (CEC, 1991)) and the baseline for 2025 (2.055 tbtu) is 4.3%. However, the forecasted daily natural gas supply for the SCAG region in 2025 was about 3.297 tbtu. Thus, while the increase due to the **RPEVs** was significant relative to the increase between 1990 and 2025, plentiful natural gas supplies *were* forecast to be available to meet the additional demand for 2025.

7.2 EMISSIONS ANALYSIS

The objective of this section is to analyze the impacts of both roadway electrification and highway automation on air quality. Roadway electrification results are presented for both the exclusive and non-exclusive scenarios. Highway automation results are presented for both the base ramp network facilities and additional ramp facilities scenarios. Results are given for five pollutants: Reactive Organic Gases, an ozone precursor (ROG), Carbon Monoxide (CO), Nitrogen Oxide (NOX), Sulfur Oxide (SOX), and Particulate Matter (PM). All results are reported for the AM peak period only. The results are reported for each of the two major vehicle types, **LDA's** and **LDT's,** and their aggregate total.

Baseline Emissions

The baseline assessment of emissions for the AM peak period was determined by use of the Direct Travel Impacts Model (DTIM). The methodologies contained in DTIM and its companion impact rate program, **EMFAC7E,** were employed, with modifications recommended by the California Air Resources Board (CARB) for 2025, to calculate the baseline emissions for each of the five pollutants. **EMFAC7E** was the most current version of **CARB's** emissions impact rate model available. **EMFAC7EP** has since superseded **EMFAC7E.** The ramifications of not having **EMFAC7EP** to use are discussed later in this section.

DTIM provided total emissions for the entire vehicle fleet disaggregated by emission type. These data needed to be further partitioned by vehicle type. To disaggregate total emissions by vehicle type, two factors were required: (1) percentage mix of each vehicle type in the vehicle fleet population, and (2) differences in emissions by vehicle type. The percentage mix for **LDA's** and **LDT's** is 74.1% and **19.6%,** respectively. Vehicle type emission differences also vary by emission type. For the baseline fleet, assumed to be entirely composed of Internal Combustion Engine Vehicles **(ICEV's),** vehicle emissions were composed of cold start, hot start, evaporative and running. Cold and hot start emissions occur as the vehicle heats up to its normal operating temperature. These emissions consist of ROG, CO, and NOX. Evaporative ROG emissions consist of diurnal, hot soak, and running evaporative losses. Diurnal emissions are those that occur from day to day due to the daily heating and cooling cycle of the fuel. Hot soak emissions happen when hot vapors are emitted at the end of a trip. Running evaporative losses occur when the vehicle is moving. Running emissions are exhaust emissions and consist of ROG, CO, NOX, SOX, and **PM pollutants.** DTIM provided emissions data (grams per hour) by vehicle speed in 5 mile per hour (mph) increments from 5 to 65 mph together with total **VHT** and VMT for each of these speeds for both vehicle types. Total running emissions were derived from the distributional emissions (grams per hour) and VHT data. A weighted average of the emissions (grams per mile) for each vehicle type was also derived based on the distribution of VMT by speed increment. The breakdown of running evaporative emissions by vehicle type was derived from these weighted averages together with the percentage mix for **LDA's** and **LDT's. CARB** provided emission rates by vehicle type for cold and hot start, hot soak and diurnal emissions for all relevant pollutants (CARB, 1991). These data were for the year 2010. It was assumed that while the specific emission rates could change between 2010 and 2025, the ratio of the emission rates (LDA/LDT) for each emission type and pollutant would remain constant. Cold and hot start, hot soak and diurnal emissions partitioned by vehicle type were derived from, these data together with the percentage mix of **LDA's** and **LDT's.**

The above analysis described the derivation of vehicle-source emissions disaggregated by vehicle type. There are two stationary emission sources also included *in* the derivation of total baseline emissions. They are refueling emissions consisting of evaporative emissions at both fuel stations and bulk plants, and petroleum refinery *emissions.* The methodology used to calculate *emissions* from these two sources was developed by Wang et al (1990). Emission factors for these two sources were derived for both **LDA's** and **LDT's** for California for 1995 and 2010. They were expressed in units of grams per mile. There are ROG, CO, NOX, SOX, and PM refinery emissions, and ROG refueling emissions. Emission factors were derived initially for 1995. These factors were then extrapolated to 2010 by assuming a 10% reduction in both types of emissions for each **5-year** period between 1995 and 2010. The same approach was used to extend the 2010 data to 2025. The ICEV fuel economy estimates for 2025 replaced those used in Wang et al (1990). The emission factors (grams/mile) were first converted to total grams by multiplying by the total VMT for each vehicle type in each RPEV scenario. Subsequently, these emission factors were expressed in units of tons to conform with all other reported pollution sources.

Roadway Electrification

Each roadway electrification scenario (exclusive and non-exclusive) was further partitioned into the following two cases: all RPEV traffic (on- and off-network traffic) and on-network traffic only. All RPEV traffic emissions refer to the pollution produced by vehicles driving during the AM peak period. However, not all this pollution is produced during this period because approximately 53% of the VMT is generated from off-network travel, that is, via power from the onboard battery. It is assumed throughout the emissions and utility usage analyses that all battery recharging occurs overnight (10PM-6AM). Thus off-network pollution is produced overnight not during the AM peak period. Total emissions are therefore reported: total emissions produced during the day by vehicles driving during the AM peak period and emissions generated during the AM peak period.

In addition to the baseline scenario, DTIM provided total emissions for both roadway electrification scenarios. These results were again expressed for the entire vehicle fleet disaggregated by emission types. The RPEV's were represented in this model run as zero-emission vehicles. The total vehicle emissions reported were for the remaining ICEV's. Though RPEV's themselves do not pollute, the power plants generating electricity used for battery recharging or roadway power do pollute. The total amount of pollution generated in both roadway electrification scenarios is the sum of the mobile source emissions generated by the ICEV's and the stationary source emissions produced by the electric power plants.

The methodology described above for the baseline case was used to derive total emissions for the ICEV portion of each RPEV scenario disaggregated by vehicle type. The last step in the derivation of total emissions was the calculation of power plant emissions by vehicle type and level of RPEV traffic (on- and off-network or on-network only).

The initial step in deriving total stationary source emissions was to derive in-basin power plant emission factors in units of grams per kilowatt-hour (g/kwh) for the year 2025 disaggregated by pollutant. The basic methodology used was developed by Wang et al (1990). Additional data needed to reflect characteristics of power plants for the SCAG region were provided by Dowlatabadi et al (1990). The calculation of power plant emission factors (g/kwh) required the (1) percentage breakdown of fuel feedstock sources for in-basin electricity generating power plants, (2) mix of power plants by type for each fuel feedstock source, (3) future emission reduction technologies utilized in each power plant type coupled with the percentage emission reduction for each pollutant, and (4) percentage-'of power plants by type employing these emission reduction technologies.

The percentage breakdown of fuel feedstock sources and the mix of power plants by type was derived from the baseline utility forecast for 2025 documented in the Phase I Report (pgs. 3-19 to 3-33). Natural gas was the only in-basin fuel feedstock source used in the derivation of power plant emission factors, generating 81% of SCAG region electricity in 2025. Gas power plants further disaggregated into steam, turbine, combined cycle, and advanced combined cycle types. Fuel feedstock sources such as hydroelectric, wind, solar and nuclear are not included in the analysis because they produce negligible emissions. Oil-fired turbines are also used in-basin to produce electricity. However, they comprise approximately 1/20 of 1% of electricity generated for 2025 and even though their level of pollution is comparable with some of the gas pollution amounts, they are omitted from the analysis. Biomass-fired powerplants were excluded (1) given their small contribution to electricity production (approximately 3%), (2) the lack of sufficient of data to describe biomass emission factors, and (3) the assumption that biomass would *not* be part of the marginal powerplant mix to produce electricity for RPEV usage (Ford, 1992). Coal-fired powerplants were not projected for the region in 2025 and so were excluded from the analysis since the focus of the study was in-basin emissions assessment.

Approximately 4% of the electricity supply was expected to be imported to the region in 2025 from out-of-basin coal and hydroelectric'power sources (SCAG, 1991), with coal accounting for approximately two-thirds of the imports and all hydroelectric power imported from the Pacific Northwest. There was insufficient data to estimate the in/out state mix for coal imports. However, based on the derivation of the total amount of daily emissions from coal-fired powerplants, there will be a minimum of 20 pounds for PM to a maximum of 200 pounds for Sox for the each of the RPEV scenarios. These additional emissions increase the before-coal powerplant emission levels at most 4% across all pollutants except Sox. Additional Sox emissions increased corresponding emission levels by 500%. However, before-coal powerplant emissions were so small that these added coal-generated emissions have no effect on the percentage change in emission levels from the baseline to the RPEV scenario for all pollutants. Thus excluding all coal-fired powerplants from the analysis displaces a small amount of emissions attributed to usage in the SCAG region to other regions.

The powerplant mix used in the analysis was representative of the average fuel feedstock percentage breakdown rather than the marginal mix of fuels needed to satisfy incremental electricity demand created by RPEVs for 2025. No forecasts have been made of such fuel combinations for the SCAG region for 2025. However, related research was performed for the Southern California region for battery-powered electric vehicle (EV) usage for 2010 (Ford, 1992). This work focused on the Southern California Edison Company's service area, one of two major electricity service providers in the SCAG region. The results of this work indicated that the overwhelming majority of the extra energy needed for Evs will come from natural gas-fired powerplants, with a range *in* natural gas usage varying between 70% and 90%. This result agrees with the fuel mix used in our research, since natural gas was forecast to fuel 81% of generated electricity in 2025.

All other necessary information ((3), (4), and (5) above) were derived from Wang et al (1990) and Dowlatabadi et al (1990) for the year 2010. Power plant emissions are assumed to be reduced by 20% between 2010 and 2025 across all power plant types and pollutants. Table 7.9 describes the in-basin power plant emission factors (grams/kwh) for each pollutant and power plant type.

TABLE 7.9

2025 IN-BASIN POWER PLANT EMISSION FACTORS

(grams/kwh)

	ROG	CO	**NOX**	**SOX**	PN
Gas Steam (SCR)	**0.0069**	**0.0275**	**0.1135**	**0.0022**	**0.0106**
Gas Turbine	**0.0946**	**0.1192**	**0.1135**	**0.0032**	**0.0723**
Gas Combined Cycle	**0.0631**	**0.0795**	**0.0998**	**0.0022**	**0.0483**
Gas ACC	**0.0492**	**0.0620**	**0.0776**	**0.0017**	**0.0377**

Note: SCR = Selective Catalytic Reduction
ACC = Advanced Combined Cycle

The emissions depicted in Table 7.9 are those produced per kilowatt-hour at the power plant. The next step is to convert the power plant emission factors to units of grams per mile by multiplying by the vehicle energy consumption (kwh/mile) for each vehicle type. Vehicle energy consumption must take into account all distribution losses between the power plant and the vehicle to derive an accurate estimate of total power plant emissions (grams/mile). Energy losses occur during the power transmission phase between the power plant and either the wall outlet or the roadway inductor. Battery and battery charging losses for off-network travel and inductive coupling system losses for on-network travel occur. Tables 7.10 through 7.13 describe emission factors (grams/mile) for each pollutant by vehicle type and power source for **RPEV's** (roadway inductor **or onboard** battery). Each entry in each table was calculated by multiplying the corresponding entry in Table 7.9 by the vehicle energy consumption listed in each table title. All four vehicle energy consumption estimates were derived from data in Wang et al (1992) and discussions with members of the Project Advisory Group.

The next step consisted of aggregating emission factors across power plant types consistent with the power plant type mix discussed earlier. This was done for each vehicle type, power source (electrified roadway or **onboard** battery), and pollutant. Subsequently, for the total RPEV traffic case, a weighted average

TABLE 7.10

2025 RPEV EMISSION FACTORS (grams/mile)

LDA's on Electrified Roadway: Energy Consumption 0.26 kwh/mile

	ROG	co	Nox	sox	PM
Gas Steam (SCR)	0.0018	0.0072	0.0295	0.0006	0.0028
Gas Turbine	0.0246	0.0310	0.0295	0.0008	0.0188
Gas Combined Cycle	0.0164	0.0207	0.0259	0.0006	0.0126
Gas ACC	0.0128	0.0161	0.0202	0.0004	0.0098

Note : SCR = Selective Catalytic Reduction
ACC = Advanced Combined Cycle

TABLE 7.11

2025 RPEV EMISSION FACTORS (grams/mile)

LDA's off Electrified Roads: Energy Consumption 0.264 kwh/mile

	ROG	co	Nox	sox	PN
Gas Steam (SCR)	0.0018	0.0073	0.0300	0.0006	0.0028
Gas Turbine	0.0250	0.0315	0.0300	0.0008	0.0191
Gas Combined Cycle	0.0167	0.0210	0.0263	0.0006	0.0128
Gas ACC	0.0130	0.0164	0.0206	0.0005	0.0099

Note: SCR = Selective Catalytic Reduction
ACC = Advanced Combined Cycle

TABLE 7.12

2025 RPEV EMISSION FACTORS (grams/mile)

LDT's on Electrified Roads: Energy Consumption 0.54 kwh/mile

	ROG	co	Nox	Sox	PM
Gas Steam (SCR)	0.0037	0.0149	0.0613	0.0012	0.0057
Gas Turbine	0.0511	0.0644	0.0613	0.0017	0.0390
Gas Combined Cycle	0.0341	0.0429	0.0539	0.0012	0.0261
Gas ACC	0.0266	0.0335	0.0420	0.0009	0.0203

Note: SCR = Selective Catalytic Reduction
ACC = Advanced Combined Cycle

TABLE 7.13

2025 RPEV WISSION FACTORS (grams/rile)

LDT's off Electrified Roads: Energy Consumption 0.55 kwh/mile

	ROG	CO	Nox	Sox	PN
Gae Steam (SCR)	0.0038	0.0151	0.0624	0.0012	0.0058
Gas Turbine	0.0520	0.0656	0.0624	0.0018	0.0398
Gae Combined Cycle	0.0347	0.0437	0.0549	0.0012	0.0266
Gae ACC	0.0271	0.0341	0.0428	0.0009	0.0207

Note : SCR = Selective Catalytic Reduction
ACC = Advanced Combined Cycle

of emission factors was derived to reflect the on-network/off-network percentage split of RPEV travel. This percentage split was 46.5/53.5 respectively. The final step converted the emission factors (g/mile) into total tons for each vehicle type and extent of RPEV travel by multiplying the emission factors by the appropriate VMT for that vehicle type and converting grams to tons. Total power plant emissions are expressed in terms of tons for each pollutant, vehicle type, and extent of RPEV travel. These stationary source emissions were then added to the total ICEV emissions (mobile and stationary source) previously discussed. The results are presented in Tables 7.14 and 7.15 for all RPEV travel and on-network only travel, respectively. Results in both tables are for all three scenarios, for each pollutant and vehicle type, and the percentage change in emissions for each roadway electrification scenario relative to the baseline.

All results indicate a reduction in the total emissions for each roadway electrification scenario relative to the baseline. The percentage reductions are slightly greater for the on-network only travel case (Table 7.15) than for the total RPEV travel case. This occurs because the off-network travel and associated power plant emissions are omitted from the calculation resulting in lower emissions and increased percentage reductions. Percentage reductions overall vary between 5.3% to 10.9%. These relatively small improvements in air quality are directly related to the small market penetration for the roadway electrification scenarios. The variation for a given pollutant and vehicle type across scenarios is small and is due to the slight differences in the total VMT for the two RPEV scenarios. Similarly, the variation for a given pollutant and specific scenario across vehicle types is also small. The variation in emissions across pollutants 'for a given vehicle type was due to the strength of relationship between pollutant and VMT. For example, Sox emissions depended primarily on miles driven yielding a percentage emissions reduction relative to the baseline

TABLE 7.14

2025 ROADWAY ELECTRIFICATION
AN PEAR EMISSIONS (in tons): ON & OFF NETWORK

	Baseline		Exclusive RPEV				Non-Exclusive RPEV			
Pollutant	LDA	LDT	LDA		LDT		LDA		LDT	
ROG	30.18	10.12	28.58	(-5.30)	9.54	(-5.73)	28.53	(-5.47)	9.52	(-5.93)
co	160.99	57.67	151.01	(-6.20)	54.08	(-6.23)	150.74	(-6.37)	53.98	(-6.40)
Nox	26.78	12.06	24.68	(-7.84)	11.09	(-8.04)	24.71	(-7.73)	11.11	(-7.88)
sox	7.02	2.47	**6.23**	**(-11.25)**	2.20	(-10.93)	**6.22**	**(-11.40)**	**2.20**	**(-10.93)**
PM	9.86	2.61	**8.85**	**(-10.24)**	2.35	(-9.96)	**8.87**	**(-10.04)**	2.35	(-9.96)

Note: LDA = Light Duty Auto
LDT = Light Duty Truck
Numbers in parentheses represent percentage changes relative to the baseline for each vehicle type respectively

TABLE 7.15

2025 ROADWAY ELECTRIFICATION
AN PEAK EMISSIONS (in tons): ON NETWORK

	Baseline		Exclusive RPEV				Non-Exclusive RPEV			
Pollutant	LDA	LDT	LDA		LDT		LDA		LDT	
ROG	30.18	10.12	28.55	(-5.40)	9.52	(-5.93)	28.5	(-5.57)	9.5	(-6.13)
co	160.99	57.67	150.97	(-6.22)	54.06	(-6.26)	150.7	(-6.39)	53.96	(-6.43)
Nox	26.78	12.06	24.63	(-8.03)	11.07	(-8.21)	24.66	(-7.92)	11.08	(-8.13)
sox	7.02	2.47	**6.23**	**(-11.25)**	2.2	(-10.93)	**6.22**	**(-11.40)**	2.2	(-10.93)
PM	9.86	2.61	**8.83**	**(-10.45)**	**2.34**	**(-10.34)**	**8.85**	**(-10.24)**	**2.34**	**(-10.34)**

Note: LDA = Light Duty Auto
LDT = Light Duty Truck
Numbers in parentheses represent percentage changes relative to the **baseline** for each vehicle type respectively

considerably greater than that for CO (across vehicle types, scenarios, and extent of travel), where the number of daily trips rather than miles driven is the determining factor.

The contribution of power plant emissions to the total RPEV AM peak emissions were extremely small. The worst case was represented by Particulate Matter (PM) in the total RPEV travel case, in which the percentage contribution in this instance was 1.2%. In general, the percentage contribution of power plant emissions over most pollutants, vehicle types, and RPEV travel level varied between 0.1% and 0.6%. These results indicate that the trade off between increased market penetration for RPEV's and an increase in the associated power plant emissions would favor RPEV's because the reduction in the remaining ICEV emissions would be greater than the increase in power plant emissions.

Automation

DTIM also provided total emissions for both automation scenarios. These results, were again given for the entire vehicle fleet disaggregated by emission types. All vehicles are assumed to be ICEV's. The automated vehicles were represented in DTIM as vehicles traveling 55 mph while on the automated network. The methodology described earlier for the baseline case was used to derive total emissions for each automation scenario disaggregated by vehicle type. The results are presented in Table 7.16 for all three scenarios, for each pollutant and vehicle type, and the percentage change in emissions for each automation scenario relative to the baseline.

All results except for Nox indicate a reduction in the total emissions for each automation scenario relative to the baseline. Percentage reductions overall vary between 1% and 7.5%. There is a slight increase in Nox emissions of between 3.3% to 3.8%. Both the emission reductions for ROG, CO, Sox, and PM and the increase for Nox is attributable to the increase in speeds for the automated vehicles.

While almost all emission changes are favorable, these results should be viewed only as a static evaluation of emissions impacts due to highway automation technology. These results do not indicate the long term consequences on emissions of implementing the technology. Over time, there could be an induced increase in VMT without-constraints on land development or the underpricing of individual travel below its marginal social cost (Shladover, 1991). Highway automation would provide a trip-maker with the option of living further from his/her employment location yet incur no increase in travel time because of the increased effective speeds attained on the automated network. Associated with increased VMT would be increased energy use and emissions without the use of

TABLE 7.16

2025 HIGHWAY AUTOMATION

AM PEAK EMISSIONS (in tons)

	Baseline		Base Network Ramps				Additional Ramp Facilities			
Pollutant	LDA	LDT	LDA		LDT		LDA		LDT	
ROG	30.18	10.12	28.67	(-5.0)	9.47	(-6.4)	28.41	(-5.9)	9.36	(-7.5)
co	160.99	57.67	155.46	(-3.4)	55.71	(-3.4)	154.50	(-4.0)	55.36	(-4.0)
Nox	26.78	12.06	27.65	**(+3.3)**	12.47	**(+3.4)**	27.77	**(+3.7)**	12.52	**(+3.8)**
sox	7.02	2.47	6.92	(-1.4)	2.44	(-1.2)	6.88	(-2.0)	2.43	(-1.6)
PM	9.86	2.61	9.74	(-1.2)	2.58	(-1.2)	9.68	(-1.8)	2.56	(-1.9)

Note: LDA = Light Duty Auto
LDT = Light Duty Truck
Numbers in parentheses represent percentage changes relative to the baseline for each vehicle type respectively

alternative propulsion systems or clean burning fuels.

A technical issue arose when both the transportation and emission models were run for the automation scenarios that could increase the emissions reported in Table 7.16. Higher speeds for the automated trips were embedded in the model just prior to the trip assignment phase of the model. It has been determined that embedding the higher speeds at an earlier stage, the trip distribution stage, would have been more realistic because higher speeds could have induced a VMT increase. However, after discussing the issue with SCAG transportation modeling staff, a qualitative assessment was made and the potential increase in emissions was deemed to be small.

New Emission Models

As previously stated, **EMFAC7E** which was the most current version of **CARB's** impact emissions rate model available to SCAG, has been replaced by **EMFAC7EP.** In fact even newer versions of the **EMFAC** model are soon to replace **EMFAC7EP.** Nevertheless, **EMFAC7EP** will reflect changes in both emission control technologies and policy initiatives that would impact the results obtained in this analysis had that version been used. The primary changes will involve a reduction in the amount of cold and hot start emissions resulting from the use of electrically heated catalysts. The following two factors are required to evaluate the potential change in the emission impact of roadway electrification: (1) percentage contribution of cold and hot start emissions out of total emissions for each vehicle type and (2) percentage reduction of these two pollution sources. Cold and hot start emissions comprise between 40% and 50% of all ROG and all CO emissions for both **LDA's** and **LDT's,** and between 25% and 35% of all NOX emissions for both **LDA's** and **LDT's.** The percentage reduction for these two pollution sources is not known with certainty. A sensitivity analysis was performed to account for this uncertainty in the percentage reduction for cold and hot start emissions and to assess the potential changes in emissions impact from roadway electrification. The difference between baseline emissions and RPEV emissions will not necessarily remain constant as a result of the reductions in cold and hot start emissions.

A few examples of the sensitivity analysis will at least provide some information on the impact of these changes. The first case was for the exclusive scenario compared to the baseline for **LDA'S,** the pollutant ROG, and both on- and off-network travel. A 45% cold and hot start emission contribution to total ROG emissions for **LDA's** is assumed. The following, three percentage reductions for cold and hot start emissions were used in the sensitivity analysis: **25%, 50%,** and 75% for both the baseline and exclusive scenarios. The revised percentage changes relative to the baseline are **-5.27%, -5.24%,** and **-5.20%,** respectively. The percentage change shown in Table 7.14 is -5.30%. The second case examined Nox emissions for **LDT's** for the exclusive scenario compared to the baseline, for both **on-** and off-network travel. A 30% cold and hot start emission contribution to total Nox emissions for **LDT's** is used. The same three percentage reductions were used as before. The original percentage change depicted in Table 7.14 is -8.04%. The revised percentage changes relative to the baseline are **-7.99%, -7.95%,** and **-7.91%,** respectively. The results of these two cases indicates the extent of the change in impact level. It must be noted, however, that as the market penetration of **RPEV's** grows, such that the total RPEV emissions become increasingly due to the power plants, the benefit of roadway electrification, as measured by the percentage change relative to the baseline, will decrease. It is recommended that a more thoroughly systematic analysis of this important issue be performed.

7.3 UTILITY DEMAND

This section analyzes both roadway electrification scenarios with respect to the amount of additional demand for electricity each scenario will place on the utilities which provide electricity to the SCAG region. The two electricity service providers are Southern California Edison (SCE) and the Los Angeles Department of

Water and Power (LADWP). A complete discussion of the utility baseline forecast for the SCAG region in the year 2025 is provided in the Phase I Report.

Since the only difference between the RPEV exclusive and non-exclusive scenarios is whether or not non-RPEV's are permitted to travel on the electrified lanes, and the volume of electrified trips is constant across scenarios, any additional demand for electricity usage resulting from roadway electrification is the same for each scenario.

All modeling efforts were originally performed for the AM peak period. This was done because peak travel periods provide a more realistic picture of demands placed on the network, and the AM peak period is considered more stable than the PM peak period because the former consists of primarily home to work trips, whereas the PM peak period includes not only work to home trips, but several other types of "other-to-home" trips. However, in assessing the additional demands placed on the utilities arising from RPEV travel, daily and PM peak electricity demands were required and were estimated.

Methodology for Estimation of RPEV Electricity Demand

For each of three time periods (AM peak, PM peak, daily) and extent of RPEV usage (on- and off-network or on-network only) the methodology is the same. Because vehicle energy consumption (kwh/mile) is used in the derivation for total energy demand and differs by vehicle type, computations are made for LDA's and LDT's separately then aggregated together.

Total energy usage is generally expressed as:

Vehicle energy consumption (kwh/mile) * Total VMT for RPEV's

A kilowatt-hour consumed by a vehicle on the road, whether from the electrified roadway or the onboard battery requires more than one kilowatt-hour of energy produced at the power plant. There are several sources of distribution losses as the electricity is transmitted from the power plant to the vehicle. These losses consist of distribution losses between the power plant and either the wall outlet *or* the roadway inductor, battery and battery charger losses for off-network travel, and inductive coupling system losses for on-network travel. There are also additional minor *energy* losses in the battery as a result of overcharging, and in the motor controller and motor. All distribution, vehicle, and roadway energy losses are included in the calculation of vehicle energy consumption.

For the case in which both roadway and battery power (on- and off-network travel) is considered, a weighted average of the two vehicle energy consumptions is derived. The weights are the proportions of RPEV VMT for on- and off-network travel, respectively in the AM peak period. The total RPEV VMT in the AM peak period is 6,248,000, with 2,903,749 VMT and 3,344,251 VMT the on- and off-network VMT, respectively. Therefore, the weights are 0.4647 and 0.5353, respectively. These weights are used for both LDA's and LDT's. For LDA's the on- and off-network vehicle energy consumptions are 0.26 kwh/mile and 0.264 kwh/mile, respectively. The weighted average is 0.2621 kwh/mile. For LDT's, the on- and off-network vehicle energy consumptions are 0.54 kwh/mile and 0.55 kwh/mile, respectively. The weighted average is 0.5454 kwh/mile. For the case in which only roadway power is considered, the original, unweighted consumption estimates are used in the computation, namely, 0.26 kwh/mile and 0.54 kwh/mile for LDA's and LDT's, respectively.

The other component in the formula for calculating total energy usage is the VMT per time period and per vehicle type. Total RPEV VMT for the AM peak period is an output from the RPEV network modeling effort. Total RPEV VMT for the PM peak and daily time periods were derived from the AM peak figure. For these derivations it was assumed that the proportion of on-freeway VMT for AM peak to PM peak, and AM peak to daily is preserved for on-RPEV network travel, and that the percentage split of AM peak RPEV travel between on-network and off-network is preserved for the other time periods. Alternative means also were used to factor the AM peak RPEV network VMT to PM peak and daily estimates, generally resulting in RPEV network VMT figures less than previously derived. For example, instead of considering on-freeway VMT, both on- and off-freeway VMT may be considered and that this ratio for the AM peak to PM peak and AM peak to daily is preserved for on- and off-RPEV network travel. Using the latter assumption yields a smaller VMT. The impact of additional demand for electricity from RPEV travel on the utilities resulting from this change in assumptions however, is small. Nevertheless, the method chosen here for factoring total RPEV network VMT to PM peak and daily, provides a worst case scenario for the utilities. This is important for planning purposes. Further discussion of this appears in a later part of this section. The total daily RPEV VMT on- and off-the network is 63,970,242. The total on-network VMT is 29,730,074. Since the analysis is performed for LDA's and LDT's separately at first, total VMT for a particular time period must be split between LDA's and LDT's. LDA's and LDT's drive approximately the same average distance per vehicle (Caltrans 1987), and thus it is assumed that for each time period total VMT is distributed uniformly across each vehicle by type. For example, total RPEV (on- and off-network) VMT is 6,248,000 for the AM peak period. This total is split between LDA's and LDTs consistent with the proportion of these two vehicle types in the region, namely, 74.1% and 19.6%, respectively.

Total energy usage for LDA's and LDT's is aggregated and converted to megawatt-hours (mwh's). Total electricity usage for either RPEV scenario is depicted in Table 7.17 below. Electricity usage for roadway power during a given time period refers to on-network travel. Overnight recharging used in a particular time period is referred to as off-network travel.

TABLE 7.17

2025 ROADWAY ELECTRIFICATION

ELECTRICITY DEMAND (mwh)

	RPEV USAGE		
	ROADWAY POWER	OVERNIGET CHARGING	TOTAL
AM PEAK	866	1,015	1,881
PM PEAK	2,595	3,038	5,633
DAILY	8,879	10,385	19,264

The baseline electricity capacity forecast for 2025 is 56,584 megawatts (MW) for the SCAG region served by SCE and LADWP. Previous analysis of California electricity demand patterns by time of day for the state's three largest electricity service providers (SCE, LADWP, and PG&E) has discovered information of value in this analysis. During the peak days of electricity consumption in 1985, occurring during the summer months, peak hours of electricity use fell between 9 AM and 6 PM. Moreover, hourly electricity demand patterns during peak days were found to be representative of consumption patterns on other weekdays. During the winter, peak hours on weekdays are generally between 9 AM and 8 PM. Peak demand is lower during the winter than during the summer. Thus using the time of day electricity demand profile representative of peak days in the SCAG region provides a worst case day for analysis and planning purposes.

In addition to electricity demand profiles by time of day, travel distribution patterns are also required to develop an accurate picture of the impact of roadway electrification on electricity service providers. If peak traffic patterns overlap with peak non-transportation electricity demand, then electricity service providers could be required to increase their generating capacity to deal with the extra load from RPEV's. Hourly traffic distribution patterns do differ by facility type, such as freeway driving or arterials. However, based on results from Wang et al (1987), hourly traffic distribution patterns remain quite stable across geographical location, socioeconomic factors, and land use patterns of the area. In general, there are two daily peak traffic periods on freeways. For the SCAG region the AM peak occurs between 6 AM and 8 AM, and the afternoon peak occurs between 3:30 PM and 6:30 PM. Thus there is a daily overlap in peaks in the late afternoon and seasonal overlaps in peaks during the summer months. Results from Wang et al (1987) were adjusted to more accurately reflect the time of day traffic distribution for on-freeway travel in the SCAG region.

Wang et al (1987) provides the time of day electricity demand profile in the SCE service area for an average summer weekday in 1985. The peak hour of that day uses 11,410 mw of electricity. The 2025 baseline utility demand is 56,584 MW. This figure has a reserve embedded in it of approximately 15%, yielding 48,166 MW as the actual 2025 baseline electricity demand. Using the only data available, it is assumed that the electricity demand distribution remains the same for our analysis and each hourly electricity demand is factored up by 4.22 (48,166/11,410) to yield the equivalent electricity demand profile for our scenario. Even though the profile is for the SCE service area, and our analysis is for both SCE and LADWP, over 77% of demand will originate in the SCE service area. Thus the SCE profile is fairly representative of the profile for the two service areas together. The electricity demand profile is given in Table 7.18.

The hourly distribution of traffic on Los Angeles freeways were first converted into percentages of traffic volume and then into hourly electricity usage estimates, assuming that hourly energy demand for transportation is proportionalto hourly traffic volume. These estimates are depicted in Table 7.19 below for on-RPEV network traffic. The total daily on-RPEV network electricity demand is 8,879 mwh (Table 7.18). The hourly percentage is expressed in terms of megawatts.

The remaining issue is the distribution of electricity demand used for battery recharging. It is assumed that batteries are recharged only overnight, all vehicles are fully charged in the morning, and all roadway power goes into driving the vehicle. While the first and last assumptions are rather strong and optimistic, working with them allows for a determination of time of day impact analysis of roadway electrification on the utilities. Allowing for opportunity charging during the day, and battery recharging while on the electrified roadway and the ramifications of these assumptions is beyond the scope of the project.

The total daily off-network (battery-driven) VMT for the RPEV's is 34,240,168. The energy consumption for LDA's and LDT's driving off the electrified network are 0.264 kwh/mile and 0.55 kwh/mile respectively. The weighted average for energy consumption is derived from the percentage of each vehicle type in the RPEV fleet. This yields 0.3034 kwh/mile. Multiplying the energy consumption

TABLE 7.18

2025 BASELINE HOURLY ELECTRICITY DEMAND

SCE AND LADWP SERVICE AREAS
(mw)

Time of Day	SCE and LADWP Service Areas
1 AM	26,447
2 AM	25,687
3 AM	25,383
4 AM	25,860
5 AM	27,801
6 AM	31,713
7 AM	36,241
8 AM	39,685
9 AM	42,318
10 AM	44,432
11 AM	45,407
12 NOON	46,319
1 PM	47,581
2 PM	48,150
3 PM	47,922
4 PM	46,897
5 PM	44,994
6 PM	43,061
7 PM	42,314
8 PM	42,035
9 PM	38,799
10 PM	30,840
11 PM	29,572
12 MIDNIGHT	28,304

(kwh per mile) by the total daily VMT derived from battery-usage yields the total amount of energy used throughout the day for battery usage. The total number of kilowatt-hours of energy used on a daily basis for battery-driven purposes is 10,388,467. This translates into approximately 10,388 mwh. This estimate is the difference between total network electricity demand (19,264 mwh) and on-network demand (8,879 mwh) found in Table 7.17. The slight discrepancy is due to rounding error.

While obviously individual household variations will exist, it is assumed for the purposes of the analysis that all overnight recharging occurs uniformly between the hours of 10 PM and 6 AM, and all households were assigned the same average recharge over an 8 hour period. Thus, on average, there will be an extra load of approximately 1298 mw of electricity demand per hour between 10 PM and 6 AM. These estimates are depicted in Table 7.19.

TABLE 7.19

2025 ROADWAY ELECTRIFICATION

ELECTRICITY DEMAND HOURLY DISTRIBUTION

Time of Day	Traffic Volume %	Electricity Demand (mw) On-Network	Off-Network
1 AM	1.3323	118	1298
2 AM	0.8160	72	1298
3 AM	0.5213	46	1298
4 AM	0.5053	45	1298
5 AM	1.6299	145	1298
6 AM	4.4025	391	0
7 AM	5.3645	476	0
8 AM	5.5403	492	0
9 AM	4.8512	431	0
10 AM	4.4136	392	0
11 AM	4.3886	390	0
12 NOON	4.3851	389	0
1 PM	4.4243	393	0
2 PM	4.9739	442	0
3 PM	8.0454	714	0
4 PM	10.3122	916	0
5 PM	9.6650	858	0
6 PM	7.3628	654	0
7 PM	4.1384	367	0
8 PM	3.2373	287	0
9 PM	2.7906	248	0
10 PM	2.6639	237	1298
11 PM	2.3409	208	1298
12 MIDNIGHT	1.8946	168	1298

Note: Electricity demand is rounded to the nearest megawatt.

Total electricity demand in the SCAG region by time of day is the sum of electricity demand for the base load (Table 7.18) and RPEV-related travel (Table 7.19). A comparison of the time of day electricity demand profile for the baseline with the RPEV scenario is depicted in Table 7.20 and Figure 24 below.

The RPEV scenario time of day electricity demand profile is still dominated by the baseline distribution even though the electricity demand from roadway electrification follows a substantially different distributional pattern. This occurs because the actual amount of electricity used is relatively small for the RPEV scenario compared with the baseline. However, the peak hour demand shifts from 2-3 PM to 3-4 PM. The additional amount represents an increase of 1.0 percent over the baseline peak.

TABLE 7.20

ELECTRICITY DEMAND COMPARISON

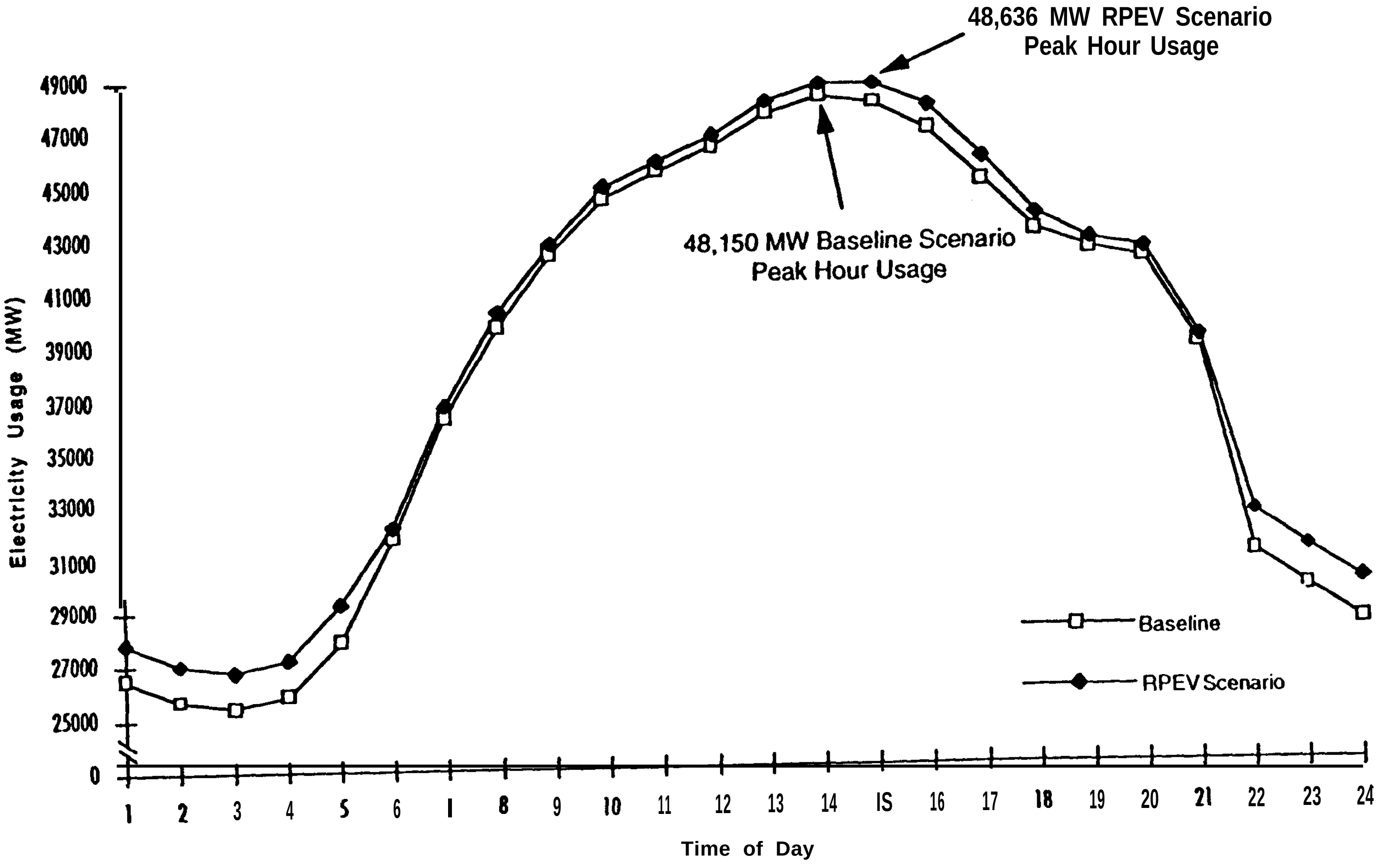
BASELINE v. RPEV SCENARIO

(mw)

Time of Day	Baseline	RPEV Scenario
1 AM	26,447	27,863
2 AM	25,687	27,057
3 AM	25,383	26,727
4 AM	25,860	27,203
5 AM	27,801	29,244
6 AM	31,713	32,104
7 AM	36,241	36,717
8 AM	39,685	40,177
9 AM	42,318	42,749
10 AM	44,432	44,824
11 AM	45,407	45,797
12 NOON	46,319	46,708
1 PM	47,581	47,974
2 PM	48,150	48,592
3 PM	47,922	48,636
4 PM	46,897	47,813
5 PM	44,994	45,852
6 PM	43,061	43,715
7 PM	42,314	42,681
8 PM	42,035	42,322
9 PM	38,799	39,047
10 PM	30,840	32,375
11 PM	29,572	31,078
12 MIDNIGHT	28,304	29,770

Figure 24: Electricity Usage Comparison

Baseline vs. RPEV Scenario


48,636 MW RPEV Scenario Peak Hour Usage

48,150 MW Baseline Scenario Peak Hour Usage

While this is not entirely negligible, it must be viewed relative to the increase in capacity that the utilities must undergo between the present and the baseline for 2025, an increase of about 93% in capacity. Clearly then with a larger market penetration of RPEV's the additional demand for electricity will also increase accordingly.

With a larger market penetration of RPEV's the additional demand for electricity will also increase. The estimate for total daily RPEV VMT in both roadway electrification scenarios is 63,970,242, representing 15.4% of total daily regional VMT. Table 7.21 below presents the results of a sensitivity analysis indicating percentage increases in peak hour electricity demand resulting from increases in the daily market penetration of RPEVs.

TABLE 7.21

IMPACT OF MARKET PENETRATION ON ELECTRICITY DEMAND

DAILY REGIONAL RPEV VMT PERCENTAGE	PERCENTAGE INCREASE IN PEAR HOUR ELECTRICITY DEMAND
15.4	1.0
20.0	1.5
30.0	2.4
40.0	3.4
50.0	4.3
60.0	5.3

While the potential of a 5% increase in peak hour demand would be possible and of concern, it corresponds to a regional RPEV VMT of approximately 55%. Based on the analysis performed in the development of the RPEV scenarios, a more likely and still conservative upper limit on market penetration would be about 40%. This corresponds to a 3.4% increase in peak hour electricity demand, again not negligible, yet a more modest increase.

7.4 Other Environmental Issues

In addition to the emissions and fossil fuel usage considerations previously discussed in Sections 7.1 - 7.3, three other environmental issues must be addressed with respect to the implementation of the roadway electrification technology. These issues pertain to: (a) the introduction of electromagnetic fields (EMF) in close proximity to the electrified lane centerline, (b) the potential hazardous waste associated with disposal of RPEV (as well as EV) batteries, and (c) the acoustic noise levels in vehicles traveling on the powered roadway.

nPEV aElectromagnetic Fields

RPEV operation entails the transfer of energy via an inductive coupling system (ICS) between the powered roadway and the vehicle. The ICS transfers power through a magnetic field. The magnetic field strength varies depending on roadway current and distance from the roadway centerline. Since EMF field strength is measured as the density of magnetic flux, attention to this issue was warranted in order to ascertain this environmental impact of the powered roadway.

Concerns that have arisen within the scientific community regarding possible health impairments due to exposure to EMF have been heightened as the number of studies correlating cancer in humans and EMF exposure have increased. (See OTA, 1989; EPA, 1990). In the most comprehensive effort to study this issue to date, the results indicated that

> "...there is now a very large volume of scientific finding based on experiments at the cellular level and from studies with animals and people which clearly establish that low frequency magnetic fields can interact with, and produce changes in biological systems. While most of this work is of very high quality, the results are complex. Current scientific understanding does not yet allow us to interpret the evidence in a single coherent framework. Even more frustrating, it does not yet allow us to draw definite conclusions about questions of possible risk or to offer clear science-based advice on strategies to minimize or avoid potential risks. Of the effects discussed, the central nervous system effects including circadian effects in animals and the possibility of cancer promotion appear most worthy of concern with respect to public health effects." (OTA, 1989, p. 67).

To adequately address these concerns, EMF measurements were studied from both static and dynamic testing of the PATH roadway powered bus and conventional vehicle experiments on the powered roadway. Test statistics were predicted via computer simulation as well as measured at the Richmond Field Station test track, and produced similar results. The results from the PATH bus and conventional vehicle powered roadway tests were compiled for an "attenuated", or vehicle shielded case and an "unattenuated", or outside the vehicle, case.

The test results from the PATH bus and conventional vehicle powered roadway experiments indicated that in an "unattenuated", or unshielded, situation, the magnetic flux density (the measure of EMF strength) is 300 milligauss (Mg), and 1.5 to 3.0 Mg for an "attenuated", or shielded position for a 240 amp roadway. (See Figure 25). These measurements were taken at 40 inches above the roadway to approximate the EMF exposure for the driver's position in a conventional vehicle. Similar "attenuated" test results indicated lower EMF exposure for the roadway powered bus. This finding was expected since the magnetic field follows the path of least resistance. Thus, in an RPEV the magnetic field passes through the pick-up unit while in a conventional vehicle, it goes through the steel chassis.

For an "unattenuated" situation at varying heights from the roadway, Figure 26 shows that the magnetic flux declines with distance from the powered roadway lane centerline. The results in this figure are not directly comparable with Figure 25 since the roadway current is approximately five times that used in the previous diagram. The pattern of magnetic flux decrease with distance from the power source found for the powered roadway is, however, consistent with studies of many other power-related appliances and delivery apparatus.

To put these powered roadway EMF readings in perspective, the interim limits for EMF exposure as recommended by the International Radiation Protection Association (IRPA), and International Non-Ionizing Radiation Committee (INIRC) are presented in Table 7.22. Comparing the aforestated powered roadway EMF exposure levels with the IRPA/INIRC standards is difficult since these standards were set for 50/60 Hz field strengths while powered roadway field strengths are significantly higher. For example, 8,500 Hz is the frequency field strength planned for the Playa Vista powered roadway demonstration. Nevertheless, roadway EMF exposure is substantially below the ceiling limits set by IRPA/INIRC. Powered roadway EMF exposure is also lower than the earth's geomagnetic field of 500 Mg. Figure 27 ranks several electrical appliances and power delivery by field strength and degree of EMF exposure (in Mg) including shielded and unshielded powered roadway cases. Finally, Table 7.23 provides distances with respect to numerous household appliances.

At this time, evidence regarding EMF exposure with respect to the powered roadway suggests that there is little need for environmental concern. Certainly in-vehicle EMF exposure is slight regardless of duration and vehicle type, i.e. conventional vehicle, RPEV. Out-of-vehicle exposure also appears to be very low although length of exposure to EMF should be considered as well as field strength. Figure 27 may provide the best approximation to the degree of risk that may be experienced in the shielded and unshielded roadway powered cases. Figure 27 suggests that a person

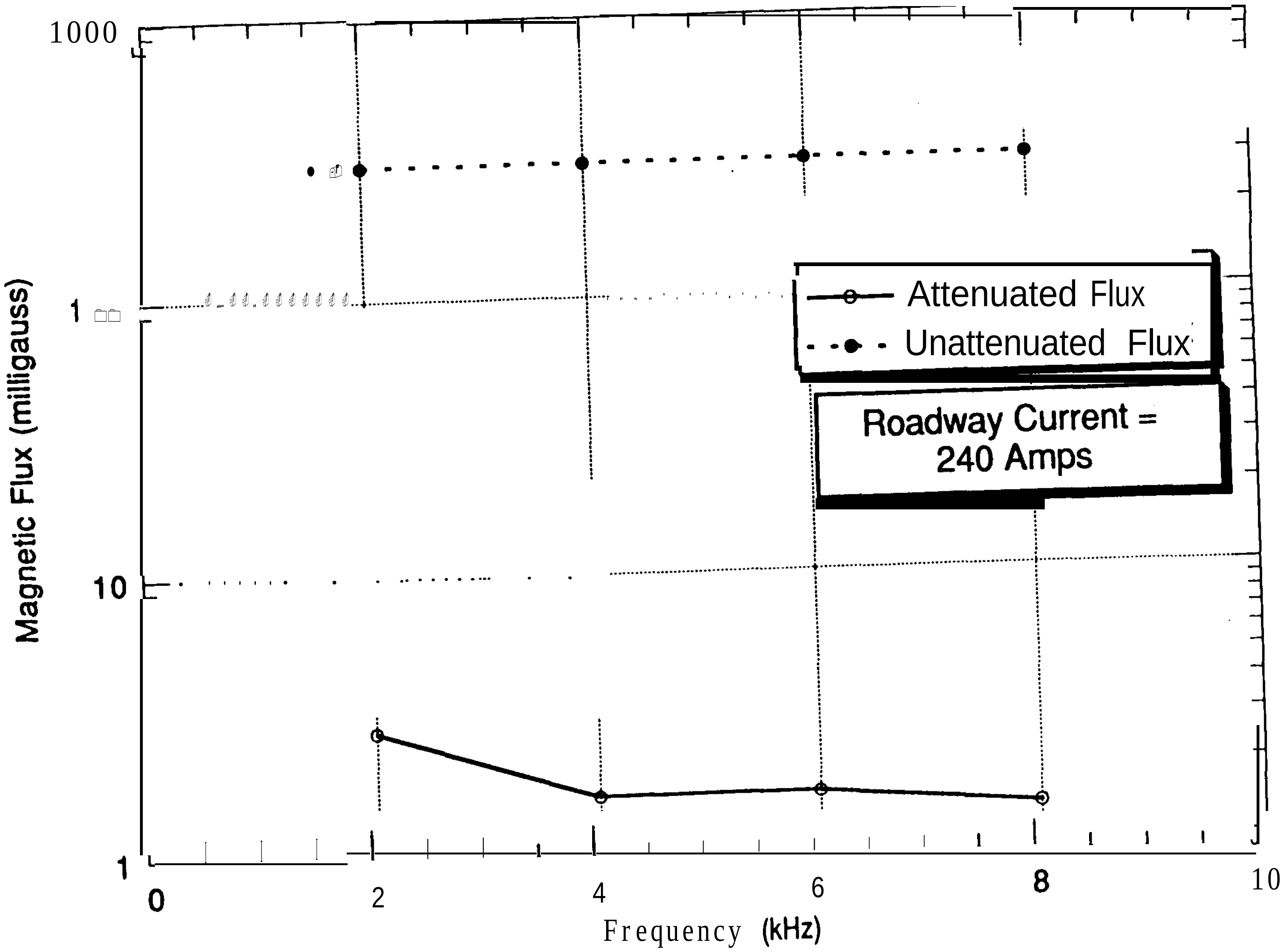


Figure 25. Magnetic Field Profile at Driver's Position

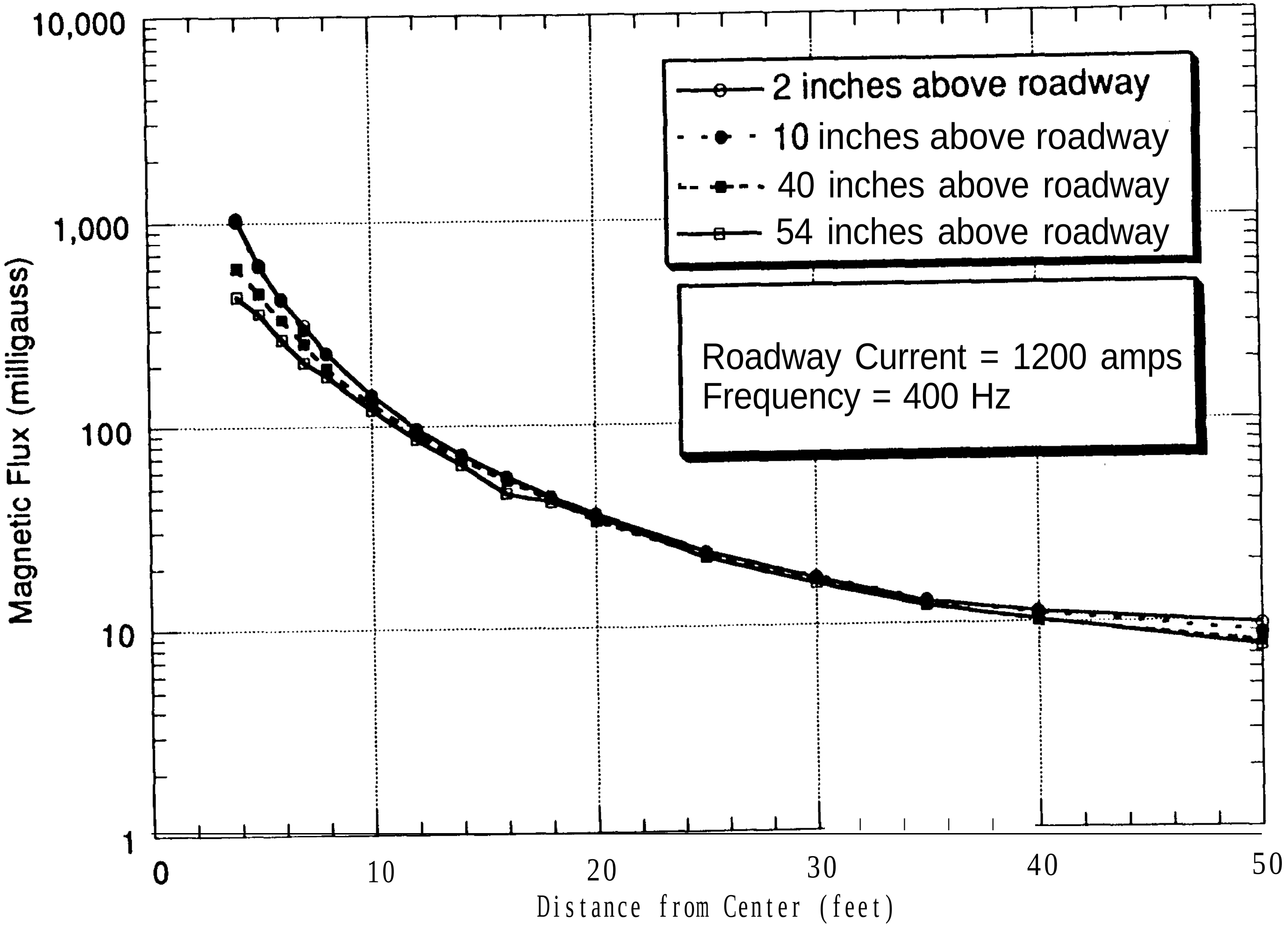


Figure 26. EMF with PATH Roadway

TABLE 7.22 IRPA/INIRC RECOMMENDED 50/60 Hz
EMF Exposure Limits

Exposure Characteristics	Electric Field Strength (kv/m)	Magnetic Flux (mg)
Occupational:		
Whole Working Day	10	5,000 ± 5G
Short Term	30[a]	50,000[b] ± 50G
For Limbs		250,000 ± 250G
General Public:		
Up to 24 hrs/day	5	1,000 ± 1G
Few hr/day	10	10,000 ± 10G

Note: a = Short-term occupational exposure to electrical field strengths between 10 and 30 kv/m is permitted, provided that the electric field strength (kv/m) does not exceed 80 for the whole working day.

b = Maximum exposure duration is 2 hours per work day.

c = These values can be exceeded for a few minutes per day provided precautions are taken to prevent indirect effects.

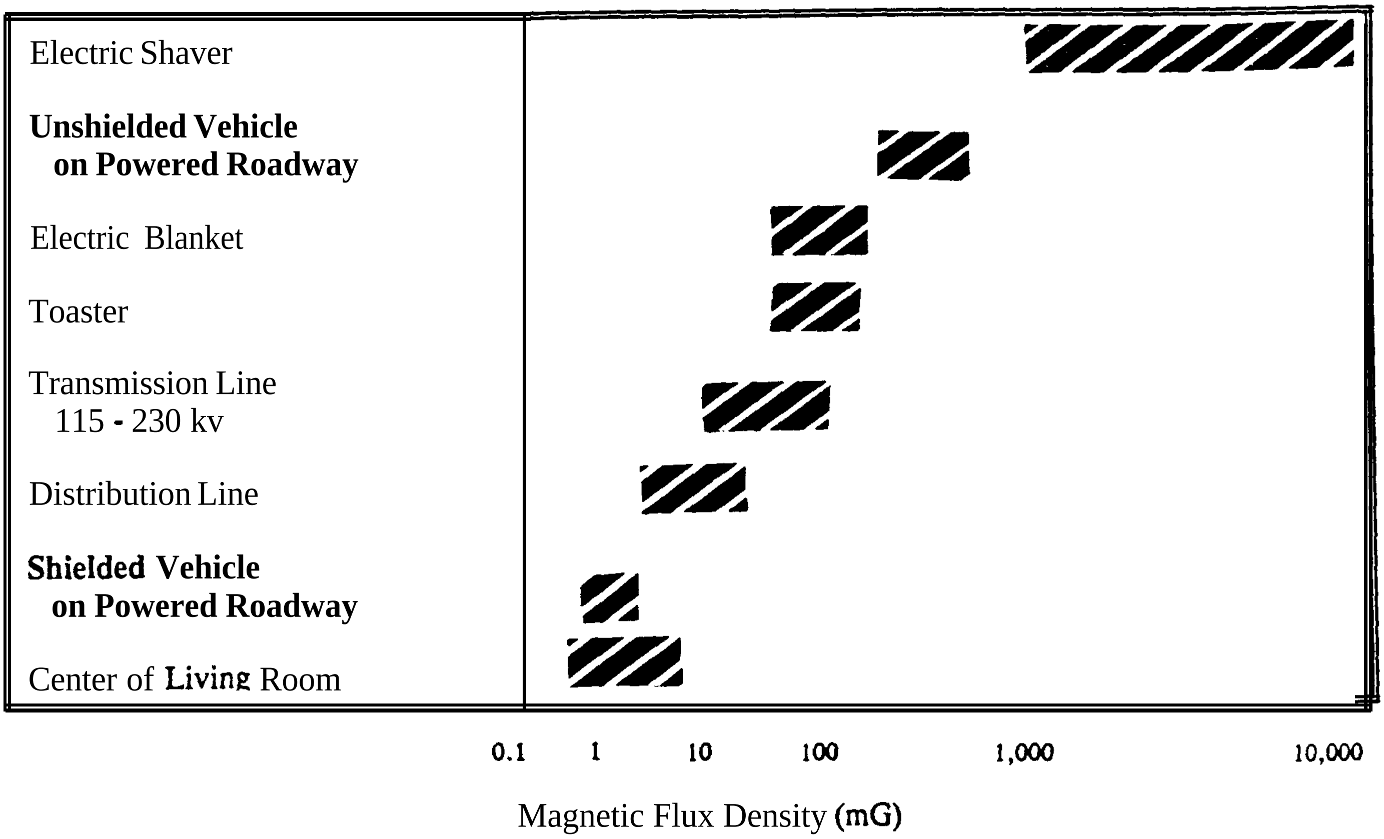
Source: Interim guidelines are approved by the International Radiation Protection Association (IRPA), developed by the International Non-Ionizing Radiation Committee (INITC), and reported in the **Health** and **Safety** Report., Vol. 7, No. 6, July 31, 1989.

TABLE 7.23 EXAMPLES OF 60 Hz MAGNETIC FLUX DENSITIES
Near Various Appliances (mG)

Appliance	Distance 3 cm or ~ 1 in.	 30 cm or ~ 1 ft.	 1 m or ~ 1 yd.
Can Openers	10,000 - 20,000	35 - 300	0.7 - 10
Hair Dryers	60 - 20,000	0.1 - 70	<0.1 - 3
Electric Shavers	150 - 15,000	0.8 - 90	<0.1 - 3
Drills	4,000 - 8,000	20 - 35	0.8 - 2
Mixers	600 - 7,000	6 - 100	0.2 - 2.5
Portable Heaters	100 - 1,800	1.5 - 50	0.1 - 2.5
Blenders	250 - 1,300	6 - 20	0.3 - 1.2
Television	25 - 500	0.4 - 20	0.1 - 1.5
Irons	80 - 300	1.2 - 3	0.1 - 0.25
Coffee Makers	18 - 250	0.8 - 1.5	<0.1
Refrigerators	5 - 17	0.1 - 2.5	<0.1

Source : WHO, 1987

FIGURE 8 EMF EXPOSURE RANKED BY FIELD STRENGTH



Source: Morgan, et al, 1989. Ranges represent 95% confidence intervals.

would literally have to sleep on the powered roadway to receive EMF exposure similar to that of an electric blanket.

Thus, it seems reasonable to continue to investigate applications of the roadway powered technology while providing ongoing research support for potential EMF risk with respect to alternative technology designs, i.e. higher frequencies, disparate field strengths, modified standards for different frequencies and field strengths, in order to remain within the margins of safety for users of the advanced technology system.

RPEV and Battery Disposal

Currently disposal of lead acid batteries constitutes approximately 50 - 60% of non-industrial and military hazardous waste. Although current federal and California laws stipulate that all lead acid batteries be recycled, only 80 - 85% of all batteries are recycled nationally as well as in California. It is the lead, sulfuric acid and polypropalene plastic associated with current illegal battery disposal that generate the environmental threat with respect to growing vehicle battery usage.

Whether lead acid, sodium sulfur, nickel cadmium, or other batteries are utilized in RPEVs (as well as Evs), increased unrecycled battery disposal is likely to become an even more damaging impact to the environment than it is at present. The concern for water quality that would be jeopardized by the increased likelihood of battery leachate in groundwater supplies warrants serious attention for "cradle-to-grave" battery management. Similarly, incineration of lead waste products raises questions regarding air quality deterioration and associated health damages. Thus, directing public policy to reinforce behavior towards participation in currently established recycling efforts is necessary to offset the potential for increased hazardous waste from illegal disposal as the market for RPEV/Evs expands. The current efforts concerning lead acid batteries include:

(a) the Resource Conservation and Recovery Act's (RCRA) identification of used batteries as hazardous waste and regulations supporting battery management at each link in the battery recycling chain,

(b) the Comprehensive Environmental Response Compensation and Liability Act's (CERCLA, or Superfund) liability provisions to support "cradle-to-grave" battery management and creation of a fund to support cleanup,

(c) the Toxic Characteristics Leaching Procedure (TCLP) which tests the slag produced in the process of smelting recycled batteries more rigorously than the previous toxicity test,

(d) the collection of hazardous waste taxes at all levels of government,

(e) **OSHA's** standard for occupational exposure to lead,

(f) EPA's creation of a National Ambient Air Quality Standard for lead, and

(g) the California Administrative Health and Safety Code regulations for spent lead acid batteries.

Further work to augment the above actions should be undertaken to strengthen the lead acid battery recycling chain. For example, Federal support of smelter subsidies and mandated usage of recycled lead are possible complements to existing policies. Enacting additional legislationthatrequires retailers to assist in battery collection, customers to recycle batteries, and manufacturers to be more involved with the recycling chain should additionally be pursued.

In a report completed for Southern California Edison by Theodore Barry and Associates, several conclusions *were* determined *concerning* potential problems posed associated with *recycling* and disposal of batteries. First, battery recycling is not difficult -- simple dismantling procedures are utilized today, a strong lead recycling chain is currently in existence and can be easily supplemented with additional capacity when it becomes necessary to do so, and the additional discarded batteries corresponding to the L.A. Initiative, approximately 5,000, will not be noticeable relative to the existing battery recycling capacity in Los Angeles. The report did, however, point out that since the lead acid battery chain is relatively sensitive to the price of lead, and environmental regulation's effects on standards, liability for cleanup costs, and incentives for turning in batteries, these linkages must be closely regulated.

RPEV and Acoustic Noise

Since interior sound levels are an aesthetic consideration to the driver of a vehicle, attention was given to analyze the acoustic noise of conventional vehicles and **RPEVs** under driving conditions on the Richmond Field Station test track. In tests of the PATH roadway powered bus, the interior noise level was found to be 40 - 45 decibels. Conventional vehicles of different makes and sizes were also examined for acoustic noise under test track driving conditions. For the conventional vehicles 40 - 70 decibel readings were experienced with the roadway powered at 400 Hz and 1200 amps. To put this in perspective, a library has an acoustic noise level of approximately 35 decibels, an office - 65 decibels, a heavy truck - 90 decibels, a jack hammer - 105 decibels, and a jet plane

- 125 decibels. Experts consider *noise* levels of 135 decibels to be painful to the ear.

The measurements for conventional vehicles were considered high enough to warrant further testing of different roadway currents and higher frequencies. The use of higher frequencies in the inductive coupling design would lower interior noise levels since humans are less sensitive to higher frequencies and the roadway current can be reduced at the higher frequencies, thereby reducing the density of the magnetic flux that induces the noise in ferrous material in the first place. Ongoing results of these *new* tests have been encouraging thus far.

8.0 **ROADWAY ELECTRIFICATION ECONOMIC** ASSESSMENT

The economic analysis contained in Sections 8.1 - 8.3 was derived for development and usage of the 2025 RPEV scenario network shown previously as Figure 13. The RPEV system infrastructure is composed of 1,035 freeway lane-miles equipped with inductors imbedded in the roadway, as well as the power conditioners and lines that transmit electricity from the existing distribution grid to the roadway. It was assumed that 173,410 electric vehicles (or 3.28% of the AM-peak vehicle population) would use the inductive coupling system during the AM peak. These vehicles generated **6,248,000** VMT of which **2,903,749** VMT, or **46.5%,** was associated with travel <u>on</u> the powered roadway. The on-roadway AM-peak VMT was utilized to estimate the number of **RPEVs** drawing power from the roadway system each day. Approximately, 28,737 **RPEVs** per lane per day was the system usage determined from the previous analysis of AM-peak vehicle trips and their corresponding VMT. (See Phase II Report, Section 5.1, pp. 5-8 to 5-14).

Two categories of costs pertain to the RPEV system: construction and operating expenses of the electrified roadway, or infrastructure, and life cycle costs to users of the facility. The cost assessment methodology links these expenditures by determining user charges that would be necessary for the RPEV system to break even in a specified year. That is, the per kilowatt-hour, or per mile, rate that equates cumulative revenue and cumulative costs for the powered roadway system is included in the life cycle user cost determination. Section 8.1 provides a detailed description of the methodologies pertaining to the cost models employed in the regional and user cost calculations. Supportive cost analysis utilized to crosscheck the infrastructure costs, and life cycle expenses associated with owning and operating a gasoline vehicle are also summarized. In Section 8.2, the description of baseline input parameters for the user and infrastructure cost models are presented as well as an interpretation of tabulated output of these procedures. Gasoline vehicle costs and alternative infrastructure cost estimates are furnished for comparative purposes.

Section 8.3 reviews sensitivity analyses that were performed for the RPEV system costs. Both infrastructure and RPEV personal vehicle costs were examined with respect to different assumptions concerning roadway construction cost, wholesale energy cost, operating and administrative expenditures, interest rates, energy consumption (kwh/mile), system efficiency, and average **vehicle-miles** per day <u>on</u> the powered roadway system. Qualitative aspects of the effects of highway electrification on the regional economy follow this evaluation in Section 8.4. In Section 8.5, several policy options pertaining to implementation of the 2025 RPEV system are described with quantitative embellishments for infrastructure and personal vehicle costs where possible.

8.1 DESCRIPTION OF COST MODEL METHODOLOGIES

In this *section,* the analytical approaches are explained *for* the computation of personal vehicle costs and infrastructure costs associated with the 2025 RPEV system. It is important to recognize that these cost calculations are preliminary estimates for the RPEV technology, in the prototype stage of development. Economies of scale associated with large-scale production, as in the case of gasoline vehicles, are presently unknown and depend on the speed of introduction and market penetration of RPEVs. In the Nesbitt, sperling, Deluchi "RPEV and Internal Combustion Engine Vehicle (ICEV) Life Cycle Cost Model" (as well as our subsequent usage of this model), RPEVs and ICEVs are postulated to benefit equally from mass production, servicing facility and parts availability, similar interior capacities and vehicle sizes, and identical depreciation rates. The RPEV is further assumed to be equipped with an AC power train, regenerative braking, and, sodium sulfur batteries.

RPEV Life Cycle Cost Methodoloav

The methodologies described in this section provide the basis for the baseline cost assessment and subsequent sensitivity analysis. RPEV life cycle cost formulations utilized the Nesbitt, Sperling, Deluchi (NSD) Model with modifications reflecting the specific configuration and input parameters recommended by the project team corresponding to the design of the 2025 RPEV scenario. The NSD model computes disaggregated costs for the RPEV with reference to a baseline sub-compact gasoline vehicle. (Modeling assumptions pertaining to the ICE vehicle are summarized in the next section.) These costs include ownership components which were amortized over their respective lives and operation and maintenance expenses. RPEV initial vehicle costs were divided into vehicle, pickup inductor, on-board controller (OBC), and battery categories. Researchers familiar with the RPEV technology and construction and testing of the PATH roadway powered bus provided estimates for the initial RPEV cost components. The cost of the RPEV, including tax and onboard charger, but excluding pick-UD inductor, OBC, and batteries, was assumed to be the same as a gasoline vehicle of equivalent size. The cost of the RPEV battery was determined as a function of battery size, efficiency, longevity, energy density, specific power, depth of discharge, and salvage value. Lead acid batteries with a battery range of 40 miles off the powered roadway were evaluated for consistency with the design of the RPEV system. The life of an RPEV was estimated to be 37.5% longer than a comparable gasoline vehicle in the amortized life cycle cost formulations.

Operating costs for an RPEV were specified as 60% of those associated with gasoline vehicles since electric motors require fewer moving parts and less maintenance due to lower stress resulting from the absence of extreme heat, pressure, and synchronized movement corresponding to an internal combustion engine. Tire replacement cost, however, was expected to increase relative to the extra weight of an RPEV compared to a comparable gas vehicle. Insurance costs for the RPEV were estimated on the basis of the complete initial cost of the RPEV, that is, purchase price including OBC, pickup inductor, and batteries. Given that the complete initial RPEV costs are larger than those for an equivalent gasoline vehicle, insurance expenses were adjusted to reflect the higher complete RPEV cost relative to that of a comparable ICE vehicle.

The NSD model determines fuel cost in dollars per gallon associated with operating an RPEV as a function of vehicle fuel economy, electricity cost, fuel tax, usage, the extent of use on the powered roadway system, and the proportion of use during peak electricity-generating periods. The efficiency of an RPEV is calculated as the product of battery charger efficiency, battery efficiency, inductive coupling system (ICS) efficiency, power train efficiency, and vehicle weight. Guidance in specifying these parameters drew on the work of NSD and research conducted at Systems Control Technology (SCT). Electricity cost measured in cents per kilowatt hour was assumed to be the wholesale rate of 7 cents/kwh for peak and off-peak use in the baseline cost estimates in Section 8.2. This assumption was necessary to assure compatibility between the life cycle cost and infrastructure cost models in the baseline cost assessment. (The infrastructure cost model did not develop peak and off-peak electricity rate analysis simultaneously. Instead, separate sensitivity analysis was conducted for a variety of utility rates.) Designation of different electricity rates for peak and off-peak periods is examined in the sensitivity analysis given in Section 8.3.

The NSD model was modified to reflect the percentage of RPEV mileage driven on the powered roadway from our modeling results. It was previously stated that 46.5% of the VMT driven by the RPEVs in the AM peak in the 2025 RPEV system occurred on the powered roadway.

The life cycle cost model developed by NSD additionally incorporates those costs associated with the electric roadway. That is, RPEV users are assumed to bear the full cost of the electrified facility, such as roadway installation and maintenance, expenses. The baseline construction cost was stipulated as $2.5 million per lane-mile with yearly maintenance costs given as 2.5% of the construction cost. The summation of these cost items plus the on network electricity charging expenses offered a rough approximation to total system cost, since energy and debt service should account for approximately 90% of total system costs. These infrastructure costs were allocated across the number of daily RPEV users per lane-mile, or 28,787, in the amortization process. The life of the powered roadway was assumed to be 25 years.

The NSD model thus immerses costs associated with roadway infrastructure and power usage into the calculation of costs to the users of the electrified transportation system. The model does not include a specific RPEV network size in terms of lane-miles nor does it contain a mechanism to allocate deficit expenses that would accrue during the early years of roadway construction and growing demand for the system. If implementation of such a system occurred in practice, it is likely that the powered roadway would be built in stages with usage increasing over time. Therefore, the NSD model was used to provide an estimate for a one-mile portion of a fully built RPEV system with a vehicle population of 28,737 **RPEVs** per lane mile per day. Further adjustments to the RPEV life cycle cost model estimates *were* computed drawing on the infrastructure cost model analyses developed by SCT utilizing input parameters specified by SCAG for the 2025 RPEV scenario.

Gasoline Vehicle Lif[redacted]thodology

The NSD **"Gasoline** Vehicle Baseline Cost **Model"** was utilized as a reference case for the RPEV life cycle cost estimation. The gasoline vehicle life cycle cost model developed by NSD allocates initial vehicle purchase price over the life of the vehicle, and itemizes yearly and/or monthly operation, maintenance, and other costs associated with vehicle usage. The model amortizes capital costs utilizing a 3.3% real interest rate. The life cycle gasoline vehicle costs were projected for a *new* sub-compact ICE vehicle in 2000. This vehicle was assumed to travel 14,000 miles per year, and 140,000 miles over the life of the vehicle or until resale. The 14,000 miles per year travel estimate was determined from an analysis of VMT and the number of vehicles projected for the SCAG region for the year 2000. Tires were expected to last 50,000 miles, and cost $320 for a full replacement set. The loaded vehicle driving weight was estimated at 2,600 pounds.

The real cost of a new gasoline vehicle, salvage value, life expectancy, and average annual vehicle mileage were expected to be consistent with present conditions. Assumptions contained in the NSD analysis were retained for most cost components in our analysis although averages of their estimates were selected for some items. The initial real price of the gasoline vehicle including tax was given as $11,000 with salvage value specified as 1.5% of the initial vehicle cost. From the NSD range of retail gasoline prices, overall fuel economy, oil expenses, gas taxes, and vehicle salvage value **(as** a **%** of initial vehicle cost), averages were utilized **to form** the baseline parameters in estimating the gasoline life cycle costs for this study. The baseline gasoline vehicle retail price of gasoline was set at $1.45 per gallon with taxes included. Overall lifetime vehicle fuel economy was specified as 35 miles per gallon. Oil expenses were estimated at $28.50 per year including taxes. Federal and state gasoline taxes were given as **$.25** per gallon of gasoline. Other operating costs included: **$484.50/year,** including taxes, for maintenance, **$44.36/month** for insurance, **$10.60/month** for parking and tolls, **$18.50/year** for accessories, and **$25/year** for both registration fees, and inspection and maintenance.

Infrastructure Cost Methodologies

Three cost models were developed by SCT to portray the relationship between costs and revenues associated with operation of the powered roadway. Each model builds upon the previous model construction adding further refinements and detail while retaining adequate similarities with the previous models to provide easy validation. The **Steady State** Model **(SSM)** is comparable with the NSD model in its treatment of roadway construction, energy, administration, operations, and maintenance expenses. That is, the SSM generates costs associated with a one-mile portion of a fully built roadway that services a **"steady state"** vehicle population or the number of vehicles that has stabilized, or saturated, at a specified size. The vehicle population saturation, also referred to as market penetration of the RPEV users, was derived from previous analysis to be 28,737 vehicles per lane per day. Financing considerations related to the development and use of the system in previous time periods were ignored. Based on the costs cited above, the retail price of energy that must be charged in order for revenues to equal costs, referred to as the **"breakeven rate,"** was determined. Revenues were therefore assumed to be based solely on roadway-based energy purchased by the RPEV users of the electrified system. The breakeven rate derived from the SSM should be approximately equal to the cost outputs of the NSD model that pertain to roadway infrastructure construction and usage given equivalence in corresponding input parameters.

The second model, referred to as the Startup Transient Model **(STM)**, is also a one-mile model analysis of the costs and revenues that corresponds to the entire 40 year period, from initial construction, to growth in the RPEV population from zero to steady state **("saturation")**, to rebuilding the roadway 25 years after the original construction. The STM differs from the SSM by including cost components to finance the deficit expenses that occur prior to the year when cumulative revenues equal cumulative costs. An initial number of RPEV users and growth of the number of users are developed over time to represent the **"startup** transient" in this model. It was assumed that 1,291 RPEV users would initially enter the system, or market, two years after construction of the roadway began (i.e. in year 3, with the roadway construction beginning in year 1). From the fourth year of construction until market saturation, or 28,737 vehicles per lane per day, was achieved, the number of users was stipulated to increase by 1,937 per year. The model designates a particular year, year 25 in our analysis, for cumulative losses to reach zero. The retail price of energy that must be charged so that cumulative revenues equal cumulative costs in that year is the time-dependent breakeven rate. Once the user population stabilizes, the annual STM results (ignoring interest on the deficits from the early years) match the SSM results. This result is expected since the deficit financing component of the STM falls to zero in the designated year. The outputs generated by the SSM and STM models thus assist in establishing preliminary infrastructure costs for a one-mile scenario that provide a foundation for the development of costs for a complete RPEV regional system.

The RPEV Economic Model (REM) incorporates the STM user, or market penetration profile, and deficit financing considerations and adds further construction scheduling assumptions consistent with the 2025 system scenario design. In comparison to the STM, the REM includes the number of years for roadway construction, the number of new system-miles built per year, and average trip length on the RPEV network as input parameters to the cost analysis. Approximately 10 years of roadway construction are required in order to build the 1,035 lane-mile RPEV network, or 52 system-miles per year. Average trip length of 33.4 miles per day on the RPEV facility was utilized from previous analysis of trip length distribution VMT on and off the powered roadway. When market penetration, or saturation, is achieved as per the previously specified growth profile, it is assumed that the average trip length on the RPEV facility is accomplished.

The breakeven rate, determined for year 25 in the REM model, fully represents all of the regional infrastructure costs associated with the design of the 2025 RPEV scenario. Again, the breakeven rate would be the retail price of electricity charged to users of the powered roadway system so that cumulative revenues and costs associated with the system would be equal in year 25. The costs imbedded in calculation of the breakeven rate were utilized to modify the life cycle RPEV user costs described in the NSD model.

It is important to emphasize that all revenues corresponding to use of the powered roadway were derived from electricity purchased by RPEV users of the electrified system. Revenues generated by the utility from at-home charging as well as other funding options, i.e. excise taxes on RPEVs sold, gasoline taxes, RPEV capital and/or operating cost subsidies, sale of emissions reduction credits, were not included in the analysis. Incorporation of such income-generating measures would substantially reduce cost incidence to the users. Further investigation of these funding possibilities are undertaken in Section 8.5.

Throughout the analysis of roadway construction costs it was assumed that loans were used to finance the capital costs. A 25-year loan period and a 3.3% real interest rate were specified for the SSM, STM, and REM models. Baseline roadway construction cost was specified as $2.5 million per lane-mile. Roadway replacement costs, included in the STM and REM models, were estimated at $1.67 million per lane-mile, and were financed at the 3.3% rate over the useful life of these improvements.

Energy costs in all three models were calculated by multiplying the amount of energy sold by the wholesale energy rate. The wholesale energy rate included the wholesale electricity price of 7 cents/kwh plus 2.3 cents/kwh to cover distribution losses as determined by the 75% system efficiency assumption. (The losses referred to include those associated with the power conditioner, distribution network, and open roadway). The wholesale energy rate of 9.3 cents/kwh contributed to the computation of the retail price of energy. Thus, the wholesale energy costs depended on system efficiency, the vehicle energy transfer rate, the number of system users, and the average on-system miles traveled by each user per day. System efficiency was specified as the DC energy delivered on-board the vehicle divided by the AC energy drawn from the power grid. Vehicle energy consumption, defined as the kilowatt-hours per mile transferred to the vehicle (via the motor controller or for battery recharging), was dependent on terrain, vehicle weight, velocity, aerodynamics, and the amount of battery charging.

Administration costs were assumed to be 2.5% of the baseline projection of the debt and energy expenses in all infrastructure models thereby linking these costs to construction activity and the number of users. Operations and maintenance costs (O&M) were set at 2.5% of cumulative roadway capital costs, excluding replacement, for all three models.

Total roadway costs were thus expressed as the summation of construction, **energy,** administration, and O&M expenses for each model with an additional component for debt financing in the STM and REM. Annual total costs were determined for all three models, and cumulative total costs were provided for the STM and REM. Annual and cumulative profits or losses were derived for the STM and REM. The SSM broke even on an annual basis by definition as explained previously. Taxes and depreciation expenditures were not included in the cash-flow analysis for any of the models.

For each model, components of infrastructure costs were additionally expressed in **$/kwh.** This format enabled determination of the retail price of energy, or breakeven rate, that would be necessary to cover costs per kilowatt hour in a specific year. The breakeven rate, measured in **$/kwh,** was measured by dividing cumulative total costs by cumulative kilowatt-hours sold in the designated breakeven year for the STM and REM. For the SSM, only a breakeven analysis is possible given model design definitions.

8.2 BASELINE USER AND REGIONAL COST RESULTS

The results from the baseline user and infrastructure cost models are presented in this section. Based on the descriptions and modeling methodologies given for each model in Section 8.1, tabulations of model inputs are provided to summarize the previous discussion of parameters specified for each model. The outputs of each model are offered next in graphical and tabular form with an interpretive narrative of the findings.

Baseline User Costs

The specified input parameters for the baseline gasoline and RPEV life cycle costs are given in Table 8.1. These inputs coincide with the selected inputs in the infrastructure cost analysis in all cases where similar parameters are utilized across these models. Table 8.2 lists the cents per mile outputs for both gasoline and RPEV life cycle user costs.

As indicated in Table 8.2, gasoline vehicle user costs are slightly lower than those for RPEVs, 24.88 cents per mile compared to 25.64 cents per mile. Initial vehicle costs are the largest component of gasoline vehicle and RPEV user costs, 36.6% versus 35.9% (or 44.1% with batteries included).

Fuel cost for the gasoline vehicle is 4.14 cents per mile while total electricity cost for the RPEV is 1.68 cents per mile. The RPEV total electricity cost consists of .78 cents per mile of on roadway electricity cost (46.5% of 1.68 cents per mile), and .90 cents per mile of electricity cost associated with off roadway charging, i.e. at home, opportunity charging throughout the day.

RPEV maintenance costs compare favorably with those of the gasoline vehicle. For the RPEV, maintenance costs are 2.08 cents per mile while the gasoline vehicle maintenance, I&M, and oil costs are 3.84 cents per mile. RPEVs have higher replacement tire expenses, registration fees, and insurance costs than the gasoline vehicle.

Gasoline vehicle user costs do not include expenses related to the development of and usage of the freeway facilities whereas the RPEV user costs cover costs related to roadway infrastructure maintenance, and installation. If these roadway costs were not assumed to be passed on to the RPEV system users, i.e. if these infrastructure costs were government subsidized, the RPEV user costs may be lower than the gasoline vehicle costs.

For the RPEV, 2.78 cents per mile of the user costs represents the allocation of infrastructure expenses and roadway electricity usage. If RPEV users did not pay these costs, their life cycle user cost would fall to 22.86 cents per mile. These costs are compared with the output from the steady state model (SSM) in the next section since the SSM estimates these items utilizing an alternative, but similar analysis.

The baseline user cost comparisons suggest that the RPEV may offer some economic advantage to users over the life of the vehicle especially if roadway infrastructure costs were subsidized similarly to the highway developments provided for conventional gasoline vehicles. Additional RPEV user cost sensitivities modeled

TABLE 8.1 INPUTS FOR BASELINE GASOLINE AND RPEV USER COSTS

Gasoline Vehicle Input Data

1.45	Retail price of gasoline, $/gallon, taxes excluded
35.00	Overall lifetime vehicle fuel economy, miles/gallon
11000.00	The initial price of the car including tax, $
140000	Miles driven over life or until resale
0.015	Vehicle salvage/resale value, fraction of initial cost
14000	Miles driven per year
2600.00	The loaded driving weight of the vehicle, lbs.
0.033	The real annual interest rate for auto loans (equal payments over life of vehicle) or foregone consumer savings (full at time of purchase)
71.50	Insurance payments, first n years with collision insurance, $/month
6.50	n, years collision insurance is carried
44.36	Insurance payments, subsequent years without collision insurance, $/month
484.50	Maintenance costs, $/year, including taxes
10.60	Parking and tolls, $/month
320.00	Four replacement tires, $/set, including taxes
50000	Life of tires, miles
18.50	Accessories, $/year
28.50	Oil, $/year, including taxes
25.00	Registration fee, $/year
25.00	Inspection and maintenance fee, $/year
0.25	Gasoline tax, Federal + State, $/gallon
1.05	Sales tax on incremental vehicle cost, (1 + % tax)

TABLE 8.1 INPUTS FOR BASELINE GASOLINE AND RPEV USER COSTS (Con't.)

RPEV Input Data

7.000	Price of peak-hour electricity at the power conditioner, cents/kwh
7.000	Price of electricity at the outlet and/or power conditioner, cents/kwh
0.875	Efficiency of battery charging
0.750	Efficiency of RPEV system from power conditioner input to vehicle battery or powertrain
0.725	Efficiency of battery
6.100	Ratio of efficiency of RPEV powertrain w/regenerative braking to ICEV powertrain efficiency
40.000	Desired urban vehicle range on battery only, miles (at DoD below)
0.800	DoD at desired driving range
Na/S	Battery type
0.015	Battery salvage value, % of initial cost
250.000	Weight of pick-up inductor & suspension system, lb.
57.500	Weight of onboard controller unit, lb.
10.000	Cost of pick-up inductor including suspension system, $/lb.
950.000	Cost of onboard controller unit, $
100.000	OEM battery cost, $/kwh nominal deliverable capacity
1.450	Ratio of retail to OEM battery cost
0.010	Pick-up inductor salvage value, % of initial cost
0.0250	OBC salvage value, % of initial cost
100.000	Battery energy density, maximum delivered wh/kg
a50.m	Battery cycles per life, at DoD stated above
0.000	Cost of RPEV (including tax & onboard charger, excluding pick-up inductor, OBC, & battery) minus cost of ICEV, $
8.500	Number of years collision insurance is carried on RPEV
0.465	96 total annual miles from roadway power
0.465	% of electric roadway miles during peak hour rates
1.375	RPEV life/ICEV life
0.900	RPEV test wt. (excluding battery, OBC, & pick-up inductor) as % of ICEV weight
0.450	Percent decrease in fuel efficiency per 1 percent increase in vehicle weight
0.600	Maintenance costs, fraction of gasoline vehicle
2.500	Cost of building electric roadway lane, $million/mile
28.737	# of RPEVs using electrified lane each day per lane mile (x 1000)
25.000	Life of electric roadway, years
62,015.500	Electric roadway maintenance cost greater than conventional maintenance, S/year/lane mile
1.000	RPEV Fuel tax gasoline tax (x100)

TABLE 8.2 OUTPUTS FOR BASELINE GASOLINE AND RPEV USER COSTS

Gasoline Vehicle Outputs (cents/mile)

4.14	Gasoline
9.11	Vehicle
5.40	Insurance
3.46	Maintenance
0.20	Oil
0.45	Replacement tires
0.91	Parking and tolls
0.18	Registration
0.18	Inspection and maintenance
0.71	Gasoline tax
0.13	Accessories
24.88	TOTAL PRIVATE COST

RPEV Outputs
(cents/mile)

1.68	Total electricity cost (46.5%, or .78* is z-roadway)
9.21	Initial vehicle cost
2.09	Batteries
6.00	Insurance
2.08	Maintenance
0.64	Replacement tires
.91	Parking and tolls
0.19	Registration
0.71	Fuel tax
0.13	Accessories
0.59	Cost for additional electric roadway maintenance *
1.41	Cost for electric roadway installation *
25.64	TOTAL PRIVATE COST

Note: * = The sum of these three items is 2.78 ¢/mile which compares with 4.05 &/mile in the steady state cost model (SSM) and 6.17 ¢/mile in the regional economic cost model (REM). The revised private cost is 26.91 ¢/mile for the SSM and 29.03 ¢/mile for the REM.

and reported in Section 8.3 were developed relative to the baseline gasoline user costs to provide further clarification of our findings.

Infrastructure Costs - Steadv State Model

The summary of steady state model (SSM) inputs and output results are provided as a precursor to the startup transient cost model. Baseline model inputs for the steady state one mile analysis are listed in Table 8.3. As explained in Section 8.1, the steady state model examines costs associated with one mile of a fully developed RPEV system with market penetration at its postulated level of saturation. Figure 28 depicts components of annual costs (also equal cumulative costs in the SSM) in $/kwh associated with the electrified roadway system's operation assuming market penetration of 28,737 vehicles per lane per day. Table 8.4 provides a summary of the energy usage corresponding to this market penetration, and its relationship to the retail energy price component of the breakeven rate.

Table 8.4 Steady State Model One-Mile Analysis

Baseline Energy Usage Summary
(Market Penetration = 28,737 v/l/d)

	Total Wholesale Kwh/yr	Wholesale Rate $/Kwh	Total Wholesale Cost $/Kwh	Contribution to Retail Price $/Kwh
Energy Sold	2,202,691	.07	$154,188	.070
Losses	734 230	.07	51,396	.023
Total Wholesale Energy	2,936,921		$205,584	.093

In Table 8.5, the complete disaggregation of annual costs, revenues and the derivation of the breakeven rate are given. The wholesale cost of energy is the largest expense, representing approximately 48% of total system costs. The breakeven rate of 19.3 cents/kwh (or 4.05 cents/mile) is the retail price of energy that must be charged to cover all system costs. Thus, the retail energy price developed with a high level of utilization of the RPEV system is approximately double the wholesale energy cost.

Table 8.3 Steady State Model Inputs

Steady State One-Mile Model

Scenario: Baseline

INPUT

Market Penetration

28,737	Volume (vehicles per lane per day)

Revenue

0.193	Breakeven Rate **($/kwh)***

Vehicle Parameters

0.21	Energy consumption of vehicle **(kwh/mile)**
75	System efficiency **(%)**

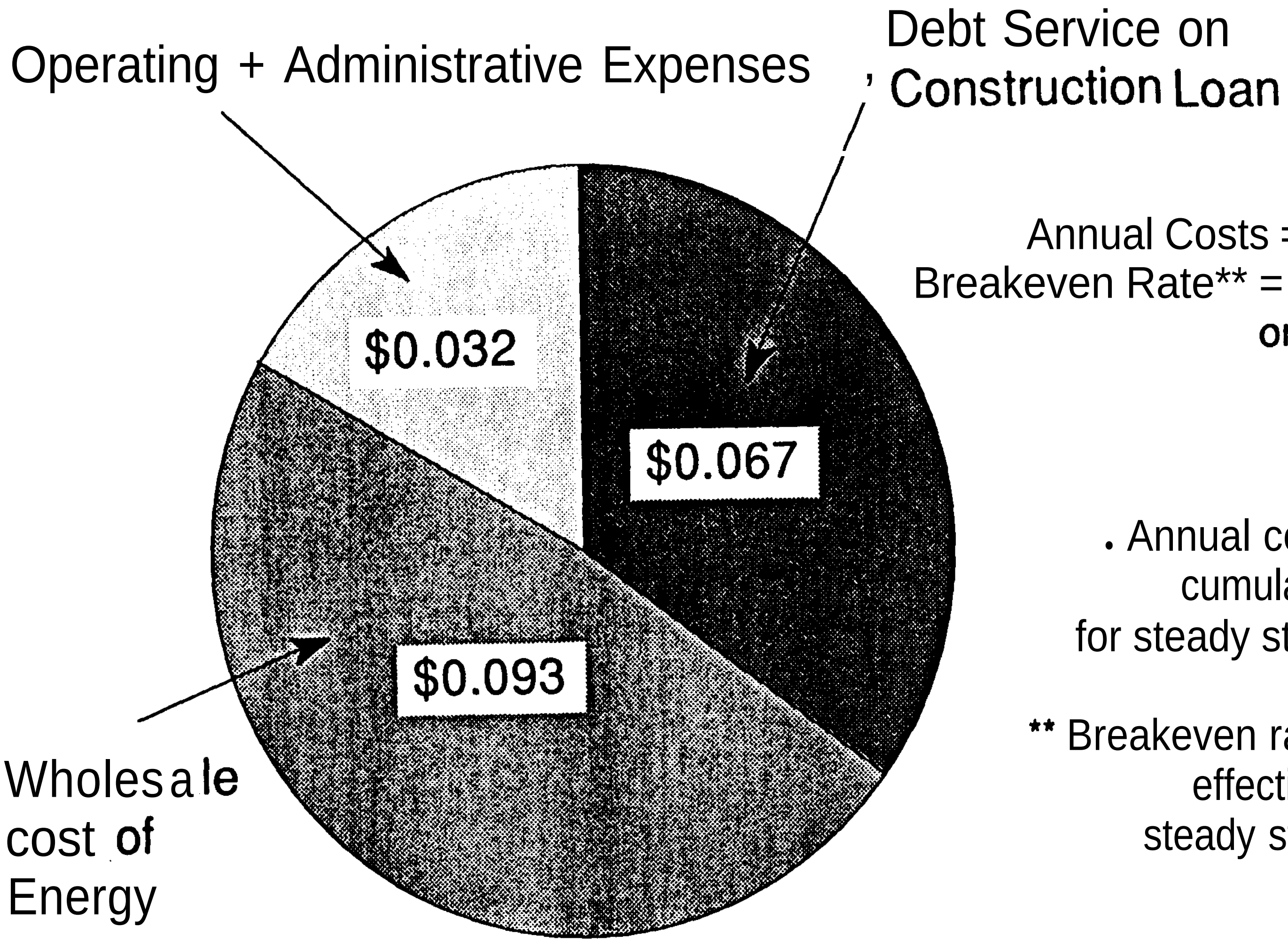
cost

2.5M	Cost/lane-mile of roadway
2.5	Administration **(%** of debt + energy)
2.5	0 & M **(%** of cumulative new roadway capital cost)
0.07	Cost of energy (wholesale $/kwh)

Debt Service

3.3	Interest rate (real %/year)
25	Life of loan and life of roadway (years)

* Output of Model



Annual Costs = $425,345
Breakeven Rate** = $0.193/kwh
or $0.041/mi

- Annual costs equal cumulative costs for steady state model

** Breakeven rate equals effective rate for steady state model

Figure 28. Steady State Model Annual Costs*

Table 8.5 Steady State Model Results

Steady State One-Mile Model

OUTPUT

Scenario: Baseline

Cost Summary	**$**	**$/kwh**
Debt service	148,411	0.068
Wholesale cost of energy	205,584	0.093
Operating expenses	71,350	0.032
Administrative	8,850	0.004
O&M	62,500	0.028
		0.193
Total Cost	425,345	0.193
Revenue Summary		
Retail energy revenue	425,345	0.193

Infrastructure Cost Results - Startup Transient Model

The startup transient model inputs and output results are an extension of the steady state model, and a preliminary step toward developing the regional economic model. The inputs chosen for the startup transient model are delineated in Table 8.6. This model expands the steady state model (SSM) assumptions by adding time-dependency conditions with respect to the profile of users on one lane-mile of a fully built roadway, and debt financing corresponding to the early years of roadway development. For years when the system was cumulatively unprofitable, a deficit interest expense component was included in system costs to finance the deficit. The breakeven year of 25 was selected given the 25 year life of the roadway and the construction loan period assumptions. The STM model spans 40 years from initial construction to allow roadway replacement analysis to be included in the cost and revenue calculations beyond the breakeven year.

Table 8.7 presents the annual cost and revenue summary for years 13, 25, and 40. For this analysis, the retail price of energy corresponding to the breakeven rate determined in the cumulative cost determination was utilized for revenue calculations. The cumulative breakeven rate, 27.1 cents/kwh (or 5.69 cents/mile), represents the charge required to insure that all costs accumulated by year 25 will be paid with accumulated revenues. This rate was higher than the rate necessary to equate total costs and revenues on an annual basis in year 20. The annual breakeven rate in the STM for year 25 was 19.3 cents as was the case for the SSM.

As indicated in Table 8.7, annual costs and revenues were approximately equal in year 13. Years prior to 13 produced losses with years following 13 demonstrating ever-increasing profits. Market saturation was achieved in year 18 and corresponded to the total cost maximum. This occurred since the number of system users when system costs were distributed reached its peak in year 18 and stabilized at that level of usage in each succeeding year. Thus, total system costs were spread over the largest number of users after that point. Total revenue, by comparison, increased until year 18 when it reached stability at $596,767 per year.

As expected, debt service represented the largest cost component in the early years of roadway construction and market development. After year 25, debt service costs decreased since the newly incurred debt to finance roadway replacement was less than the original roadway construction loan expense. In addition, interest payment on the debt incurred in the early years of roadway development fell to zero in year 25.

Table 8.6 Startup Transient Model Inputs

Startup Transient One-Mile Model

Scenario: Baseline

INPUT

Market Penetration

3	Start year
1,291	RPEV users in the initial year of market growth
1,937	Number of users per year until market saturation
28,737	Saturation cap in average vehicle/lane/day

Revenue

0.242	Cumulative breakeven rate ($/kwh)*

Vehicle Parameters

0.271	Energy consumption of vehicle ($/kwh)
75	System efficiency (%)

Miscellaneous

25	Designated year for cumulative breakeven rate

Cost

2.5M	Cost/lane-mile of roadway
1.67M	Replacement cost ($/mile)
2.5	Administration (% of debt + energy)
2.5	0 & M (% of cumulative new roadway capital cost
0.07	Cost of energy (wholesale $/kwh)

Debt Service

3.3	Interest rate (real % per year)
25	Life of loan and life of roadway (years)

*Output of Model

Table 8.7 Startup Transient Model Results

Startup Transient One-Mile Model

Scenario: Baseline

OUTPUT

Annual	Year 13		Year 25		Year 40	
	$	**$/kwh**	**$**	**$/kwh**	**$**	**$/kwh**
Cost Summary						
Debt service	148,411	0.094	148,411	0.068	98,941	0.045
Wholesale cost of energy	147,809	0.093	205,584	0.093	205,584	0.093
Operating expenses	69,905	0.039	71,350	0.032	70,113	0.031
Administrative	7,405	0.004	8,850	0.004	7,613	0.003
O&M	62,500	0.035	62,500	0.028	62,500	0.026
Interest on cumulative deficit	44,844	0.048	0	0.000	0	0.000
Total Cost	410,969	0.279	425,345	0.193	374,638	0.170
Revenue Summary						
Retail energy revenue	429,056	0.271	596,767	0.271	596,767	0.271
Total Revenue	429,056		596,767		596,767	
Profit/Loss	18,087		171,422		222,129	

Wholesale energy cost increased corresponding to growth in the number of system users and stabilized at $205,584 in year 18 when market penetration of 28,737 v/l/d was completed. In year 25, as in the SSM, and thereafter wholesale energy cost was the predominant component of system costs representing approximately half of total expenses. Figures 31 and 32 are provided in the graphics section at the end of Section 8.3 to offer additional confirmation of these findings.

Cumulative revenues and costs developed in the STM are portrayed in Table 8.8 for years 13, 25 and 40. While year 13 demonstrated an annual breakeven, losses are apparent when a cumulative perspective of revenues and costs was undertaken. In year 25, cumulative revenues equal cumulative costs at the breakeven rate of 27.1 cents compared to the annual STM and SSM's breakeven rate of 19.3 cents. Thus, accounting for the accumulated expenses for the first 25 years of project life in order to breakeven in the specified year substantially increased the retail energy rate that must be charged to users. Figure 29 shows that approximately half of the cumulative expenses in year 25 are represented by debt service and interest payments on the cumulative deficit. These expenses fall, however, relative to wholesale energy costs in the years after the breakeven year since roadway replacement costs were less than the initial roadway expenses, and the initial roadway construction loads were paid. Figures 33 - 36 at the end of Section 8.3 offer illustrations of these findings.

Although all system costs rise with time, the contribution of each cost component to the retail price of energy demonstrated different growth patterns. Debt service and interest on the cumulative deficit fell as the number of system users increased. The contribution of debt service to the retail price of energy fell to half its value from year 13 to year 25 while the interest on cumulative deficit component decreased by more than half over this period. Operating expenses also fell as they were spread over a larger number of users. Consequently, as time proceeded the fraction of the retail energy price attributed to wholesale energy cost, which is constant, represented an ever-increasing percentage of the retail price of energy. Figure 29 illustrates the cost components of the breakeven rate for year 25. In that year cumulative debt service and cumulative interest on the cumulative deficit were approximately half of the breakeven rate.

Infrastructure Cost Results -- Regional Economic Model

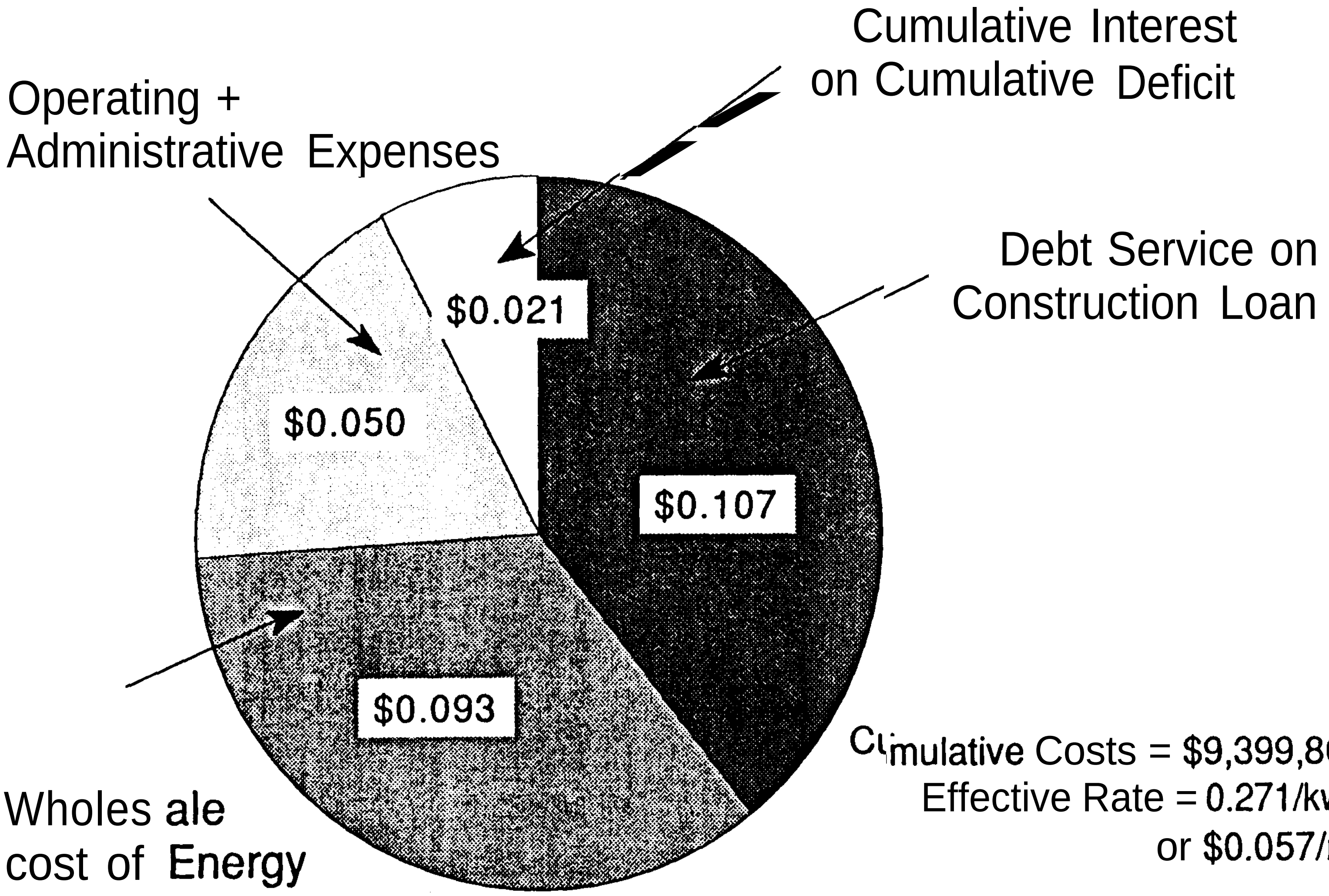
The regional economic model (REM) incorporated the technical and market assumptions corresponding to the 2025 RPEV scenario. This model is a scaled up version of the STM in that the REM included the 1,035 lane-miles of roadway as specified in the RPEV scenario network. The REM also contained a roadway construction schedule, approximately 104 new system lane-miles per year for ten years, as well as a system replacement timetable similar to the initial

Table 8.8 Startup Transient Model Results

Startup Transient One-Mile Model **Scenario:** **Baseline**

OUTPUT

Cumulative	Year13		Year25		Year40	
	$	**$/kwh**	**$**	**$/kwh**	**$**	**$/kwh**
Cost Summary						
Debt service	**1,929,344**	0.209	**3,710,276**	0.107	**5,194,387**	0.077
Wholesale cost of energy	863,745	0.093	**3,238,230**	0.093	**6,321,997**	0.093
Operating expenses	882,327	0.095	**1,736,213**	0.050	**2,787,910**	0.041
Administrative	69,827	0.007	173,713	0.005	287,910	0.004
O&M	812,500	0.088	**1,562,500**	0.045	**2,500,000**	0.037
Interest on cumulative deficit	444,483	0.048	715,151	0.021	715,151	0.011
Total Cost	**4,119,900**	0.445	**9,399,870**	0.271	**15,019,445**	0.222
Revenue Summary						
Retail energy revenue	**2,507,263**	0.271	**9,399,870**	0.271	**18,351,370**	0.271
Total Revenue	**2,507,263**		**9,399,870**		**18,351,370**	
Profit/Loss	**-1,612,636**		0		**3,331,925**	



Cumulative Costs = $9,399,869
Effective Rate = 0.271/kwh
or $0.057/mi

Figure 29. Startup Transient Model Cumulative Costs
(Year 25)

roadway construction schedule. The market penetration profile imbedded in the STM was modified in the REM to reflect the additional assumption that each system user traveled an average of 33.4 miles per day on the powered roadway. Financing conditions utilized in the REM were identical to those developed in the STM. When the system was cumulatively unprofitable, a cost component was added to debt service to finance the deficit.

Table 8.9 presents the REM inputs for the 2025 scenario. In Table 8.10 annual revenues and costs are given and indicate that breakeven occurred in year 16. The cumulative breakeven rate was higher in the REM, $.294/kwh, compared to the STM. This rate was utilized in the annual revenue determination so that annual costs could be compared with the retail price of energy that must be charged to enable cumulative losses to reach zero in the breakeven year. In year 16, costs per kilowatt hour are approximately equal to the breakeven rate, causing the system to first break even on an annual basis in that particular year.

Total annual costs increased most rapidly during the ten years of initial roadway construction and continued to grow at a slower pace to year 25. Following year 25, roadway replacement costs which were assumed to be two-thirds of initial roadway construction expense, and removal of the deficit interest expense enabled total costs to decline. Annual revenue increased until stabilization at $671.1 million in year 27 when market saturation of 28,737 v/l/d was achieved. These results are portrayed in Figures 37 and 38 at the end of Section 8.3.

Approximately half of the retail price of energy was needed to cover debt service and interest on cumulative deficit expenses in year 16, the annual breakeven year. This result is similar to that found in the STM and SSM. By year 25, wholesale energy cost was the largest component of system costs as expected from the STM results. From years 25 to 40, the wholesale cost of energy was slightly less than one-third of the retail energy price.

The cumulative cost and revenue analysis for the RPEV scenario is given by the REM results in Table 8.11. All previous infrastructure cost analyses provided confirmation of the modeling procedures that were utilized to validate the assumptions and relationships among cost components contained in these findings. In Table 8.11 the cumulative breakeven of all system costs and revenues occurs in year 25, the designated breakeven year. In that year, costs equal revenues of $7,552.8 million. Thus, to build and operate the RPEV system, users would be charged $.294/kwh to cover the system costs of $7,552.8 million. By year 40, the cumulative REM results indicate that profits would be $4,016.3 million.

The wholesale price of energy was approximately one-third of the retail price in the breakeven year with debt service and cumulative interest on the cumulative deficit representing nearly half of the

Table a.9 Regional Economic Model inputs

Regional Economic Model	**Scenario** Baseline
INPUT	
Market Penetration	
4,000	Number **of RPEV** users in the **initial year of** market growth
6,000	Number of users per year until market saturation
3	Start year
26,737	Volume limit in **vehicles/lane/day** (or **vehicle-miles/lane-mile/day)**
Revenue	
0.264	Cumulative breakeven rate’
cost	
2.5M	Cost per lane-mile of roadway
1.67M	Replacement cost **($/lane-mile)**
2.5	Administrative **(%** of debt + energy)
2.5	**O&M (%** of cumulative new **roadway** capital **cost**
6.07	Wholesale cost of energy **($/ kwh)**
Vehicle Parameters	
0.21	Energy consumption of vehicle **(kwh/mile)**
75	System effincy **(%)**
33.4	**Average** vehicle-miles per day on the system
Debt Service	
3.3%	Interest rate (real **%/year)**
25	Life of loan and life of roadway (years)
Miscellaneous	
25	**Designated** year for cumulative breakeven rate
9.95	Number of years for roadway **construction**
5 2	New system-miles **per** year **(104** lane-miles)

*Output of model

Table 8.10 Regional Economic Model Results

Regional Economic Model **Scenario:** Baseline

OUTPUT

Annual	Year 16		Year 25		Year 40	
	M$	**$/kwh**	**M$**	**$/kwh**	**M$**	**$/kwh**
Cost Summary						
Debt service	153.6	0.109	153.6	0.068	102.4	0.045
Wholesale cost of energy	131.4	0.093	210.7	0.093	212.6	0.093
Operating expenses	71.8	0.051	73.6	0.032	72.6	0.032
Administrative	7.1	0.005	9.1	0.004	7.9	0.004
O&M	64.7	0.046	64.7	0.028	64.7	0.028
Interest on cumulative deficit	38.5	0.046	0	0.000	0	0.000
Total Cost	395.3	0.299	438.1	0.193	387.6	0.170
Revenue Summary						
Retail energy revenue	414.7	0.294	665.1	0.294	671.1	0.294
Total Revenue	414.7	0.294	665.1	0.294	671.1	0.294
Profit/Loss	19.4		227.0		263.5	

Table 8.11 Regional Economic Model Results

Regional Economic Model

Scenario: Baseline

OUTPUT

Cumulative	Year 16		Year 25		Year 40	
	M$	**$/kwh**	**M$**	**$/kwh**	**M$**	**$/kwh**
Cost Summary						
Debt service	1,766.1	0.226	3,148.3	0.123	4,914.4	0.087
Wholesale cost of energy	728.8	0.093	2,393.2	0.093	5,582.9	0.093
Operating expenses	806.1	0.103	1,464.4	0.057	2,558.4	0.042
Administrative	62.4	0.008	138.6	0.005	262.4	0.004
O&M	743.7	0.095	1,325.8	0.052	2,296.0	0.036
Interest on cumulative deficit	362.2	0.046	546.9	0.021	546.9	0.009
Total Cost	3,663.2	0.468	7,552.8	0.294	13,602.6	0.226
Revenue Summary						
Retail energy revenue	2,299.9	0.294	7,552.8	0.294	17,619.0	0.294
Total Revenue	2,299.9	0.294	7,552.8	0.294	17,619.0	0.294
Profit/Loss	-1,363.2		0		4,016.4	

retail energy price. (See Figure 30). As in the STM results, the wholesale cost of energy represented an increasing proportion of the retail energy price over time while all other cost components' percentage contributions to the retail price of energy declined. This result was expected since all system costs other than energy were spread over a larger number of users over time. Energy costs, however, although proportional in rate, comprised an increasing percentage of total system costs as system usage increased. These results are additionally confirmed in Figures 39 - 42 at the end of Section 8.3.

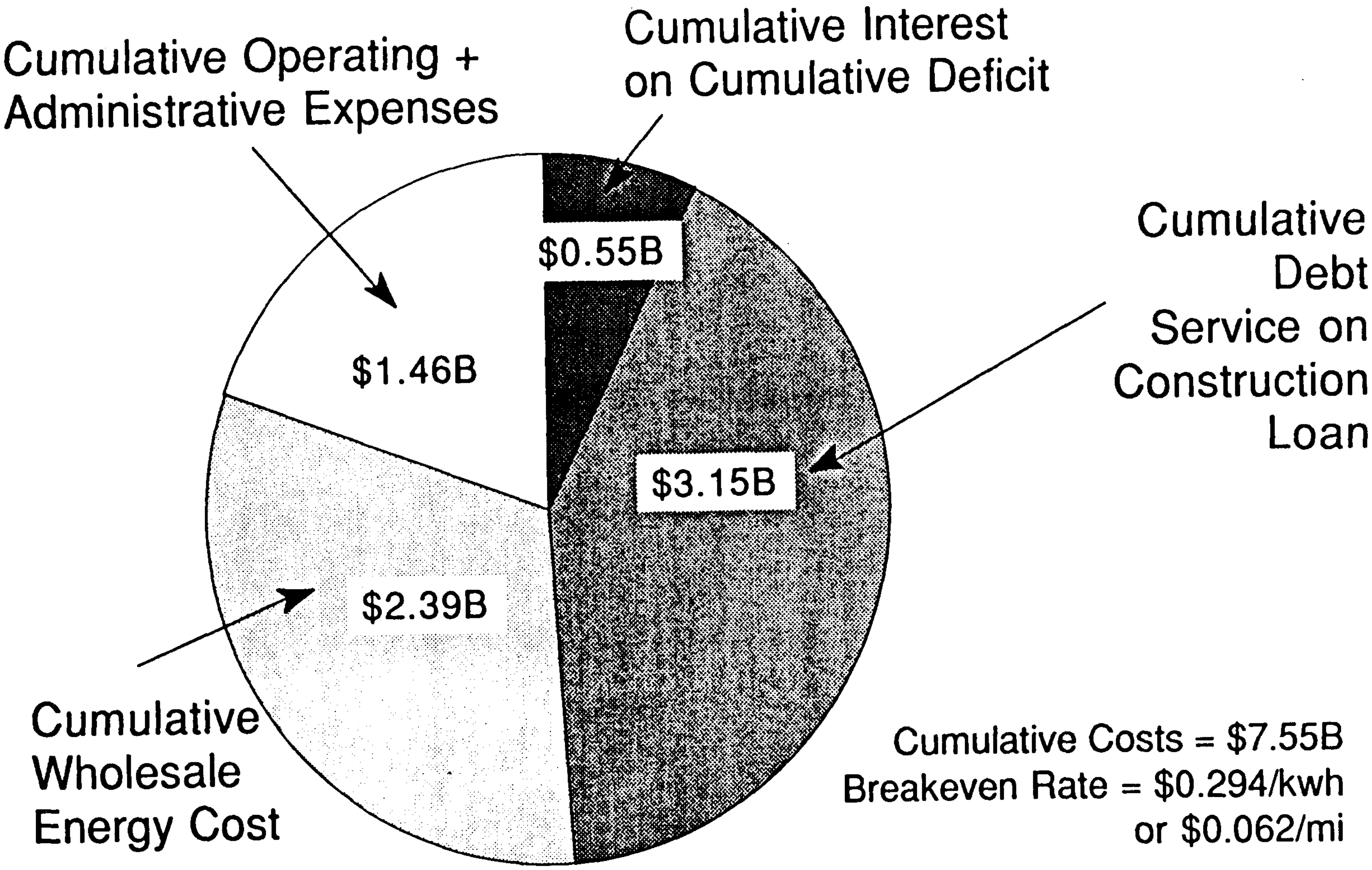
Again, the cumulative REM results are the relevant baseline results for consideration in implementing the roadway system. The REM model more closely represents the practical application of the system design, and time-dependent cost considerations are necessary for correct planning purposes. This model and its baseline results thus provide a vehicle through which additional system cost analyses may be examined.

The REM baseline model produced a cumulative breakeven rate of $.294/kwh or 6.17 cents per mile. This retail energy rate was useful in modifying the NSD model's RPEV life cycle cost estimate for system users. In the NSD model baseline analysis, 2.78 cents per mile was attributed to costs associated with building and operating the powered roadway as well as the portion of electricity expense corresponding to <u>on</u> system charging. For the REM model, these roadway costs were higher due to the cumulative cost analysis which included deficit financing and roadway construction timetable considerations. The revised baseline life cycle cost to the RPEV system user of 29.03 cents per mile incorporates these REM revisions.

In comparison, with the NSD model's 24.88 cents per mile life cycle cost estimate for conventional vehicles, the baseline RPEV user cost was approximately 17% higher. As noted previously, subsidization of electrified roadway construction and operating costs would reduce the disparity in life cycle cost comparisons between conventional gasoline and RPE vehicles. The sensitivity analyses in the next section include roadway construction subsidization estimates for system users.

8.3 USER AND REGIONAL COST SENSITIVITY ANALYSIS

In this section sensitivity analysis is performed for selected model parameters so as to generate a series of comparisons with the findings given in the baseline results for the 2025 RPEV system. The baseline results are studied with respect to changes in roadway costs, wholesale energy cost, roadway operating expenses, interest rates, energy consumption, system efficiency and average vehicle-miles per day on the system. Where applicable user cost sensitivities are additionally offered in these comparisons.



Cumulative Costs = $7.55B
Breakeven Rate = $0.294/kwh
or $0.062/mi

Figure 30. RPEV Economic Model Cumulative Costs
(Year 25)

Table 8.12 lists the previously stated sensitivity measures and identifies the baseline results with asterisks. The REM cumulative cost results are utilized for all sensitivities. The REM cumulative breakeven rate in year 25, and the cumulative costs and revenues for years 25 and 40 are also provided. Cumulative system profits for year 40 are also offered. Figures 43 - 50 at the end of this section graphically depict these sensitivities for the REM breakeven rate comparisons.

When viewing Table 8.12 each sensitivity may be contrasted with the baseline entry assuming all other measurements have been maintained at their baseline values. For example, the cumulative breakeven rate for a roadway construction cost per mile of $1.5 million is 24.1 cents/kwh (5.06 cents/mile) relative to the baseline value of 29.4 cents/kwh (6.17 cents/mile) with all other baseline input amounts retained. The $0.0 million per mile roadway cost is included in the analysis to represent a roadway cost subsidization case. If roadway construction expense was subsidized, the lowest cumulative breakeven rate is produced, 15.6 cents/kwh (3.28 cents/mile), which is approximately half the baseline cumulative breakeven rate. The highest cumulative breakeven rate occurs when roadway cost is set at $6.0 million per lane mile, or 49.2 cents/kwh (10.33 cents/mile). The range of cumulative breakeven rates mirrors the range of cumulative cost estimates for all sensitivity measures since the minimum and maximum values occur within the roadway cost category.

Cumulative breakeven rates generally increase as expense category sensitivity values increase and decrease as sensitivity measures related to system performance and/or usage increase. Increased system efficiency, however, reduces cumulative costs.

The range of cumulative system profits for year 40 indicates a difference of $7,865.1 million, given the cumulative profit minimum of $1,009.1 million with roadway cost subsidization and maximum of $8,874.2 million assuming a 9.9% real interest rate. Cumulative profits of $4,016.3 million for baseline conditions are offered as the most reasonable estimates.

Cumulative costs, revenues, and profits are found to be sensitive to alternative roadway cost and interest rate measures. Cumulative profits in year 40 are insensitive to wholesale energy cost, energy consumption, system efficiency, and average vehicle-miles per day on the system since these measurements equally impact both cumulative costs and revenues. Roadway costs and interest rates produce the largest variation in cumulative profits (as well as losses) over time.

Table 8.13 translates the REM model's cumulative breakeven rate from $/kwh to cents per mile to enable calculation of RPEV life cycle user cost sensitivities. The results in Table 8.2 indicated

Table 8.12 Regional Economic Model Results: Sensitivity Analysis

		OUTPUTS			
Sensitivity Measures	Cumulative Breakeven Rate (Year 25) $/kwh	Cumulative Revenue = Cumulative Costs (Year 25) M$	Cumulative Revenue (Year 40) M$	Cumulative Costs (Year 40) M$	Cumulative Profit (Year 40) M$
Roadway Cost					
$0.0M	0.156	3,998.0	9,326.4	8,317.3	1,009.1
$1.5M	0.241	6,182.1	14,421.5	11,518.6	2,842.9
~~$2.5M*~~	~~0.294~~	~~7,552.8~~	~~17,618.8~~	~~13,602.6~~	~~4,016.3~~
$4.0M	0.376	9,646.3	22,502.5	16,725.8	5,776.7
$6.0M	0.492	12,613.3	29,424.0	21,197.6	8,226.4
Wholesale Energy Cost					
$0.05	0.267	6,851.9	15,984.0	11,967.6	4,016.3
$0.07*	0.294	7,552.8	17,618.8	13,602.6	4,016.3
$0.09	0.322	8,253.7	19,254.0	15,237.6	4,016.3
Operating Expenses					
1.0%	0.256	6,573.0	15,333.2	11,966.3	3,366.8
2.5%*	0.294	7,552.8	17,615.8	13,602.6	4,016.3
5.0%	0.358	9,185.9	21,428.6	16,329.7	5,099.0
Interest Rate					
3.3%*	0.294	7,552.8	17,615.8	13,602.6	4,016.3
6.6%	0.377	9,675.7	22,571.2	16,438.4	6,132.8
9.9%	0.481	12,340.8	28,788.3	19,914.0	8,874.2
Energy Consumption					
0.16	0.357	6,968.7	16,256.4	12,240.1	4,016.3
0.21*	0.294	7,552.8	17,615.8	13,602.6	4,016.3
0.26	0.256	8,136.9	18,981.4	14,965.1	4,016.3
System Efficiency					
65%	0.309	7,930.2	18,499.3	14,483.0	4,016.3
75%*	0.294	7,552.8	17,618.8	13,602.6	4,016.3
85%	0.283	7,264.2	16,945.7	12,929.3	4,016.3
Average Vehicle-Miles/Day on System					
33.4*	0.294	7,552.8	17,619.8	13,602.6	4,016.3
40	0.262	8,037.6	18,749.8	14,733.4	4,016.3
50	0.229	8,772.0	20,463.0	16,446.7	4,016.3

Note: • = Baseline values

TABLE 8.13 LIFECYCLE RPEV USER COST: SENSITIVITY ANALYSIS

Sensitivity Measures	Cumulative Breakeven Rate (Year 25) $/kwh	Cumulative Breakeven Rate (Year 25) &/mile	Lifecycle RPEV User cost (Year 25) ¢/mile
Roadway Cost			
$ 0.0m	0.156	3.28	26.14
$ 1.5m	0.241	5.06	27.92
$ 2.5m *	0.294	6.17	29.03
$ 4.0m	0.376	7.90	30.76
$ 6.0m	0.492	10.33	33.18
Wholesale Energy Cost			
$ 0.05	0.267	5.61	28.21
0.07 *	0.294	6.17	29.03
0.09	0.322	6.76	29.79
Operating Expenses			
1.0%	0.256	5.38	28.25
2.5% *	0.294	6.17	29.03
5.0%	0.358	7.52	30.38
Interest Rate			
3.3% *	0.294	6.17	29.03
6.6%	0.377	7.92	33.07
9.9%	0.481	10.10	37.67
System Efficiency			
65.0%	0.309	6.49	29.34
75.0% *	0.294	6.17	29.03
85.0%	0.283	5.94	28.86

Note: * = Baseline Values

a personal vehicle cost of 25.64 cents per mile for the RPEV owner. Of this life cycle cost, 2.76 cents per mile was attributed to roadway installation and maintenance costs, and the electricity cost associated with <u>on</u> roadway vehicle charging. The REM model estimates these cost components to be .294 $/kwh, or 6.17 cents per mile given baseline conditions. As stated previously, the REM results more accurately represent these cost components for the specific design of the RPEV scenario by including a roadway construction and replacement timetable, and an account of deficit financing for the early years of roadway utilization. Thus, column four of Table 8.13 offers the revised RPEV life cycle user costs for the baseline conditions (indicated with an asterisk), and sensitivities relatedtothe alternative cost and system parameters given in Table 8.12's REM results.

The findings from Tables 8.12 and 8.13, show that the RPEV scenario will require users to pay 6.17 cents per mile for system-related expenses, and a total life cycle cost to own and operate an RPEV of 29.03 cents per mile. The cumulative breakeven rate of ,294 $/kwh, or 6.17 cents per mile, would be the retail energy rate necessary to enable cumulative revenues to match cumulative costs in year 25. Thus, the breakeven retail energy rate would be adequate to cover the $7,552.8 million system costs of the RPEV scenario.

As was the case with the REM results in Table 8.12, RPEV life cycle user costs vary by the greatest amount when alternative roadway costs are considered. If roadway cost was subsidized, RPEV system user cost would be 26.14 cents per mile rather than the baseline estimate of 29.03 cents per mile. Compared to the baseline vehicle life cycle user cost figure of 24.88 cents per mile, this RPEV user cost would be slightly higher.

It is important to note that comparisons of the RPEV and gasoline vehicle user cost rely on direct, or tangible, cost information. Consideration of the external, or intangible, costs associated with operation of a gasoline vehicle, i.e. pollution costs corresponding to health, productivity, visibility, material, and other damages, are not factored into these calculations. Obviously, the ability to calculate such externalities would increase the life cycle costs associated with conventional vehicles. A complete cost analysis that includes direct and external cost components would thus provide the correct measure of gasoline vehicle user costs. For the RPEV, external costs would be approximately zero, given the negligible increases in power plant emissions associated with the level of RPEV market penetration contained in the RPEV scenario. (Battery disposal and electromagnetic field exposure issues are not expected to produce external costs for RPEV usage. See Section 7.4 of this report for further comment on these topics).

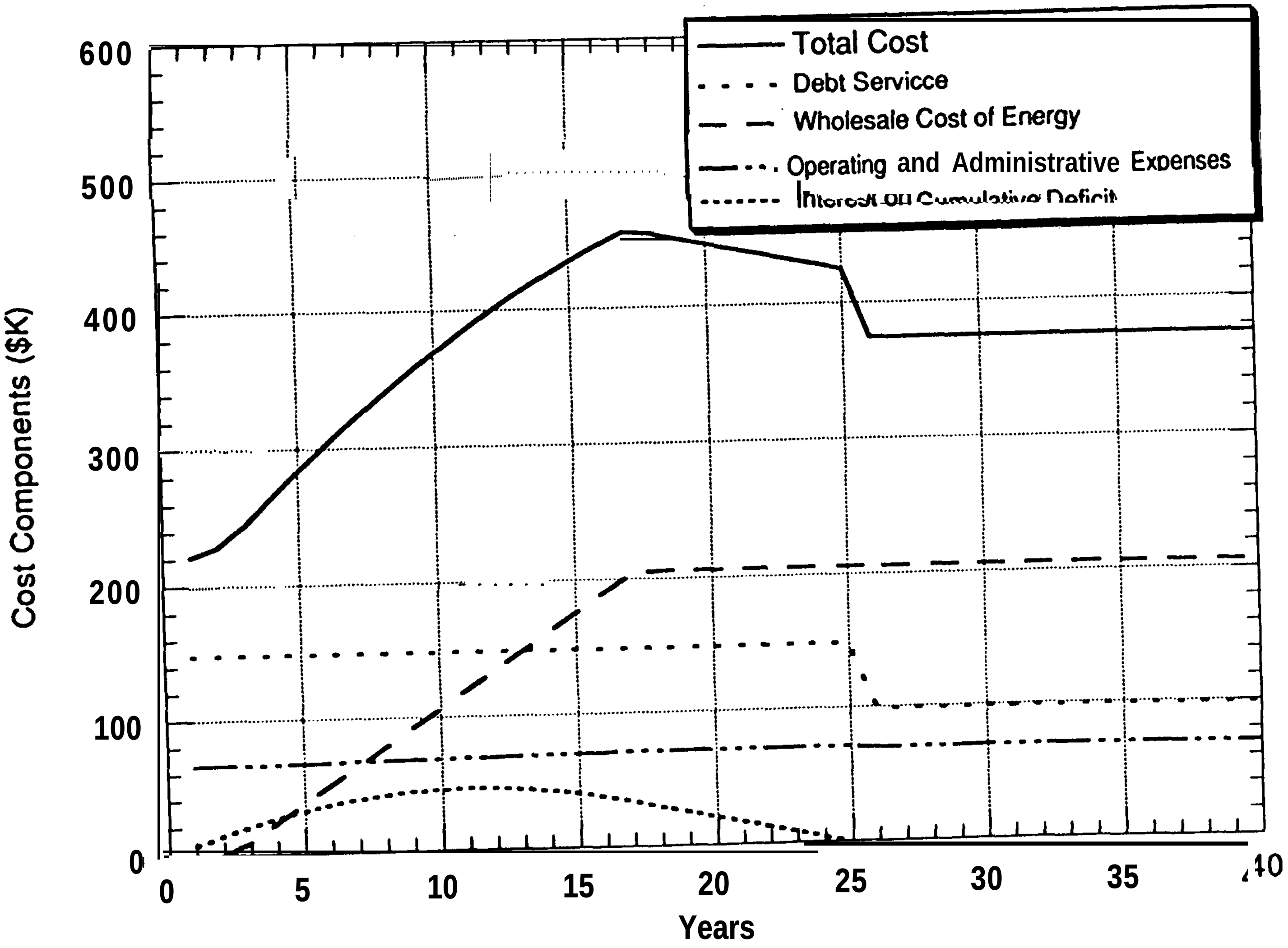


Figure 31. Startup Transient Model Annual Cost Components

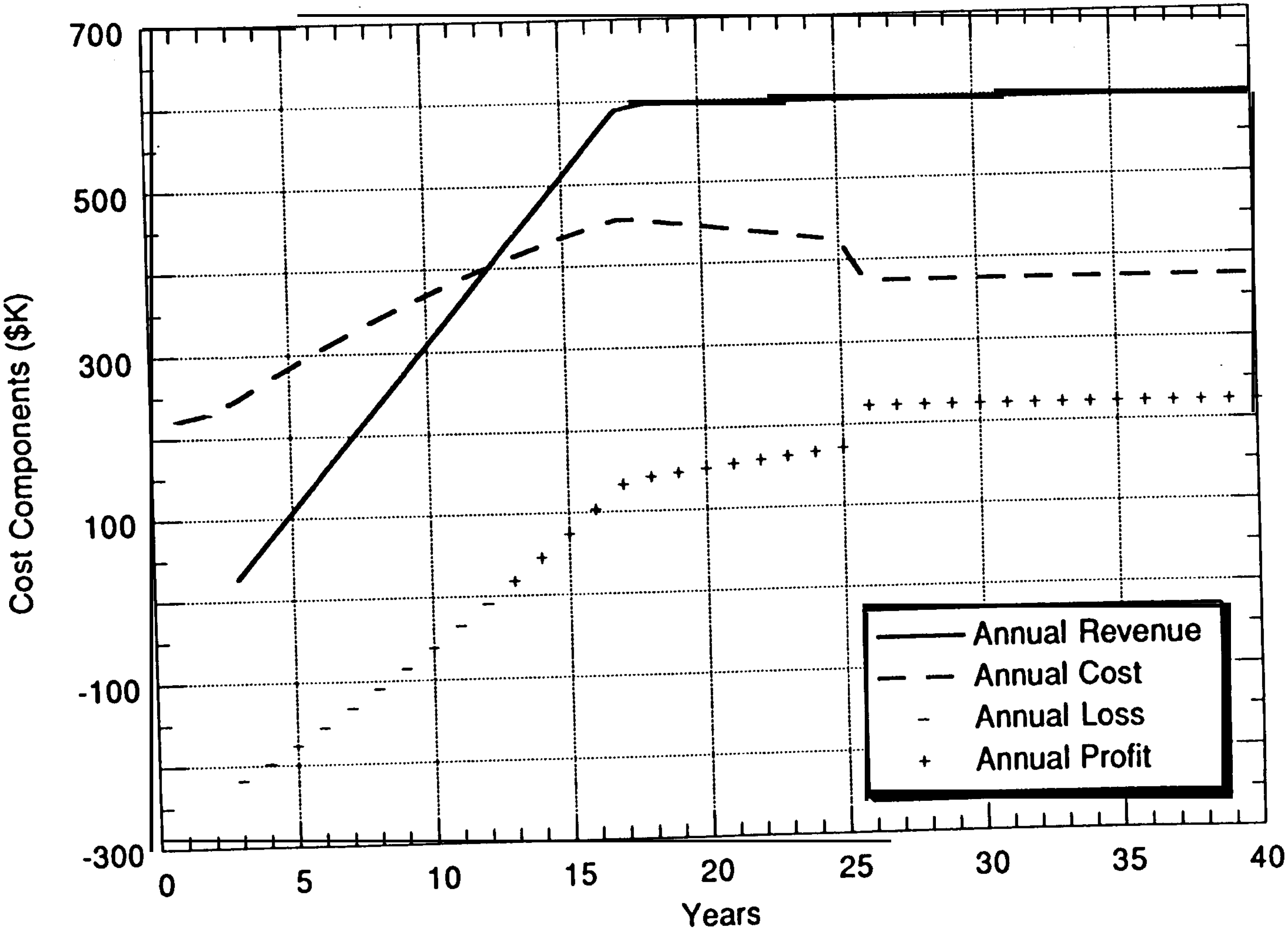


Figure 32. Startup Transient Model Annual Revenues and Costs

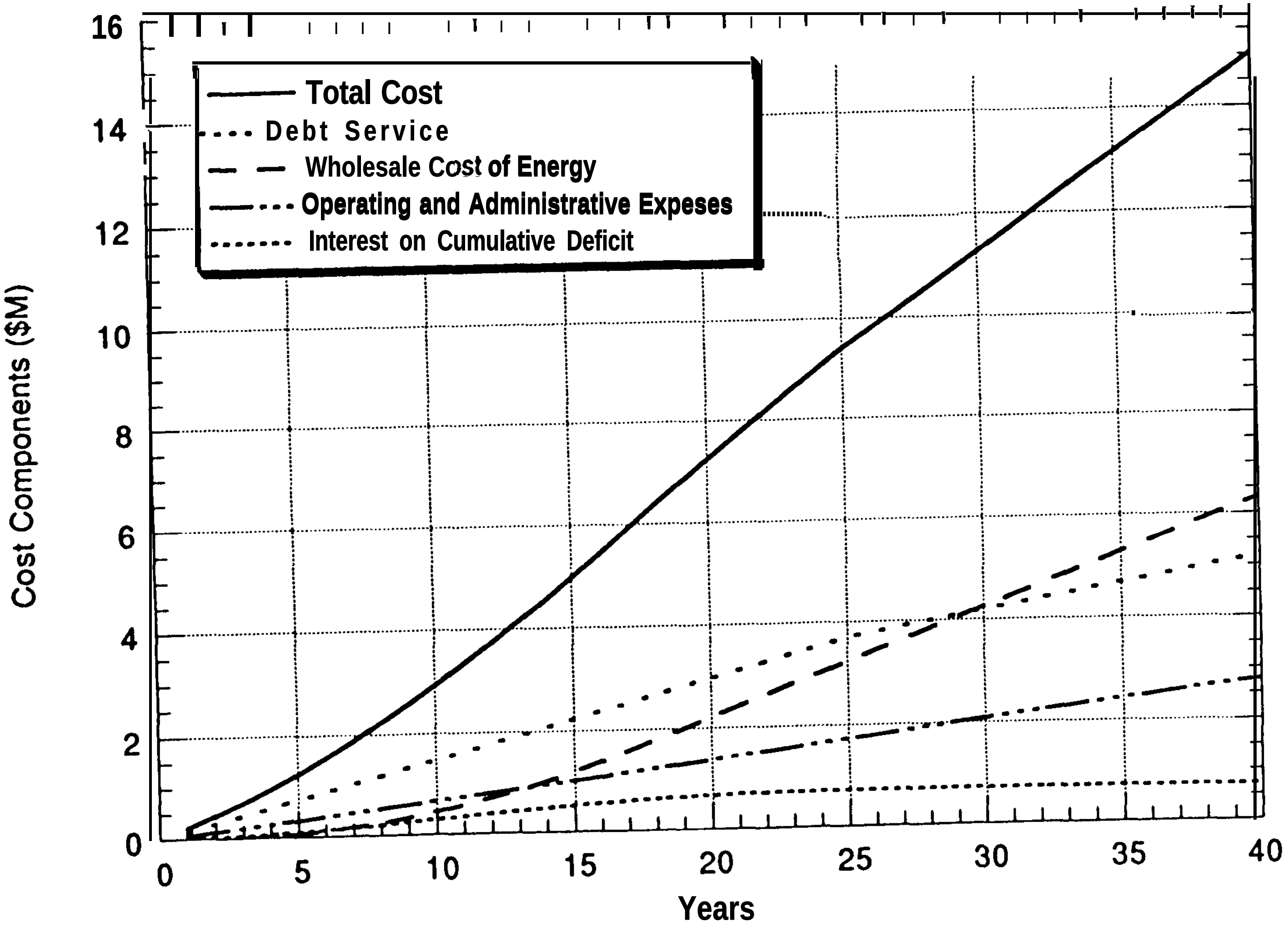


Figure 33. Startup Transient Model Cumulative Cost Components

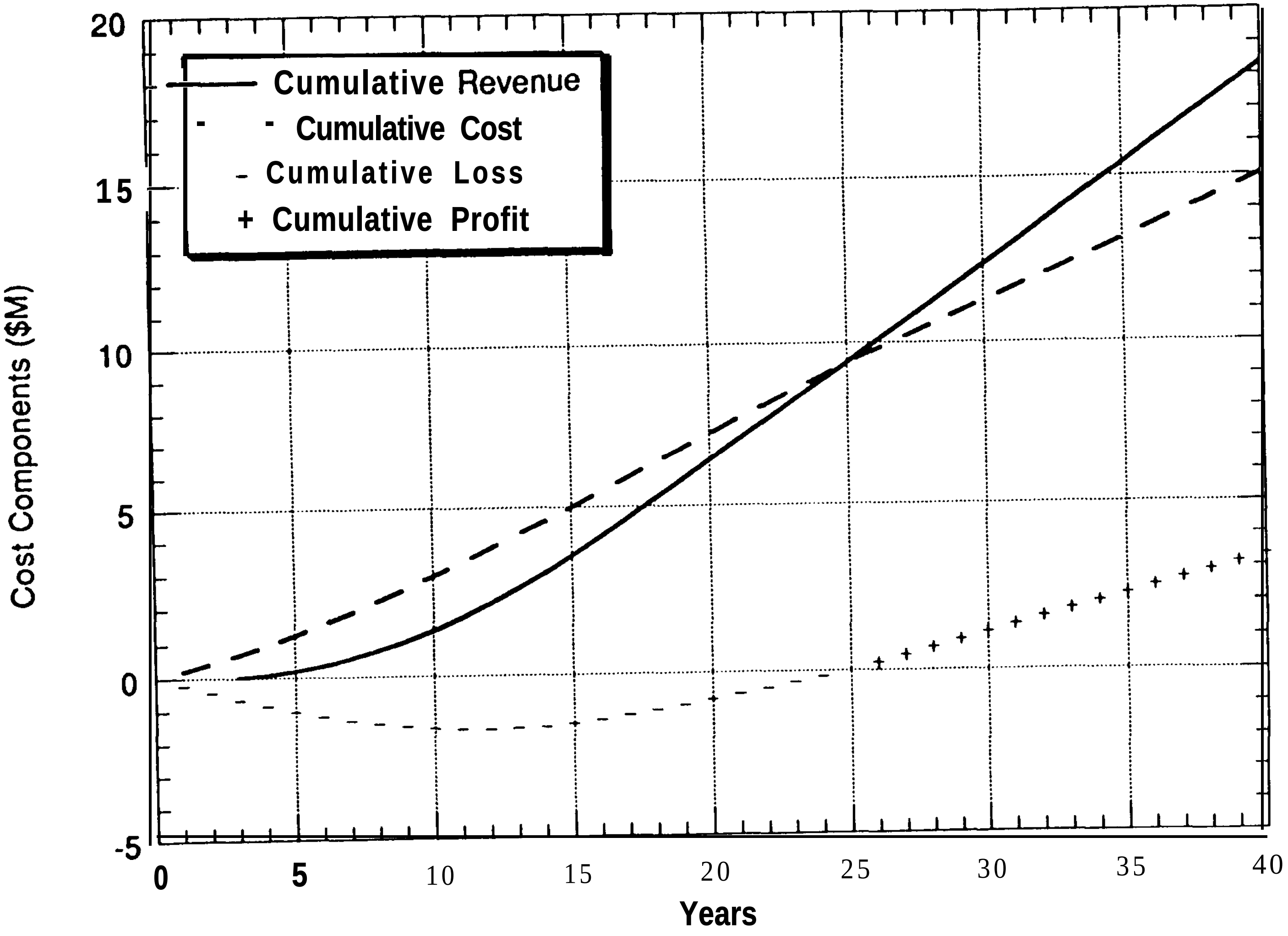


Figure 34. Startup Transient Model Cumulative Revenues and Costs

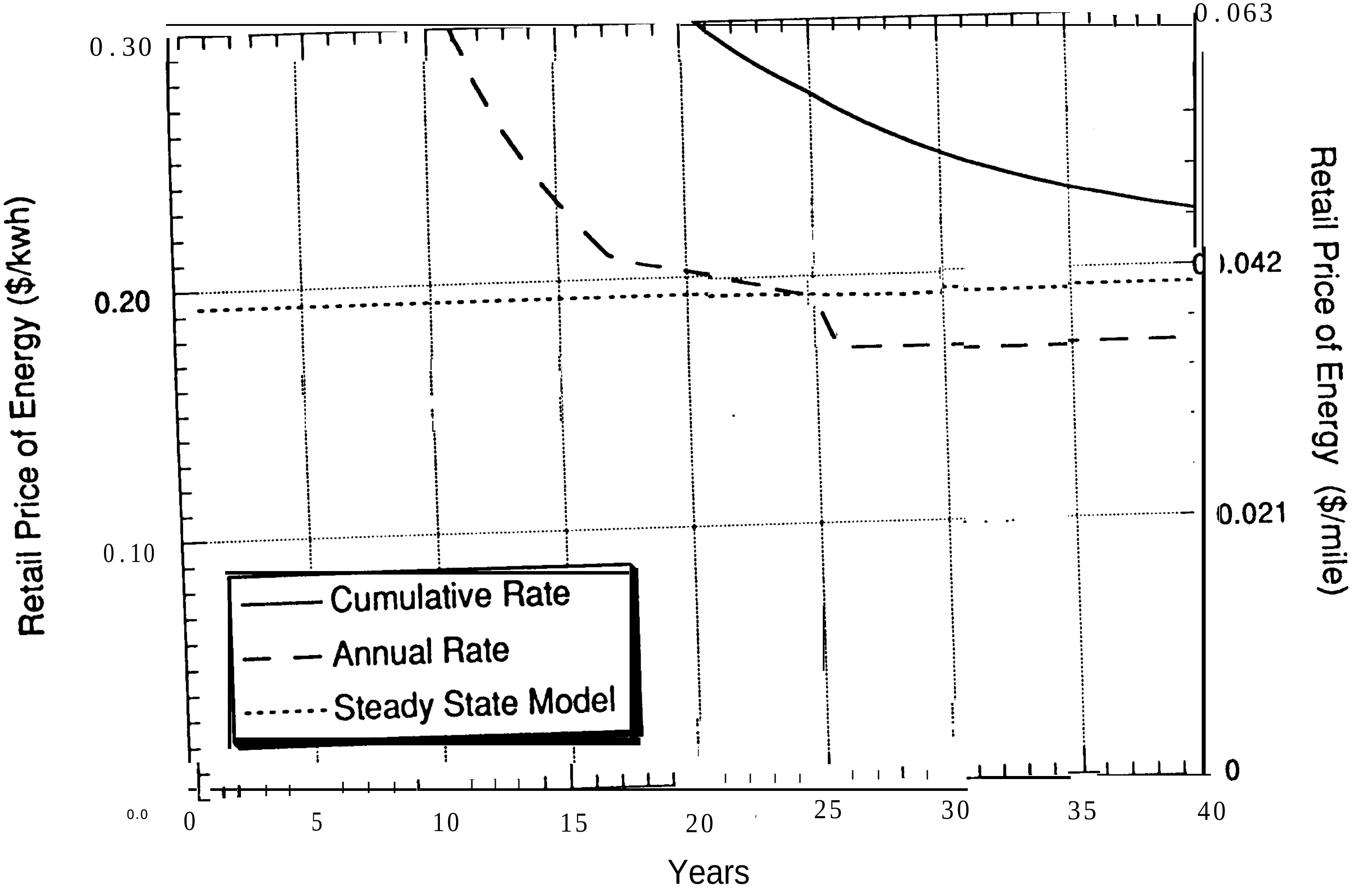


Figure 35. Startup Transient Model Breakeven Rate Comparisons

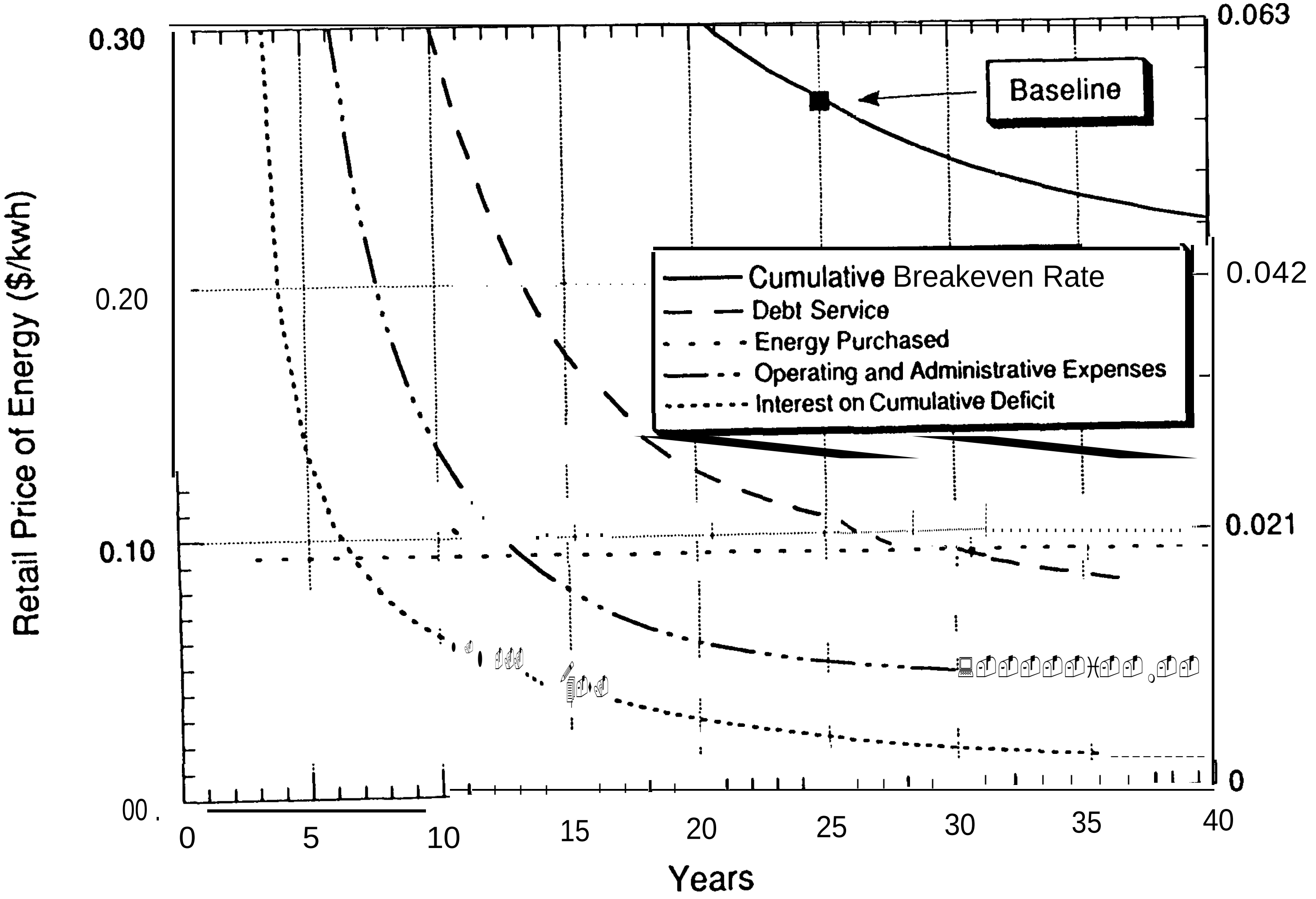


Figure 36. Startup Transient Model: Cost Components of Cumulative Breakeven Rate

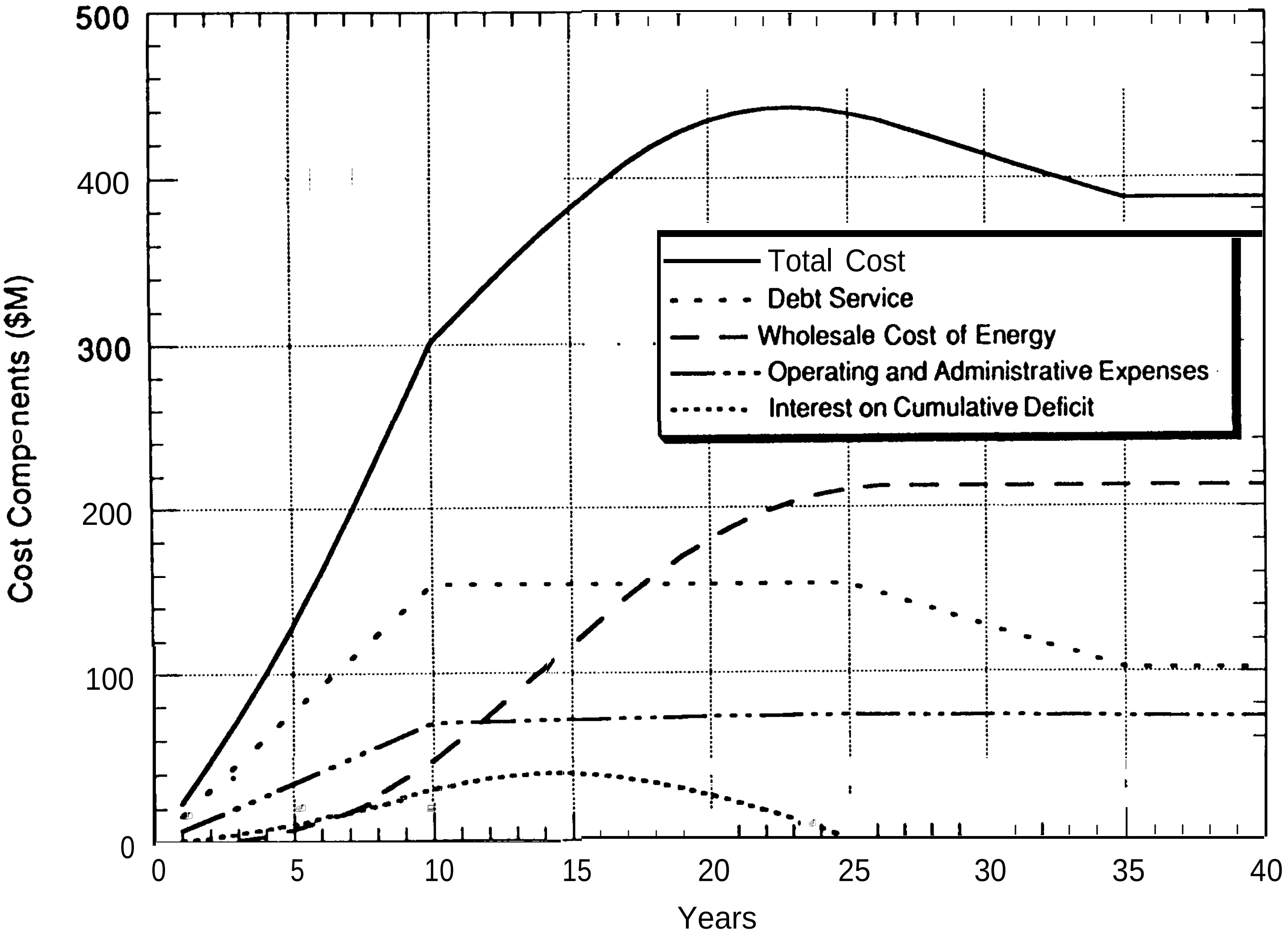


Figure 37. RPEV Economic Model Annual Cost Components

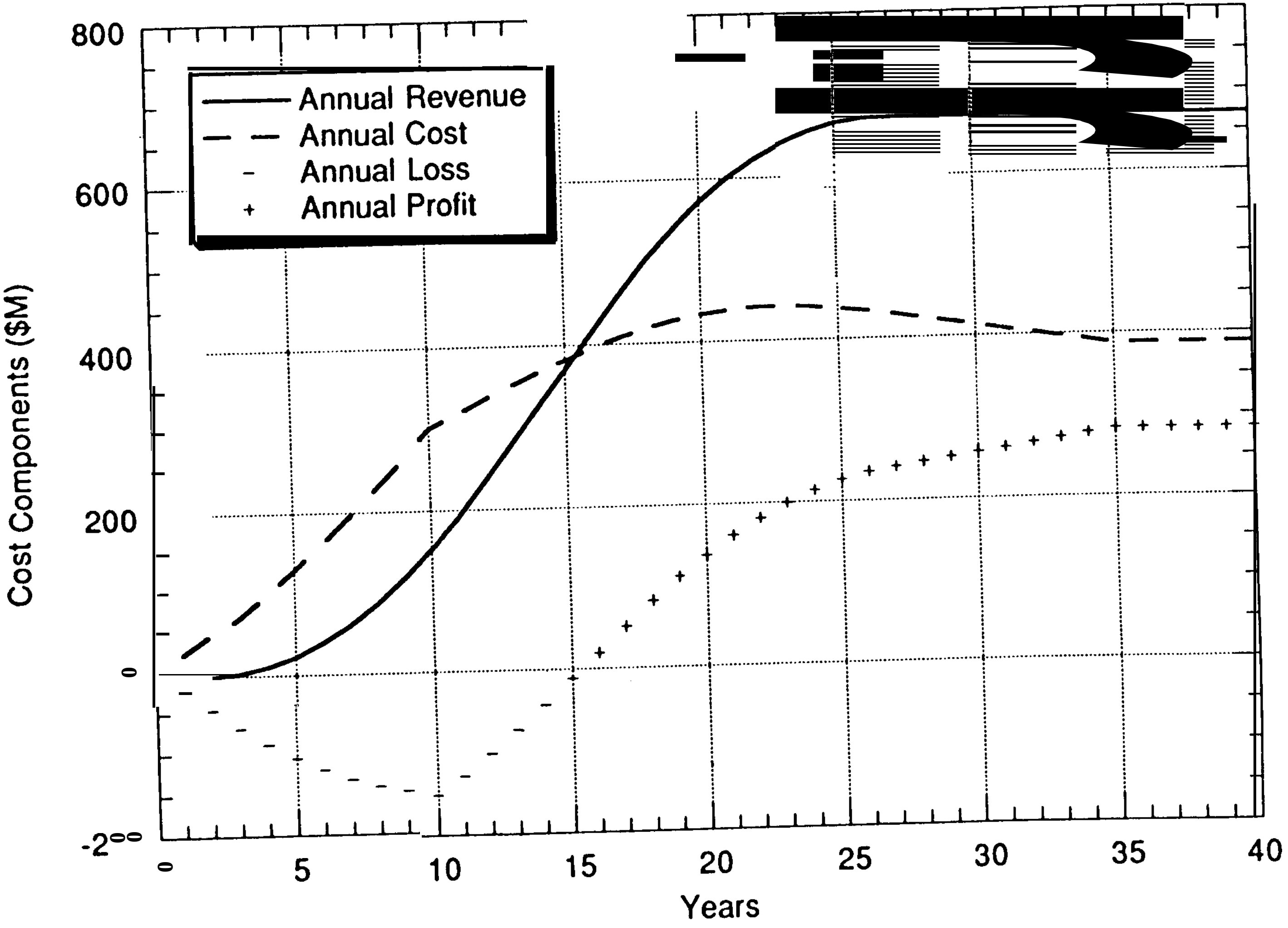


Figure 38. RPEV Economic Model Annual Revenues and Costs

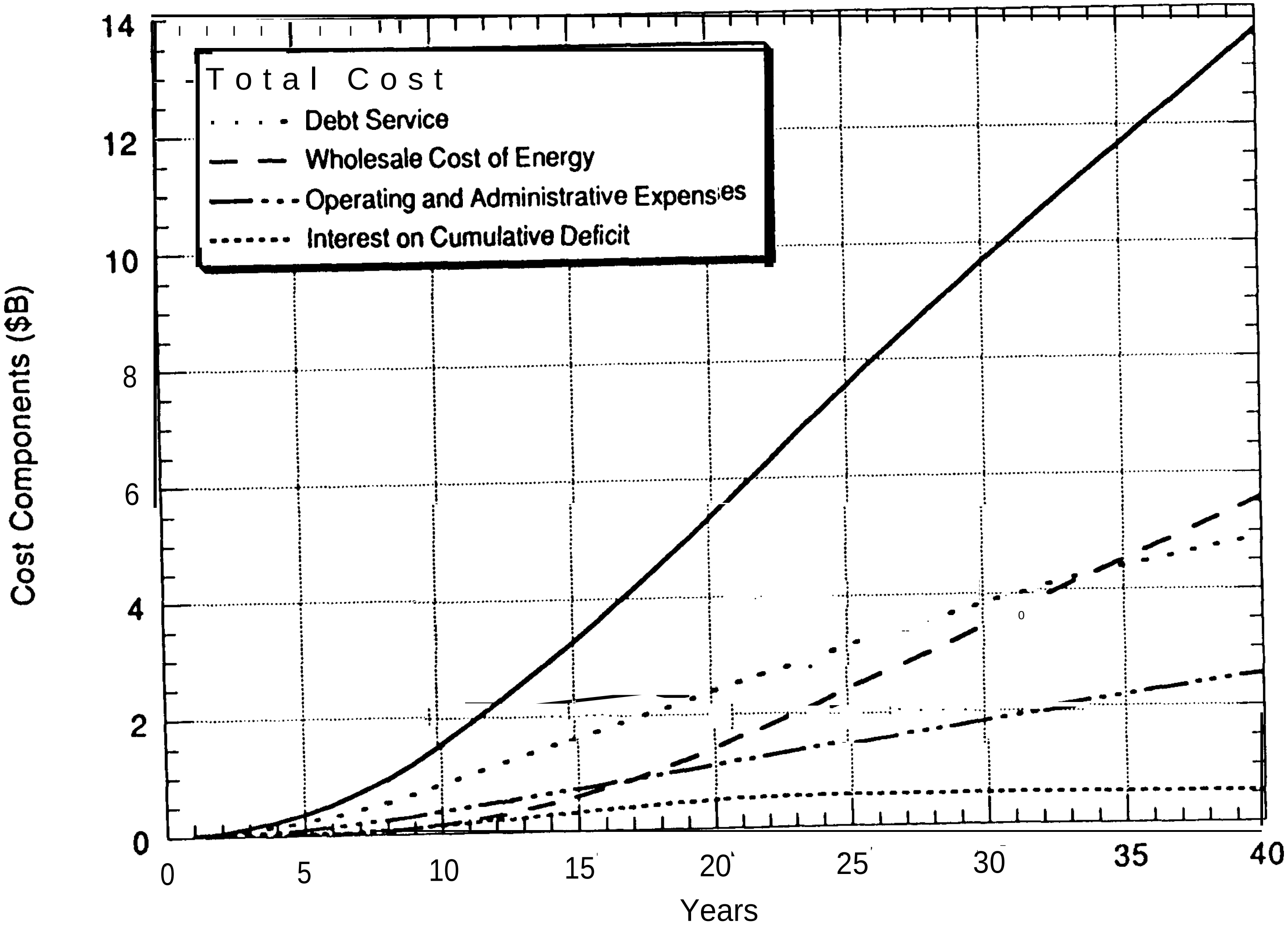


Figure 39. RPEV Economic Model Cumulative Cost Components

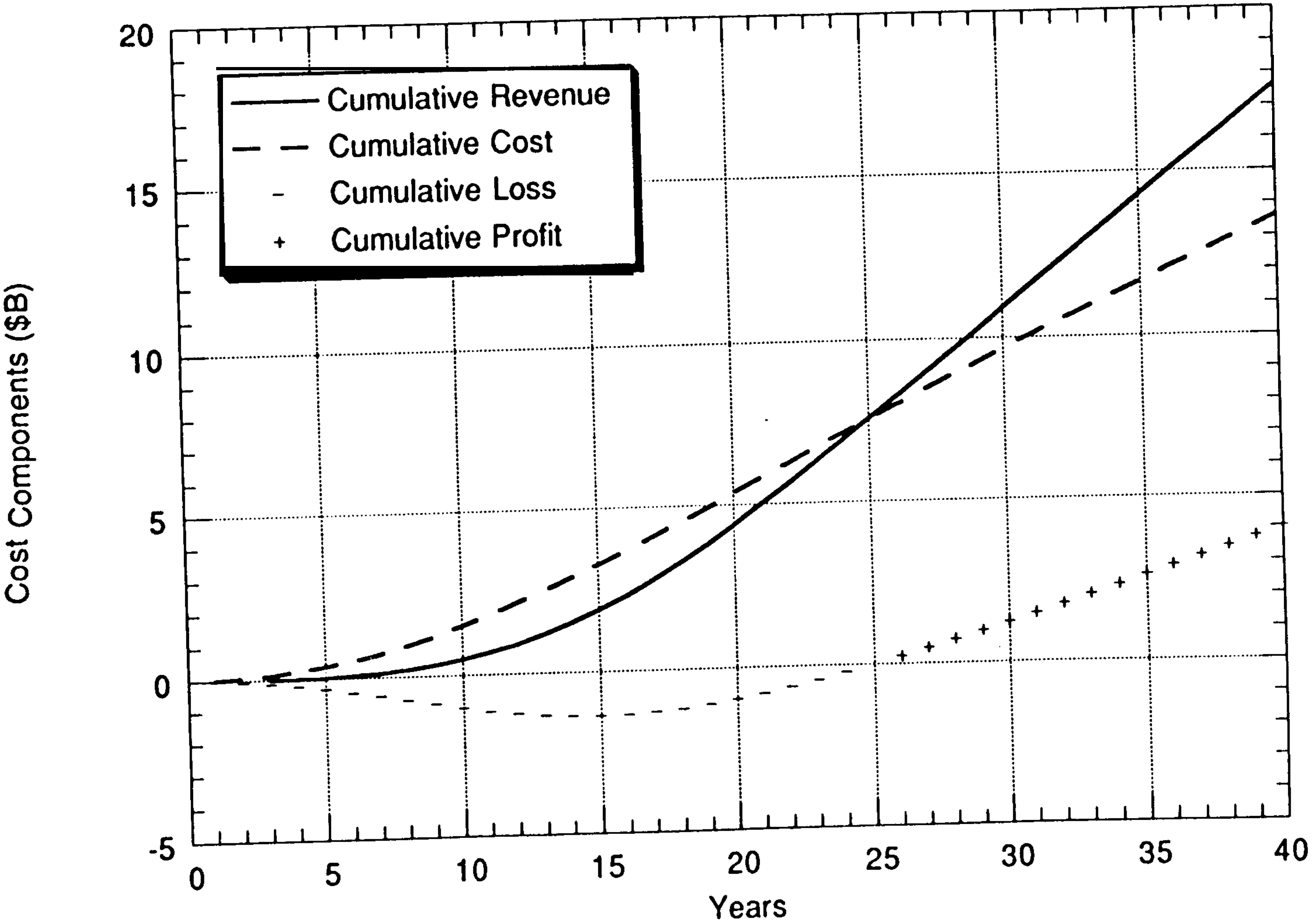


Figure 40. RPEV Economic Model Cumulative Revenues and Costs

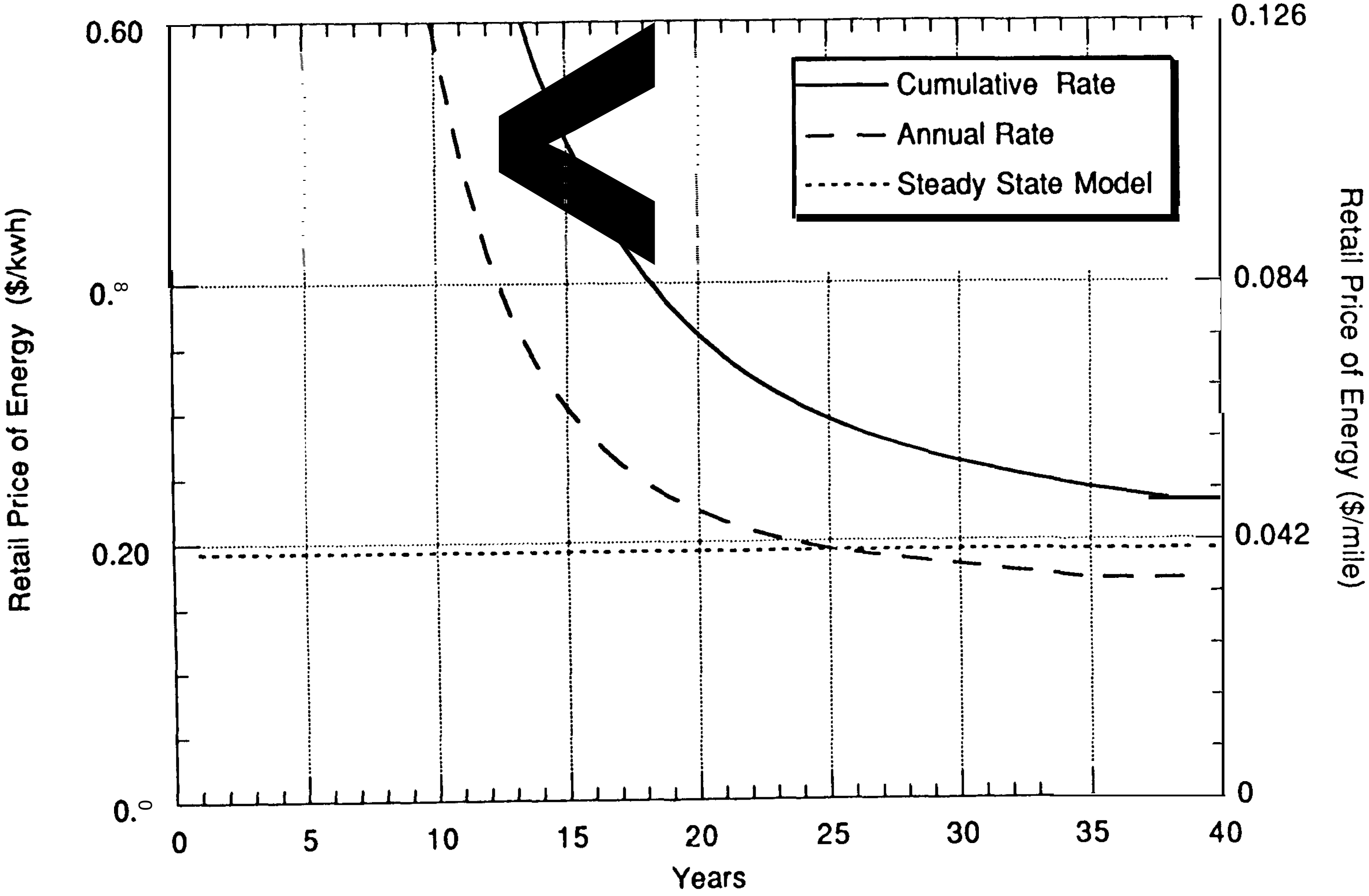


Figure 41. RPEV Economic Model Breakeven Rate Comparisons

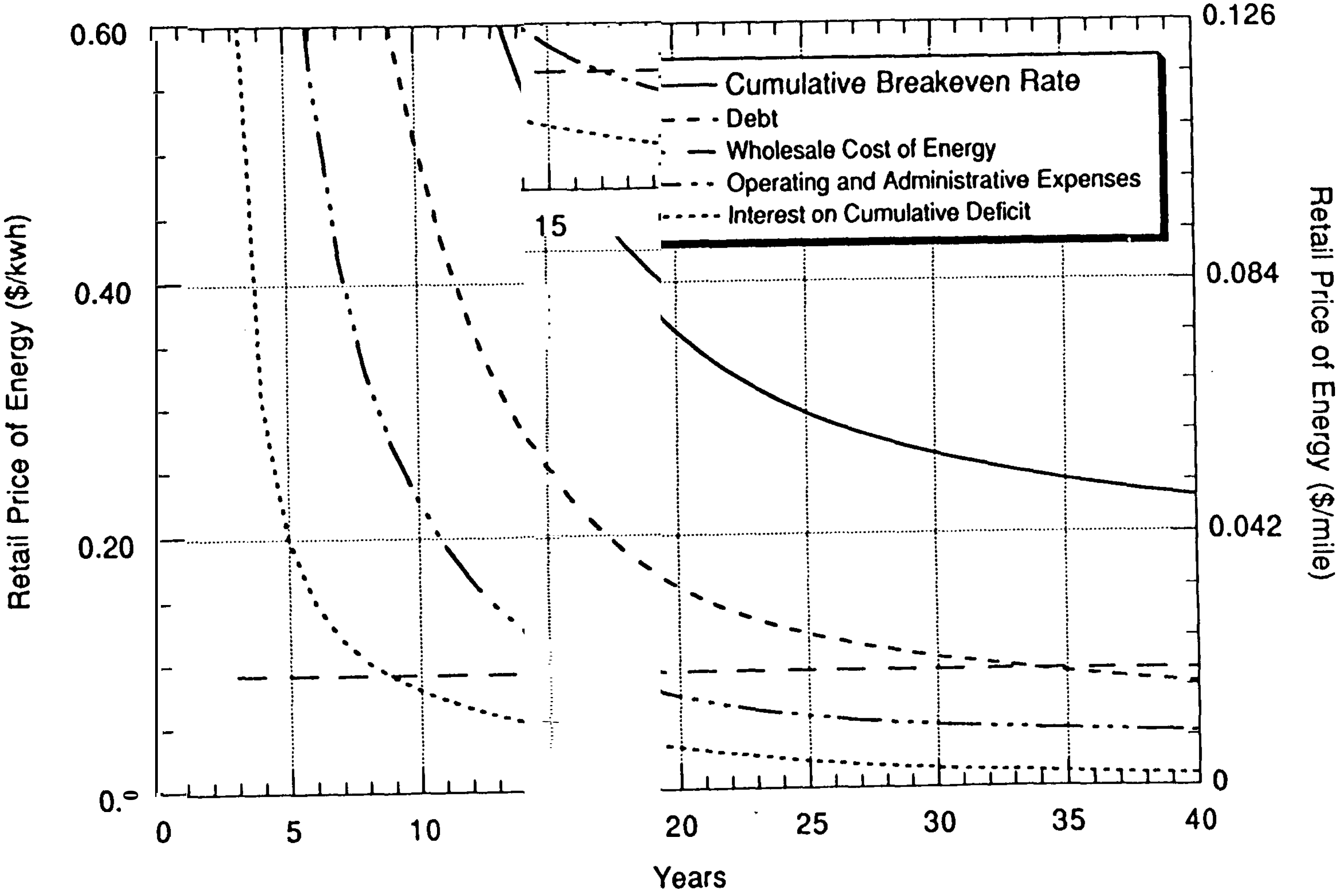


Figure 42. RPEV Economic Model: Cost Components of Cumulative Breakeven Rate

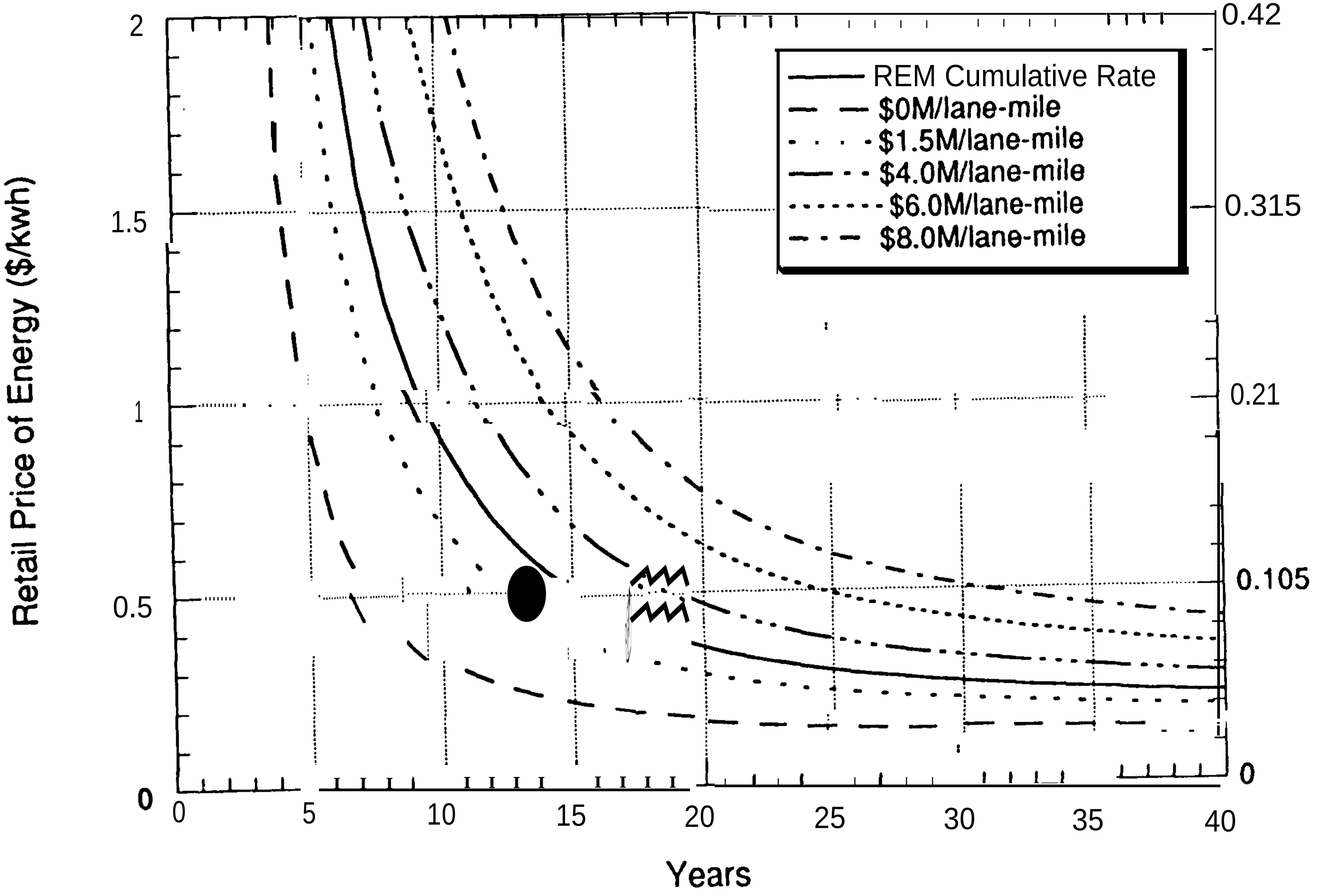


Figure 43. RPEV Economic Model Breakeven Rate Comparisons: Alternative Construction Costs

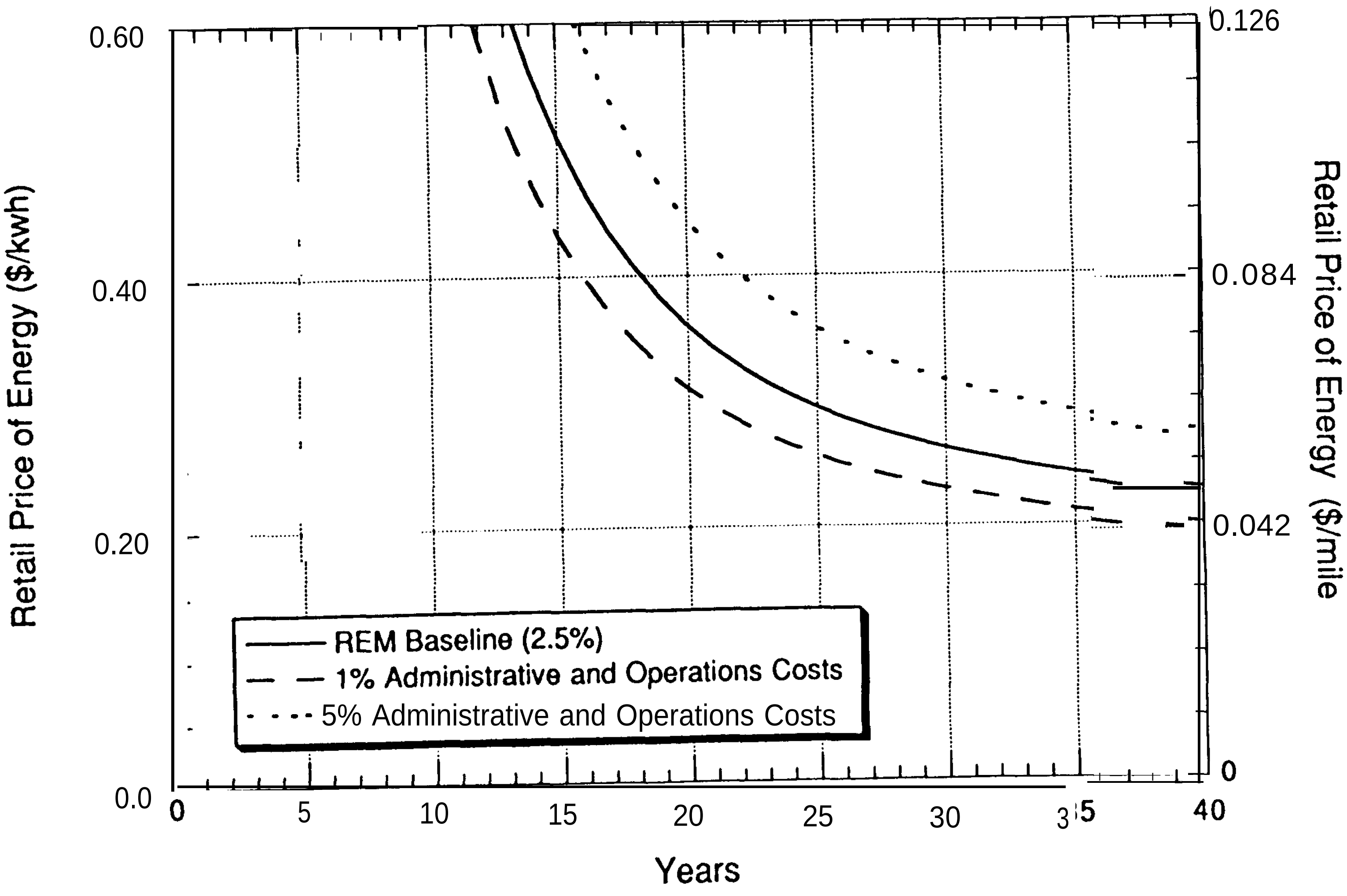


Figure 44. RPEV Economic Model Breakeven Rate Comparisons: Alternative Operating Costs

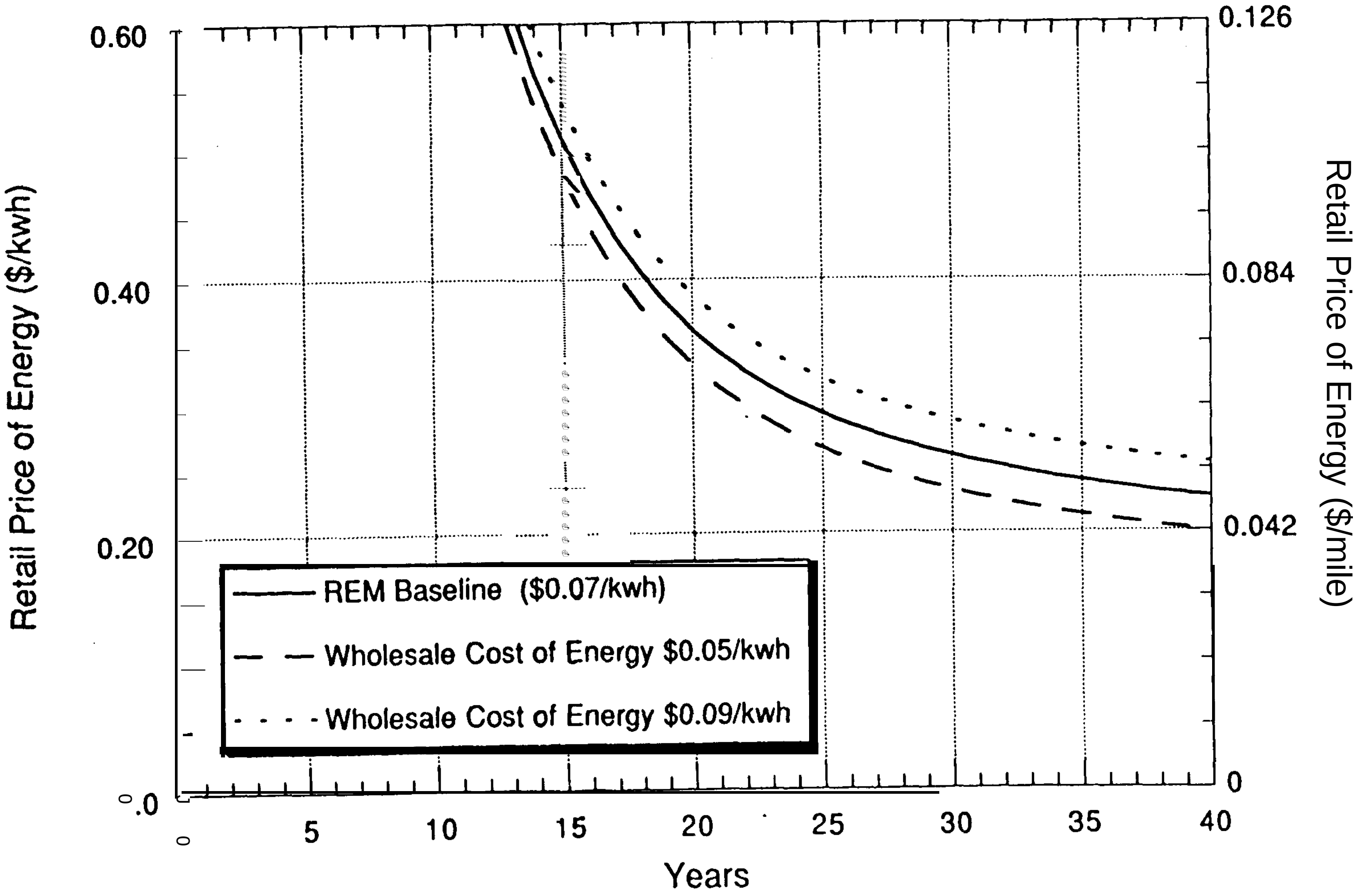


Figure 45. RPEV Economic Model Breakeven Rate Comparisons: Alternative Energy Cost

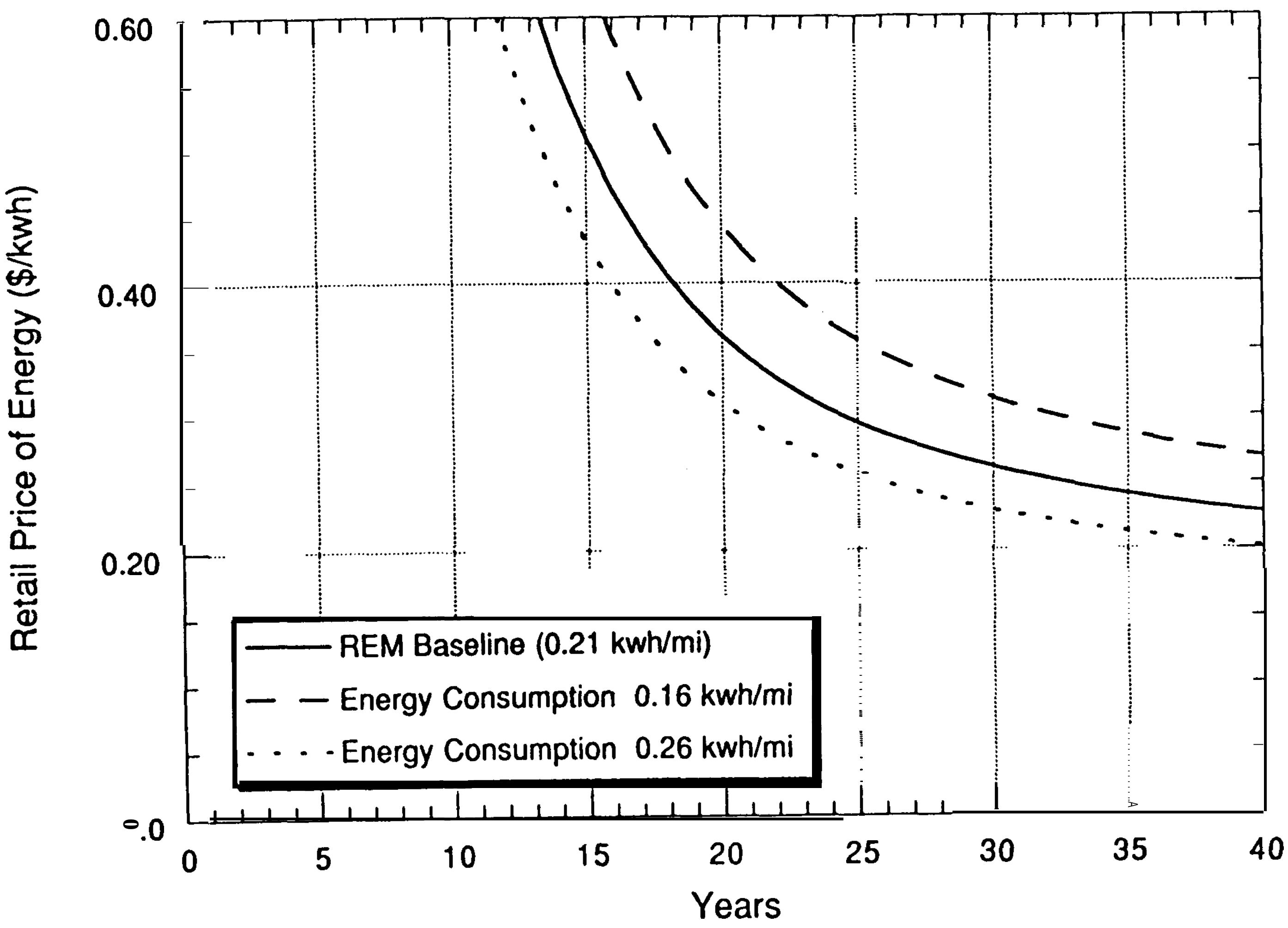


Figure 46. RPEV Economic Model Breakeven Rate Comparisons: Alternative Energy Consumption

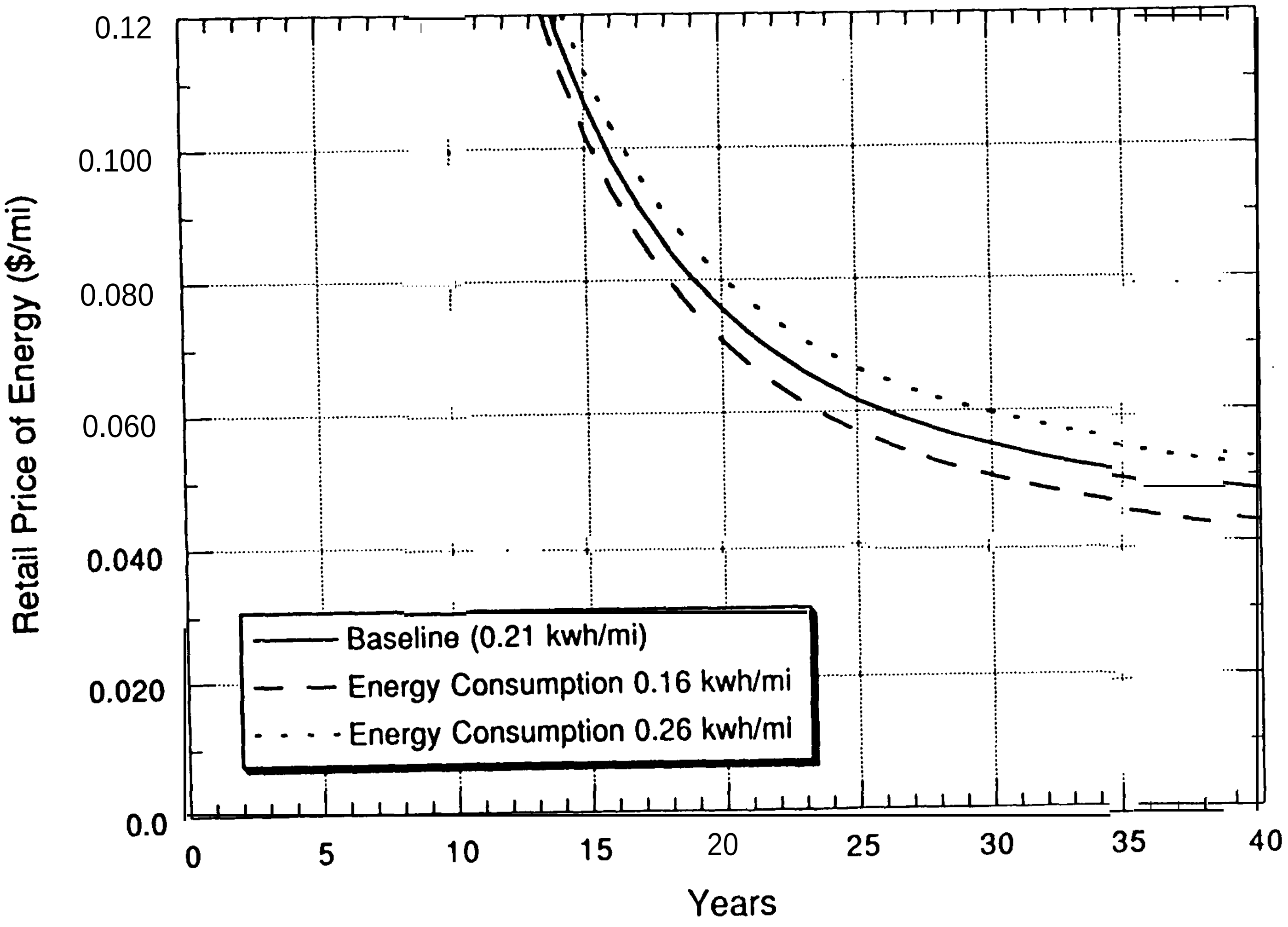


Figure 47. RPEV Economic Model Breakeven Rate Comparisons: Alternative Energy Consumption

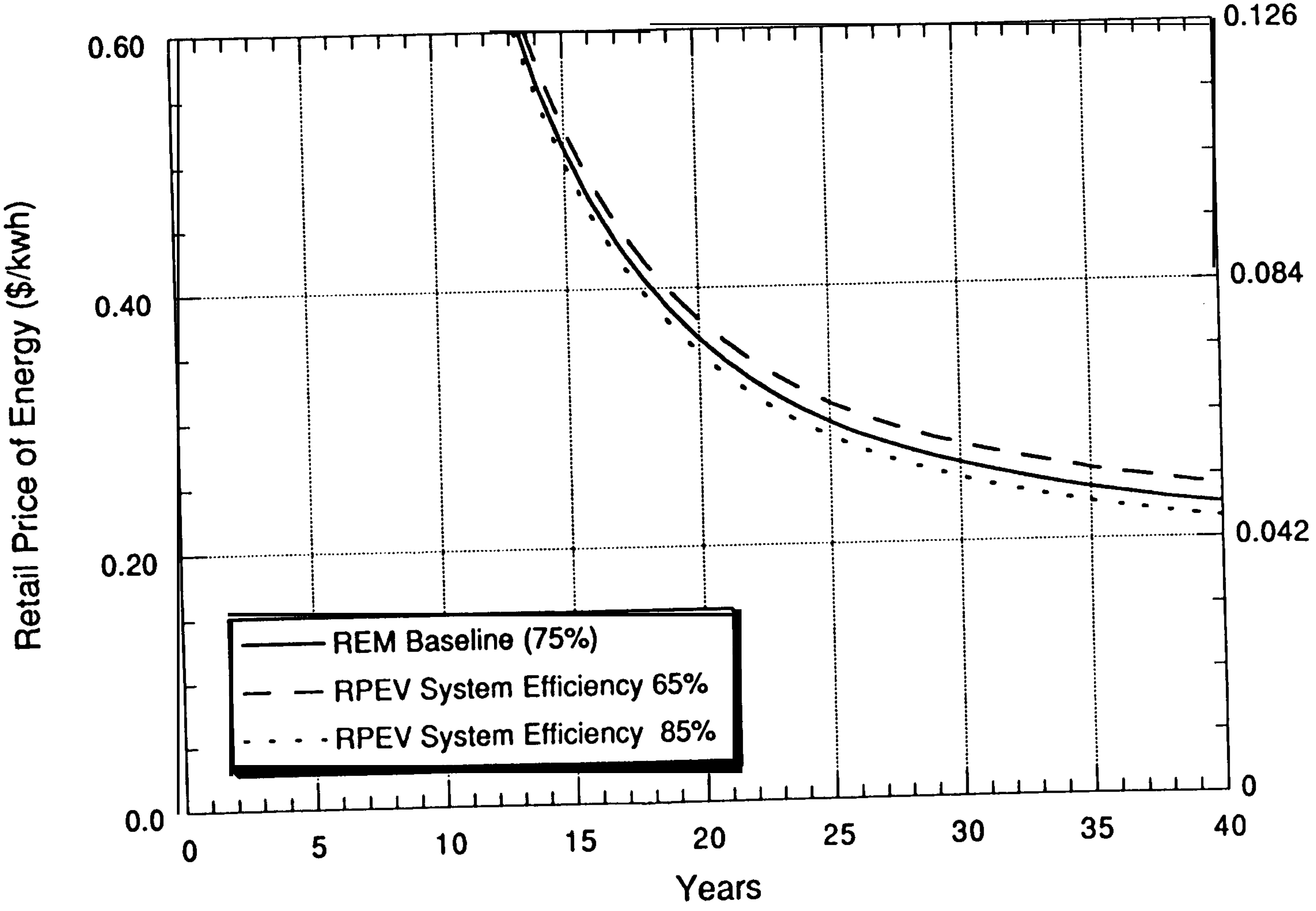


Figure 48. RPEV Economic Model Breakeven Rate Comparisons: Alternative System Efficiency

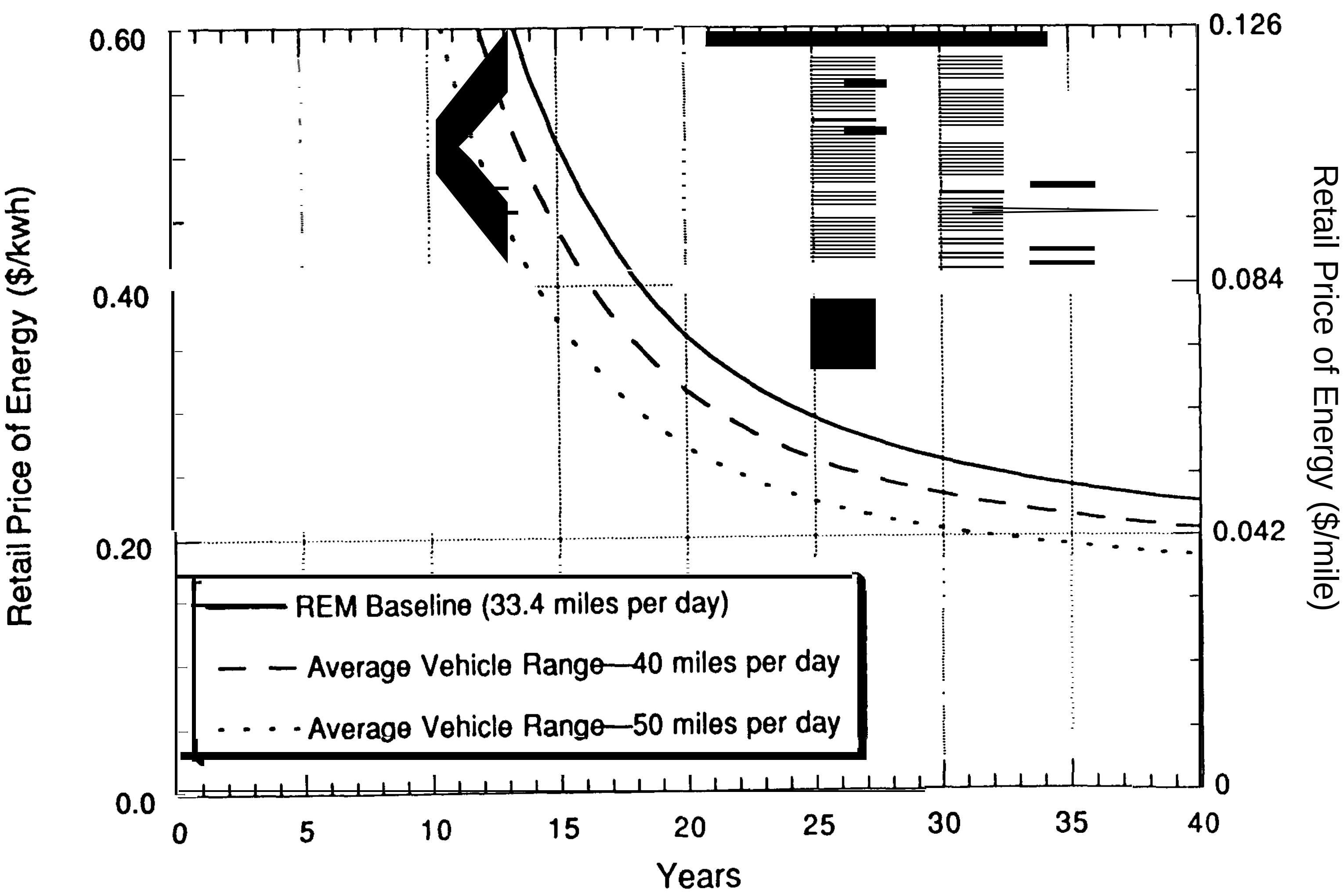


Figure 49. RPEV Economic Model Breakeven Rate Comparisons: Alternative Vehicle Range

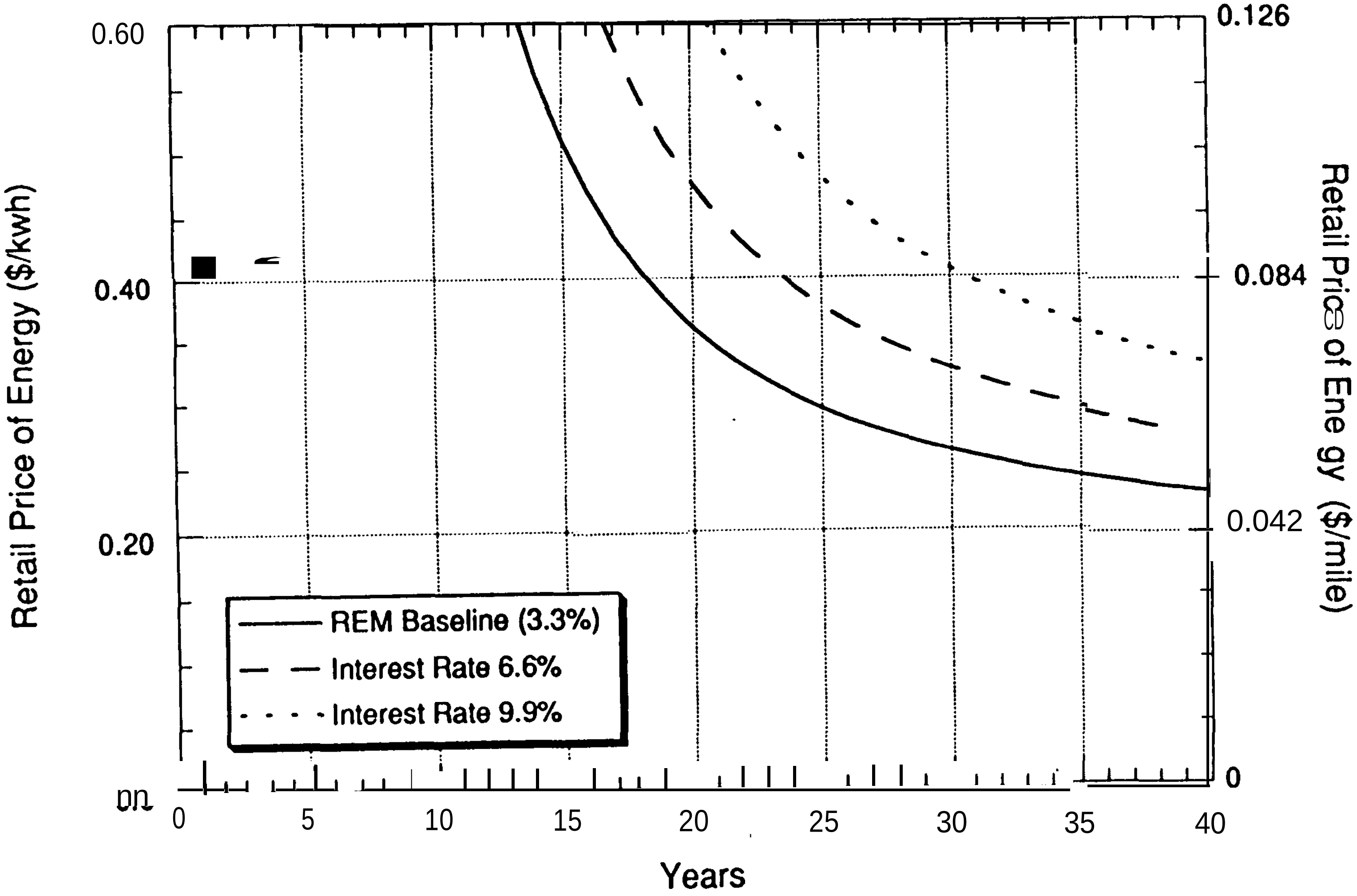


Figure 50. RPEV Economic Model Breakeven Rate Comparisons: Alternative Interest Rates

a.4 Regional Economic Impacts from System Application

In this section, impacts to the SCAG regional economy associated with the RPEV scenario are provided in a qualitative manner. This approach is taken due to difficulties in quantifying many of the fundamental changes that correspond to implementation of the RPEV system described in Section 6.1 and Figure 15.

The most significant regional economic impacts associated with the RPEV scenario are the benefits from air quality improvement. Tables 7.14 and 7.15 in Section 7 of this report presented detailed reductions in the criteria air pollutants, ROG, CO, NOX, SOX and PM, for the AM-peak. Relative to the baseline air pollution projections for 2025, these improvements in air quality ranged from approximately 5 - 10% depending on pollutant and vehicle type. Importantly, these improvements were derived from a modest market penetration analysis, 15% of AM-peak VMT or 3.28% of total AM-peak vehicle trips. On a daily basis it is likely that air quality impacts would be substantially larger than the AM-peak estimates due to travel associated with battery only trip linkages throughout the day that were not captured in the transportation model analysis. The AM-peak air quality improvements thus constitute a conservative computation of complete daily mobile source pollution reduction.

An economic evaluation of benefits to the SCAG region from such increased air quality would require quantification of the primary health benefits accompanying this improvement. This type of assessment was beyond the scope of this study. A complete health benefit evaluation would, however, be nontrivial, and contain improved mortality and morbidity estimation, calculation of decreased occurrence of respiratory infections and other illnesses, reduced days of pollution discomforts, fewer work and other activity absences, and decreased use of medication for eye and throat irritation, nausea, wheezing, and headaches. A monetary calculation of such reduced health expenditures would require evaluations of personal exposure and dose-response relationships in order to accurately quantify the health benefits from air quality improvement (Kleinman, et al, 1989). Even the most comprehensive research efforts that performed health benefits analyses to date for this region have accomplished only partial assessments of these monetary reductions in damages to persons (Hall, et al, 1989; SCAQMD, 1991).

In addition to health benefits, increased crop yields for produce that is sensitive to ozone damage, visibility improvements and the associated increased property values, reduced damage to livestock, and decreased deterioration of materials, are further regional economic benefits that would be associated with air quality improvement (SCAQMD, 1991). Again, existing monetary estimates from these air quality improvements are incomplete, and therefore offer underestimates of these economic benefits (SCAQMD, 1991).

For illustrative purposes, average annual benefits corresponding to implementing the 1991 AQMP for the South Coast Air Basin (SCAB) region were estimated by SCAQMD to be $6.113 billion (1987 dollars). This figure did not include 95% of the health benefits nor complete crop yield and visibility benefits. As noted in this study, the reported benefits calculations considerably understated the total air quality benefits associated with AQMP implementation. In an earlier effort, Hall, et al (1989), estimated the benefits of achieving the federal ozone and PM10 standards at $9.4 billion annually and $14.3 billion annually for complying with California standards based on 1984-86 air quality data (1988 dollars) for the SCAB region. These estimates support the monetary significance that may be attributed to air quality improvement for a small portion of the complete air quality benefits as would be the case for the level of RPEV implementation described in this study.

In addition to the air quality benefits noted above, further benefits associated with the impact of improved environmental quality may exist in the labor market. Numerous studies have demonstrated that areas that provide amenities, such as a clean environment, cause migration of workers and, subsequently, labor-oriented firms to these areas (Graves, 1979; Porell, 1982). This phenomenon, that firms follow workers rather than workers following firms, may suggest important implications for the SCAG region from air quality improvements, such as those associated with adoption of the RPEV technology. Further comprehensive research to investigate the extent to which numerous changes in regional amenities, i.e. air quality, congestion, crime, public service provision, cultural activities, affect the growth in labor supply for this area would be required to determine the magnitude of such air quality amenity improvements.

The benefits of reduced reliance on petroleum consumption to fuel the SCAG region's transportation system are a second primary economic impact associated with the application of the RPEV technology. The savings in daily petroleum consumption associated with the RPEV scenario's market penetration is approximately 15%. Many of the benefits associated with reduced petroleum dependency occur at the national level, i.e. decreased military expenditures to protect oil production and transport facilities, reduced costs of the Strategic Petroleum Reserve and fuel subsidies (Deluchi, et al, 1987). Other benefits, such as decreased production of greenhouse gases associated with petroleum fueled vehicles are experienced globally and are difficult to quantify. At the regional level, it is likely that decreased consumption of petroleum fuels could provide further environmental quality improvements in the area of water pollution reduction. Oil residues mixed with runoff from roadways during rain storms, improper fuel storage and disposal leachate in groundwater supplies, accidental combustion and arson occurrences, and the possibility of oil spills related to the Southern California coastal areas would tend to decrease with lower petroleum usage.

Again, the monetary valuation attached to these environmental improvements would be difficult to quantify, but would be of significant magnitude.

Losses to regional economic sectors providing petroleum would correspond to the reduced reliance on these fuel products. Jobs associated with petroleum industry, i.e. petroleum refining, gasoline sales, in the region would fall as the shift toward clean fuel vehicles, such as the RPEV, increased. For the modest introduction of the RPEV technology in this study, it is unlikely that the distributional impacts on jobs and income in the petroleum related sectors would experience significant declines. A more advanced stage of **RPEV** development would, however, produce marked reductions in these sectors.

A potential benefit for the **RPEV** scenario exists if efforts are successful in the areas of manufacturing and commercialization of the RPEVs in the SCAG region. Since it is assumed that RPEVs and **EVs** will be developed simultaneously, most of the comments on this subject pertain to both types of electric vehicles. Such developments would necessitate provision of complete production systems that would integrate local industries, service centers, and training and research facilities toward building an industrial base for the emergence of this technology. Localization economies could be fostered by clustering firms within the **RPEV/EV** industry in the SCAG region so as to capture scale economies in the production of intermediate inputs, labor market economies, and communication economies. Such localization economies, i.e. parts fabrication, low worker job search costs, information exchanges, would enable firm costs to decrease as overall industry production increased. This type of nurturing environment would be crucial to stimulating introduction of the RPEV technology. Production and servicing **RPEV/Evs** within the region could generate local multiplied impacts on jobs and income as well as provide possible export multiplier impacts for the regional economy if market demand for the technology spread to other areas.

In a recent research effort, Morales and Storper, et al (1991), investigated the prospects and policies for pure electric vehicle manufacture and usage in the Southern California area. This study identifies several regional characteristics that offer promise for the development of electric vehicles which would apply to RPEVs as well. Prominent in this regard are the existing skilled workers in the automotive and aerospace industries that could play a crucial role in transitioning growth from these declining technology sectors to new regional electric vehicle opportunities. The large concentration of scientific, technical, and managerial expertise found throughout the SCAG region would play an important part in the creation of industrial capability for such market advancement. The regional awareness of the need for supportive financial, public policy, and complementary infrastructure availability would additionally assist in promoting these capabilities.

The electricity demand associated with the **RPEV** scenario, 12,440 mwh/day, for on and off roadway charging would provide increased revenues to the utilities. These revenues would depend on the ownership and financing mechanisms associated with the powered roadway, and the rates paid by users for on and off roadway charging. The REM model estimated revenues of $212.6 million per year when the RPEV scenario's market penetration of users was achieved. This estimate was based on the retail energy rate of **$.294 $/kwh** that assured a cumulative revenue and cost breakeven in year 25 for the RPEV system. This rate is approximately three times larger than the wholesale energy rate, **$.093/kwh,** since it accounts for all system costs , wholesale energy, roadway construction and operation, and deficit financing. On roadway charging was associated with 46.5% of the vehicle miles traveled by the **RPEVs.** Therefore, significant additional electricity revenues would accrue to the utilities from off roadway charging albeit at lower rates.

The increased electricity demand was not assumed to require additional power plant capacity given the modest market penetration and analysis of plant capacity utilization relative to the 2025 baseline. Continued growth in the usage of **RPEVs** would ultimately require new plant capacity. Cumulative profits that grow after year 25 could, however, be allocated to offset the costs of the needed new capacity development.

The utility sector would experience income and job growth associated with the RPEV scenario. To what degree such impacts emerge would depend on the rate structure adopted and subsequent generated revenues. Secondary income and employment opportunities may also develop in the utility sector as research and development opportunities associated with this technology expand with market growth.

In the construction, maintenance and vehicle servicing sectors, it is unclear to what degree employment and income will change related to the **RPEV** scenario. It is more likely that shifts in the distribution of jobs and income will occur as powered roadway construction and RPEV usage develop. Whether new, different, or fewer construction, maintenance and vehicle servicing job opportunities are provided must be determined. While it seems reasonable to assumethatnew construction opportunities may emerge corresponding to building the powered roadway, it is conceivable that these jobs'may replace construction work that would relate to foregone transportation alternatives. The provision of new expenditures for roadway **electrification** would be necessary to properly assess employment and income impacts on the construction sector associated with the **RPEV** system. Similarly, although maintenance and vehicle servicing are expected to be substantially reduced by the **RPEV/EV** technology, workers may gain skills necessary to provide assistance to **RPEV/EV** users, and/or acquire different positions as part of a newly created **RPEV/EV** industry.

Increased vehicle battery sales are an important benefit to battery manufacturers throughout the region. Producers of other **RPEV** parts, i.e. on-board controllers, inductive coupling systems, on-board electronics, regenerative braking systems, as well as firms specializing in powered roadway construction components, i.e. core module fabrication, power conditioner manufacturing, roadway engineering and installation, would also acquire revenues. To what extent such development occurs within the region is the determining factor in the impact to the local economy. The greater the employment and income opportunities from such production in the region, the greater the multiplied impacts on additional jobs and income locally.

Higher battery disposal costs may occur with growth in the market penetration of **RPEV/EVs.** The extent to which these costs may be recovered via carefully coordinated battery pricing, ownership and recycling options would determine the overall impact to the region associated with battery disposal. Intra-regional distributional impacts are most likely to occur with possible gains to those parties that determine marketable uses for recycled batteries, and possible losses to repeat battery purchasers. Overall regional economic impacts would weigh the influences on all affected parties.

The ability of the Southern California region to attract Federal funding as well as new private capital outlays toward development of the **RPEV** system design would play an important part toward capturing many of the significant income and employment impacts within the region. Thus, the degree to which such outside funding is attracted to the project will thus assist in the success of improving regional economic growth. Clearly, the capability to design the proper incentives to stimulate increased **RPEV/EV** market penetration, to provide supportive public and industrial policies to assist technology development, and to build an integrated support structure for maintaining and servicing these new technologies, remain of tantamount importance in the overall determination of regional economic impacts. In the next section suggested and prevailing mechanisms to encourage **RPEV/EV** system development in these three areas are presented.

0.5 Policy Options for System Implementation

As explained in Section 8.4 many of the primary benefits from implementation **of** an RPEV system concern societal improvements that are difficult to measure. Increased air quality and reduced reliance on petroleum fuels, while important goals, will be difficult to achieve if cost comparisons between roadway powered vehicles, as well as battery only electric vehicles, and conventional petroleum fueled vehicles render **RPEV/EVs** less affordable. Additional regional economic benefits concomitant with development of these new technology vehicles in the Southern

California area are also subject to provision of a comprehensive technological base in the area in order to capture these significant monetary benefits locally. Policy efforts to implement an RPEV system thus necessitate coordinated planning and management efforts that address market penetration, continued technology development, and support service dimensions of system implementation simultaneously in order to capture maximum regional benefits. Mobilization of local collaborations consisting of industry, government, university, and other institutional participant expertise would thus be a first step toward system development.

Policies to Increase **RPEV/EV** Market Penetration

On the consumer front, policies to allow **RPEV/EVs** to compete favorably with **ICEs** must be designed to reduce disparities that exist in vehicle pricing, performance and acceptance via development of appropriate market incentives. It is not enough to assert that **RPEV/EVs** provide or offer lower fuel and maintenance costs, and longer life in order to stimulate purchases of these vehicles. It is not enough to demonstrate that an RPEV system would offset the limited range problem with **EVs.** Nor are the pervasive environmental improvements that would be experienced by all members of society compelling enough to enable market penetration growth of the new technology vehicles. Psychological obstacles that exist concerning individual choice of relatively new technologies with perceived higher cost versus known technologies with established networks of servicing and costs can only be broken with innovative, integrated, and supportive measures.

Logical market incentives to advance **RPEV/EV** usage would include various government subsidies to decrease user costs. These subsidies would attempt to equate life cycle costs across vehicle choices. As shown in Table 8.2, the comparison of the **RPEV** and gasoline vehicle private costs indicated a slight cost advantage to gasoline vehicle users. Our analysis examined the effect of government subsidization of powered roadway construction and demonstrated that this type of assistance would narrow the cost differences between the two vehicles studied, i.e. the **RPEV** cents per mile life cycle costs decreased from 29.03 to 26.14, comparing more closely with the gasoline vehicle's 24.88 cents per mile.

Additional sensitivity analyses performed with the NSD model showed that subsidizing battery cost, eliminating fuel taxes for **RPEVs** and lowering energy costs would additionally improve the RPEV life cycle cost profile relative to the gasoline vehicle. For a fully subsidized battery cost scenario, life cycle RPEV costs decreased to 26.77 cents per mile. Subsidizing half of the battery generated a 27.90 cents per mile estimate for the RPEV relative to baseline conditions. Without RPEV fuel taxes, the NSD model produced 28.32 cents per mile, and 28.68 cents per mile RPEV life cycle costs. Decreasing wholesale energy costs with a **$.02/kwh** subsidy slightly reduced **RPEV** user costs to 28.21 cents per mile relative to the baseline. These cents per mile results, while comprehensive in scope, may be difficult to convey in a vehicle marketing strategy. Furthermore, as demonstrated by the cents per mile sensitivities compiled, the subsidy-induced changes in cents per mile RPEV life cycle user costs are very subtle.

Targeting the most noticeable vehicle user costs for government subsidization may produce greater **RPEV/EV** marketing advantages than drawing vehicle buyer attention to cents per mile vehicle differences. For example, subsidizing vehicle capital costs and supporting low cost battery leasing programs may generate more immediate and effective consumer responses. Companion tax credits, subsidized car loan interest rates, removal of licensing and/or registration fees, reduced auto insurance, preferential parking, and energy cost limits to **RPEV/EV** purchasers would also stimulate market growth. Improving car dealer sales and maintenance circumstances, i.e. regional service centers, with respect to offering the new technology vehicles may also enable cost savings to be passed on to the consumer. In conjunction with disincentives for owning and operating gasoline vehicles, i.e. higher gasoline taxes, penalties for vehicles failing to meet transitional low emission standards, emission fees, the cost differences between these vehicle types could be eliminated, or possibly turned to the advantage of the **RPEV/EV** purchaser. Again, the market incentives selected must include mechanisms directed at the more substantial and tangible vehicle cost differences in order to achieve the broadest consumer appeal.

With respect to stimulating **RPEV/EV** market penetration by businesses, additional market incentives in the form of business tax credits, low interest loans, and/or mobile emission offsets could be designed. Tax credits might be offered on corporate income taxes for each vehicle purchased, with added discounts for large fleet orders. Such credits would assist in reducing the cost differences to these enterprises from acquiring the new technology vehicles instead of conventional vehicles. Disincentives for companies that delay fleet conversions could be captured in higher vehicle registration and licensing fees for example.

Government fleet purchases of **RPEV/EVs** would also assist market penetration of these vehicles. Cost subsidization to allow these vehicles to compete on favorable terms with gasoline vehicles, as suggested above, would apply to these acquisitions as well. Purchase price cost discounts may be justifiable for large fleet orders for government operations as the postal service, and other routine field work. A motion to this effect was approved on December 8, 1989 by the Los Angeles City Council to support state legislation to subsidize government agency purchase of electric vehicles and installation of electrified transportation systems in non-attainment areas-, and waive state sales tax and registration fees for electric vehicle purchasers. Such efforts are important in increasing the visibility of these vehicles toward stimulating greater market demand.

Legislation requiring the market penetration of clean fuel vehicles may enable **RPEV/EV** development to proceed more rapidly. Recent amendments to the 1991 Clean Air Act stipulate that additions to vehicle fleets, such as taxis and delivery vans, in CO and ozone non-attainment areas consist of 30% clean-fueled vehicles from 1998 with an increase to 70% by 2000. In addition, for California these amendments require 150,000 clean-fueled vehicles sales for 1996 - 1998 automobiles rising to 300,000 per year after that period. California Air Resources Board policy mandated that 2% per year of each automobile manufacturer's light duty vehicle sales in California be zero emission vehicles beginning in 1998 and increasing to 10% of yearly sales by 2003. At present only **RPEV/Evs** are capable of meeting the zero emission vehicle classification.

These regulations are further complemented by the South Coast Air Quality Management District's Proposed Rule 1601thatwould require operators of fleets of 15 or more passenger or light duty vehicles to phase in use of **ULEVs, LEVs** and **TLEVs** to commence July 1, 1993. Compared to the CARB supply mandate, the **SCAQMD's** adoption of Rule 1601would in effect place demand requirements on likely clean fuel vehicle niche markets. Unfortunately, several federal legislative efforts that would have offered impetus toward achieving the Districts' demand goals by supporting commercialization of clean fuel vehicles with cost sharing plans and investment tax credits, died in session. The recently introduced, SB 1113 is a new attempt to foster commercialization of low emission vehicles by acquiring funds via a $50 surcharge on imported new cars and light duty truck purchases.

At the local level Councilwoman Ruth Galanter has drafted a resolution requesting the Los Angeles County Board of Supervisors to utilize their authority under Section 9250.11 of the Vehicle Code to increase vehicle registration fees by $1 to fund air quality improvements. Such fee revenues could be redirected toward purchasers of clean fuel vehicles, particularly **RPEVs** or Evs.

Policies to Support RPEV/EV Development

Due to the early stage of development of both the EV as well as RPEV industry, and the likelihood that these technologies will develop together, suggested policies to stimulate industrial development throughout this section are assumed to pertain to both vehicle types unless additional qualifications are provided. Many of the points suggested here were drawn from the UCLA Lewis Center's report @'Prospects for Alternative Fuel Vehicle Use and Production in Southern California" (Morales and Storper, et al, 1991) that focused on EV development.

Recognition of the multitude of ongoing research and development efforts in the EV arena as essential prerequisites to successful **RPEV** industry growth are summarized first. These ongoing actions include:

- the Department of Energy's (DOE) electric and hybrid vehicle program that emphasizes battery and propulsion systems development,
- Congressional authorization of credits toward Corporate Average Fuel Economy (CAFE) requirements for businesses producing alternative fuel vehicles,
- California Electric Vehicle Task Force (CEVTF) efforts toward commercialization of electric vehicle technology,
- the Electric Power Research Institute's (EPRI) comprehensive program that includes testing and long-term battery development,
- state aid for technology transfer and commercialization of new products via the California Competitive Technology Program,
- passage of the Energy Efficiency Technology Competitiveness Act of 1989 that assists in establishing joint ventures to commercialize renewable-energy and energy efficient technologies,
- South Coast Air Quality Management District's (SCAQMD) authorization of a five year Clean Fuels Program to advance alternative fuels research,
- the L.A. Initiative introduced by Los Angeles Councilman Marvin Braude and supported by Los Angeles Department of Water and Power (LADWP) and Southern California Edison (SCE) for development and sale of at least 5,000 electric vans and 5,000 electric passenger cars by 1995,
- the **Playa** Vista RPEV demonstration project near LAX (see **Chapter 9),**
- formation of the U.S. Advanced Battery Consortium (Ford, GM, and Chrysler) to develop advanced battery technology, and
- **RPEV/EV** research conducted at the Partners for Advanced Transit and Highways (PATH), Institute of Transportation Studies, University of California, Berkeley, UC - Davis, Lawrence Berkeley Laboratory, **Lawrence Livermore National** Laboratory, and the California Institute for Energy Efficiency.

The variety and enduring nature of this work is crucial as part of an overall **RPEV/EV** industrialization policy.

Industrial policy initiatives should focus on an early start for the **RPEV/EV** development that blends public and private energies. Acknowledgment of the diverse technology needs and the initial small scale or production must prevail throughout the **decision-**making process. Creation of policy initiatives to recover the cost of early investments in **RPEV/EV** commercialization, as well as support through the infant industry period, should move quickly. Some, but not all of these policies should entail transitioning conventional vehicles to **RPEV/Evs,** i.e. support of vehicle conversions similar to the LA initiative. Development of policies for purpose-built, or newly designed, vehicles must be forwarded with even greater effort since these vehicles are more efficient in design and performance relative to conversions.

Whether small scale specialty manufacturers (as in the LA initiative) of large automakers produce the vehicles, both producer groups will need to rely on a myriad of intermediate parts suppliers and subcontractors in the early stages of industry growth. Choosing an area which can be utilized to integrate all production phases in close proximity is crucial to enable location economies, i.e. lower transportation costs, access to a large pool of personnel, information exchanges, and creation of a community spirit toward the industry. Job, investment, and property tax credits, relocation assistance, and coordinated land use measures to insure availability of reasonable cost sites, are a recommended policy entre. Where possible location advantages should be exploited with respect to abandoned and/or underutilized plants in existing industrial corridors, i.e. south of downtown LA between the 110 and 605 freeways. Further, careful scrutiny of flows of inputs and outputs between relevant economic sectors should generate further evidence of where locational economies may be exploitable.

Southern California offers one of the world's largest concentrations of engineering, technological, scientific, and managerial personnel. This fact coupled with the abundance of blue collar workers in auto and aerospace would offer the type of **multi-**tiered labor force necessary to **RPEV/EV** industrialization. Given current declines in the defense and aerospace industries in Southern California, weaving the plentiful supply of available technology-oriented workers into the fabric of new technology development is a necessary and challenging opportunity. Under Public Law 101.510 Title IX, a planning grant to develop economic adjustment plans to reduce the impacts from defense industry downsizing might be pursued for use in retooling aerospace and defense workers for **RPEV/EV** production. Programs to train these workers may also be integrated into the curricula at the California Community Colleges, California State Universities, and University of California. Coordinated and speedy moves to train these workers for new positions is important to preserve and maintain Southern California's labor supply.

Clearly financial ability for firms to undertake **RPEV/EV** development must be made attractive in order to insure an early start toward the industrialization goal. Federal assistance directed toward lending policies that encourage financial institutions to make **"patient"** loans, i.e. lending not dependent on high, short-term returns), for public and private participants would be necessary.

Policies to Build An Integrated RPEV/EV System Support Structure

The requirement for a carefully conceived, integrated **RPEV/EV** system is fundamental to achieving regional economic growth and maximum overall economic benefits linked to this technology. In this regard, four recommendations of the UCLA Lewis Center report are noteworthy and are modified to include the **RPEV** technology. These suggestions are:

- Formalization of a Southern California Industrial Liaison Group to define research priorities, cooperative procedures, and tasks,.
- Coordination of the liaison group's work with the California Institute in order to link Southern California efforts to strategic state planning,
- Incorporation of a regional R&D consortium for **RPEV/EV** technology, referred to as the California Regional Capital Manufacturing and Technology Corporation, and
- Provision of financial assistance for technology development, manufacturing implementation, and ongoing modernization and innovation of **RPEV/EV** developments.

These recommendations as well as the detailed demonstration suggestions given in Chapter 9 would strengthen the region's overall economic status and provide a worthwhile opportunity to satisfy local employment, air quality, and fossil fuel energy usage concerns simultaneously. At a time when industrial rebuilding and transitioning options are being discussed at every level of government nationwide, the ability for the Southern California region to utilize its labor, capital, and material resources to promote an improvement in the quality of life for most of its residents with these new technologies is certainly a window of opportunity that should not be dismissed lightly.

9.0 DEMONSTRATION OPPORTUNITIES FOR ELECTRIFICATION

Identification of demonstration opportunities for applying the roadway powered electric vehicle (RPEV) concept needs to address a wide array of subjects, including: type of vehicle(s); powered roadway considerations; mechanism(s) for roadway electric power cost recovery; type of demonstration (ie. freeway, arterial, special characterization); **location** of demonstration opportunity; continuing technology R&D; and, market penetration. Choosing demonstration opportunities must be done carefully, taking into consideration recent developments and likely future possibilities.

9.1 IDENTIFICATION OF SPECIFIC APPLICATIONS

Various types of applications exist for demonstrating the RPEV technology. The following list of applications have been suggested by the consultant, H.R. Ross Industries, Inc., who has done work in the area of roadway electrification technology applications for several years:

- in a local application on arterial or local streets.
- in a local activity center application on an arterial highway(s).
- in a freeway high occupancy vehicle **(HOV)** application.
- in a freeway setting (single or multiple freeway segments).

Local Application on Arterial or Loc eets

Development of demonstration opportunities on arterial or local streets has the potential for applying the technology in a situation where both static and dynamic charging is possible. This type of demonstration would lend itself to the traditional urban transit bus or a multiple occupant vehicle (MOV). The MOV is an advanced concept public transportation vehicle. Its distinguishing characteristics include:

- Electric propulsion using roadway power, with **"opportunity** charging" at layovers and stops.
- Two-compartment passenger module (15 passenger total).
- Two entry doors (one per compartment).
- Low floor design allowing for easy handicapped access.
- Automatic lateral guidance for lane centering.
- Electronic coupling of up to 3 vehicle platoons.

In the following demonstration discussions, this application is suggested for the Cest y-a Demonstration and Plava Vista Demonstration.

Local Activity Center Application on an Arterial Highway

Application of the technology on arterial highways serving a major activity center (like the **Playa** Vista Office Center near the Marina Del Rey section of Los Angeles, Los Angeles International Airport or the Anaheim area (Orange County) around the Convention Center, Stadium and Disneyland) will also provide opportunities for demonstrating both static and dynamic charging of vehicles. This type of demonstration could involve a range of vehicles (buses, **MOVs,** mini vans and automobiles). In the following demonstration discussions, this application is utilized in the **Pilot Scale Demonstration, Subregional** Demonstration and LAX Shuttle Bus Near-Term Demonstration.

Freeway High Occupancy Vehicle Application

Application of the technology on a high occupancy vehicle lane of a freeway has a variety of potential applications in southern California. Dynamic charging would be used on this type of facility. The HOV facility could accommodate buses, **MOVs,** full size vans, mini-vans or multi occupant automobiles. In the following demonstration discussions, this application is utilized **in the** Busway Electrification Demonstration Project, I-15 **San Diego** Area HOV **Demonstration** and the Near-Term HOV Demonstration.

Freeway Setting (Single or Multiple Segments) Application

The application of the **RPEV** in a single or multiple segment freeway demonstration is essential if the technology is to be ultimately extended to regional or statewide freeway networks. Dynamic charging would also be used for a freeway application. All previously noted vehicle types, including some types of trucks, could utilize **RPEV** freeway segments. In the following demonstration discussions, this application is utilized in the **Subregional Demonstration, Thin Regional Alternative, Marina** Freeway Demonstration, Feasibility and the **Proposed** Western National **Transportation** Research and **Development** Center.

9.2 **PLAYA VISTA RPEV** TESTING AND DEMONSTRATION STUDY

Background

In 1989 work began on the crafting of an RPEV testing and demonstration study in Southern California. The principal objective was to move the **RPEV** from the laboratory at Richmond Field Station, to a site closer to the people and to an environment where ultimately the concept could become a reality. Maguire Thomas Partners, owners and developers of a proposed large scale development in Los Angeles/Los Angeles County, offered a building and roadway on their site to demonstrate the **RPEV** concept. The **Playa** Vista site is located west of the I 405 freeway and about 2 miles due north of Los Angeles International Airport (See site location map). Its high visibility location is well situated as a jumping off point for subsequent RPEV applications.

Phase I of the **Playa** Vista project started in January 1990 with a commitment of $2.0 million, equally divided between Southern California Edison (Edison) and the City of Los Angeles, Department of Water and Power (DWP). This phase was to consist of the construction of an 1,100 foot powered roadway; a power conditioner and distribution system; adaptation of 2 electric G-vans with RPEV technology; and, conversion of an old hangar building to accommodate project offices, shops, laboratory, conference space, public display area, and a staging area for subsequent site development. Edison and DWP contracted with HR Ross Industries, Inc. for a $2.0 million contract to complete the Phase I work. Ross in turn contracted with other suppliers for necessary work, including: infrastructure design and construction management (Bechtel); technology development (Systems Control Technology, Inc.); and, vehicle and industrial design support (Designworks).

In June 1990, the Phase I effort was changed to focus on R&D activities related to solving acoustic noise and electromagnetic field (EMF) problems that had been encountered at the **PATH** Richmond Field Station test facility. Funds were redirected to a one-year research, redesign, testing and prototyping effort to solve the noise and **EMF** problems. The principal design changes involved increasing the roadway excitation frequency from 400 Hz to 8,500 Hz; reduction in roadway current from 1,200 amps to 240 amps; and, installation of field cancellation windings in the roadway inductor, to further reduce EMF strengths in the immediate vicinity.

The refocused efforts resulted in a new design for the powered roadway, power supply and test vehicle inductive pickup and power electronics. A 20 foot section of a totally redesigned powered roadway segment was build at Richmond Field Station to test power coupling. A multiple unit experimental power supply was purchased and installed at the Richmond site. While not capable of full power coupling for the G-van, the unit could either produce full current or full voltage, but not both at the same time. A totally redesigned power module and related power electronics was installed in a G-van supplied by the Electric Power Research Institute through Southern California Edison. The power module design was an expedient attempt to adapt the technology to an existing vehicle, without major structural changes. Power coupling tests were carried out at the Richmond facility, and noise and EMF measurements were made on a limited scale. Detailing of the redesign work and subsequent testing are set forth in **"Playa** Vista Roadway Powered Electric Vehicle Project Summary **Report"** (July 1991).

Test results substantiate that the initial noise and EMF problems were eliminated by the redesign work. Vehicle interior noise was reduced from about 70 DBA to 40 dDBA, or less (hardly perceptible) and vehicle interior EMFs, which ranged from 20 milligauss to 300 milligauss with the old design, were reduced to 1 to 3 milligauss under the new design. These numbers should be viewed as preliminary and additional testing, at various locations within the vehicle, will be needed. Wayside EMFs at 50 ft from the centerline dropped to less than 1 milligauss. These levels are below those experienced in the typical home or work environment. The results demonstrate that a substantial advancement in the technology has resulted from the redesign efforts.

While the redesign and testing was occurring, as previously described, work continued on other aspects of the Phase I effort. The design of the Playa Vista facility was completed, including: construction drawings and specifications, and the obtaining of bids for constructing the roadway and support building. Substantial effort was undertaken to secure funding for execution of Phase II. A proposed restructuring of project sponsorship would transfer program responsibilities from Edison and DWP to Caltrans. Other efforts were undertaken to help guide the restructuring of the R&D plans, for Phase II and subsequent phases.

Current Status and Future Plans

The one-year Playa Vista R&D effort resulted in significant improvements to the RPEV technology. A total of $1.6 million in Phase I funds have been expended, $1.0 million of which was spent on redesign and testing. One prototype vehicle (an adapted electric G-van) has been built; a short section of redesigned powered roadway was installed; a high frequency power supply was procured; and, initial testing has taken place at Richmond Field Station.

The vehicle noise level has been substantially reduced and the EMF problem, for both the vehicle and wayside, has been virtually eliminated. Roadway currents are much less, thus resistance losses have been significantly reduced. Power coupling with the G-van is about 10 to 20 percent more efficient than with the original bus at Richmond. The pickup and controller for the van are more efficient than for the bus. Moreover, the van is smaller and lighter than the bus even **after** accounting for the reduction in the output power rating for the van relative to the bus. The van is also quieter than the bus.

Edison and DWP have pulled back from their initial high level involvement in the Playa Vista Project. They have stated that "RPEV technology is still in its technological infancy and would benefit from additional laboratory-scale development". They have decided to co-fund $100,000 in additional technological research at Richmond. This research involved further testing of the G-van electronics, power conditioner and other related efforts. Specifically, testing characterized the performance of both the PATH bus and the **Playa** Vista electric G-van; analyzed alternative frequencies to further reduce or eliminate acoustic noise; and identified and defined technology development issues to help evaluate the technical and economic feasibility of the RPEV concept.

Playa Vista Phase II & III Demonstration Plan

Phase II-A, Late **1992-Mid** 1994 ($1.5 million) -- This phase is centered on design and construction of the initial test facility at **Playa** Vista. This consists of testing and characterization of the advanced high frequency inductive coupling devices at Richmond Field Station or other advanced energy transfer technologies. The initial G-van will undergo design changes and corrective measures, and the power electronics will be packaged for **onboard** control. The following will be installed at the **Playa** Vista site: high frequency power **supply;** 1,000 feet of powered roadway; rehabilitating one building for the project office, shop/laboratory, vehicle storage and display area; and, repaving of a staging area containing static charging strips for one vehicle. Phase II-A will result in a first stage operational test facility, and one operational vehicle which can be used to demonstrate the technological concept. No public demonstration will occur during this phase.

Phase II-B, Mid **1994-Mid** 1995 (between $11.5 million and $14.0 million) -- This phase will parallel Phase II-A and consists of the design and building of up to four additional RPEV equipped vehicles, including several or all of the following: **minivan,** automobile, multiple occupant vehicle (MOV) and electric transit bus. The number of vehicles will be dependent on availability of funding. One of the smaller vehicles may be built from the ground **up.** Efforts are underway to collaborate with a major auto maker on the design of one of the vehicles. In addition, this phase will include: installation of a high frequency power conditioner, capable of switching under load; 2,000 feet of second generation powered roadway; and, additional shop, laboratory and office space improvements. During Phase IX-B research will be undertaken on the following technological elements: **EMF** and **EMI** effects; lateral guidance; air gap control; energy storage, advanced on-board control systems; and, roadway design and construction. Technical studies will also be conducted involving network analysis for demonstration, demonstration planning and market penetration. Finally, program development studies will occur on advanced Phase III vehicle concepts, Phase III budget and funding plan, and a pilot stage demonstration at the **Playa** Vista site.

Phase III, Mid-1995-1997, with the public demonstration extending beyond that, perhaps for a three year period. (Budget projected to be about $24 million, however only a portion of this amount would go to the actual public demonstration). This phase will develop a prototype operational electrified roadway network on a portion of the **Playa** Vista site to demonstrate publicly the viability of the RPEV concept. The plan is to build 5 multiple occupant vehicles **(MOVs)** and several additional automobile prototype vehicles to operate on the internal roadway distribution network. An advanced power supply will be developed that will be capable of powering a freeway segment. This power supply will be tested at **Playa** Vista.

Phase II Funding Strategy -- Federal, state, regional and utility funds are being sought in the amount of $16.0 million to fully fund Phases II-A and II-B. Possible funding sources include: (1) Federal Highway Administration, (2) Federal Transit Administration, (3) Caltrans, (4) Los Angeles County Transportation Commission, (4) South Coast Air Quality Management District, (5) Electric Power Research Institute, and (6) the private sector.

9.3 FREEWAY AND ARTERIAL DEMONSTRATION OPPORTUNITIES

Playa Vista: Highway Electrification Studies and Demonstration Planning (As Adapted From the Phase II Program Design)

Deployment of the electrified roadway on a large scale in either a freeway or arterial application poses a number of questions that require system definition, analysis, engineering and economic studies for purposes of understanding the characteristics of the powered roadway system to be implemented. Deployment also requires staged demonstration of the system, starting with a very simple network with only a few vehicles, advancing progressively to more complex networks where hundreds or thousands of vehicles can use the powered roadway, and where the stated objective is to get a critical mass of demonstration, such that economic feasibility can be assessed and public policy decisions made as to regional and state demonstration of the system. The critical factors in economic feasibility relate principally to market penetration rates, ie., for a given network density, how many of the vehicles are freely purchased as a consumer product, and the capital and operating costs of the powered roadway infrastructure and vehicles. The Phase II studies are aimed at providing answers to the above questions.

Network Analysis

The network analysis will be centered on the various stages of demonstration envisaged, starting with the simplest networks with no public demonstration on the **Playa** Vista site, leading to a logical pilot scale demonstration in the environs of the site, and to a subregional demonstration that will represent a critical mass of system deployment. It will be extended to consider the parameters of a regional network, using the current study by the Southern California Association of Governments (SCAG) as a point of departure. In the last case the principal focus will be on market penetration modeling for various densities, and assessments of economic feasibility.

The network analysis will be directed at the complex problem of threshold size for significant use, in which some balance is struck between the static and dynamic charging, and between freeway and other arterial use for maximum effectiveness of the capital investment. In simple bus applications, for example the MOV system envisaged for the **Playa** Vista site and its environs, "opportunity charging" ie., static charging when the vehicle is at rest, will be an important consideration in economic practicality. In this case the network will be very simple, only two or three miles in extent, perhaps ten times the initial test facility length, and consisting of a good bit of static charging. For the pilot scale installation, the target is to have an initial fleet of 500 vehicles, where the objective is to determine the optimum network that can serve a preselected user group involving mostly private automobiles, but also some fleet vehicles with zonal operating characteristics. On a subregional system the goal would be to have a large zone, perhaps 50 square miles (1 to 2 percent of the southern California region), where the network density is representative of that which would be used on a full scale system, with some optional mixture of static, non freeway arterial and freeway system. In this case the network analysis will consist of simulation and system engineering to determine this mix and the consequences of greater or lesser density of usage and market potential. The subregional network analysis may take advantage of the SCAG models developed and applied on the current regional study. In all cases the network analysis will be used as a tool for demonstration planning and definition.

Demonstration Planning

At this point in time, plans for demonstration of the roadway powered electric vehicle system at the **Playa** Vista site and environs are mostly conceptual. The purpose of the Phase II effort in this area is to flesh out the concepts in terms of: the objective of the demonstration, sites, network scale, power distribution system required, number and types of vehicles, ownership plan (test vehicles, public, lease of private vehicles, or purchase), costs of deployment, schedule and institutional arrangements. The four levels of demonstration described below are progressively larger, more costly, further away in time, and more conjectural.

Test **Facility** Demonstration. In Phase II up to 6 vehicles are proposed to be developed for the powered roadway, ranging from a full size transit bus (or articulated bus), to the multiple occupancy vehicle **(MOV),** on down to G-vans, TE-vans, and the private automobile. The Phase II-A powered roadway will be about

1,000 **ft.,** located in a controlled access right of way; in Phase II-B this will be extended to approximately 2,000 **ft.** The powered roadway will also include various static charging segments to experiment with opportunity charging. Power supplies appropriate to these test facilities will also be installed. Although no "public demonstration@* is planned, these vehicles will be repeatedly demonstrated to visitors having an interest in the technology. The object of this effort will be to convincingly show that the technology is practical for both public transit, at low risk, and as a consumer product represented by the private automobile.

The principal planning tasks for this level of demonstration will soon be underway. In addition to this work, a demonstration plan will be developed in the Phase II-A work to specify the nature of this activity, which will begin to get underway as soon as the first vehicles are ready and the first stage powered roadway is operational. The time frame for Phase II is Late 1992-1995 inclusive; however demonstrations as defined above will continue beyond that time period.

Plava Vista Demonstration. Maguire Thomas Partners has indicated its willingness to consider use of the **Playa** Vista site for demonstration of the roadway powered electric vehicle system. The intention of this effort is to put a network on the permanent roadway system that might be 2 to 4 miles in extent, ie., about 10 times the scale of the test facilities. This is envisioned as part of the R&D effort in Phase III. This assumes that Maguire Thomas Partners is satisfied that the system proposed has no remaining technical problems, or high probability of failure, or would otherwise detract from normal use of the public roadway system. The expectation is that the test facilities in Phase II will provide evidence that will satisfy Maguire Thomas Partners; the contingency plan would be to seek an alternative site.

The vehicles for the Phase III public demonstration will be of the second generation **MOVs.** Operation would be at low to moderate speeds, and service will be initially confined to the site. These vehicles will serve essentially local trips during this part of the demonstration. Although several other vehicles will be designed and tested in Phase III, the intention is to use only the **MOVs** for demonstration. The costs of the demonstration will be borne by the project. Although experiments on electronic coupling and platooning of up to 3 of the **MOVs** is planned for Phase III, this type of operation is not encompassed in the public demonstration.

Phase III has a time frame of Mid 1995-1997; however, the actual public demonstration will extend beyond that.

The planning tasks associated with the Phase III public demonstration are to define, in collaboration with Maguire Thomas Partners, the location of the powered segments (both static and dynamic), the routes to be served, the stops, and the characteristics of the MOVs to be used. The network analysis described previously will include operational simulation and optimization for the system to be demonstrated. Planning efforts include a deriving a cost estimate and schedule for the installation planned, a definition of objectives, and a specification of the scope and time frame for the demonstration beyond Phase III. The original Phase III cost was projected to be in the $20 to $30 million range, however, only a portion of this would go to the actual public demonstration. No estimates have been made of the number of vehicles during this phase.

Pilot Scale Demonstration. The first extension of the technology beyond the confines of the Playa Vista site, and encompassing private vehicles as well as MOVs, is referred to as a "pilot scale demonstration". It might include about 25 lane miles of powered roadway, and is envisaged as a non-freeway arterial installation (e.g. Sepulveda Blvd., Lincoln Blvd. and Santa Monica Blvd.); thus it might consist of a roughly rectangular loop serving the Playa Vista site on the south and Santa Monica on the North, although at this time the plan is only conceptual. The objective of the pilot scale installation is to provide a network of sufficient extent that 500 to 1,000 private vehicles, leased to selected users, can effectively use it in conjunction with strategically located static charging. It may include fleet vehicles (mini vans) that have a zone of operation where the arterials form the main routes, for example mail or other delivery vehicles. It may include an expanded MOV fleet. However, the goal is to begin to commercialize the technology for the automobile by demonstrating a fleet of sufficient size and a powered roadway of sufficient length that economies of scale will come into play.

The cost of the pilot scale demonstration is expected to be on the order of $65 million. It would be designed and specified in 1996 and executed in the 1997-1998 period.

Subregional Demonstration. The final stage of demonstration prior to areawide deployment is referred to as "sub regional", signifying that it will occupy an area in the Southern California urbanized region of perhaps 50 square miles and possibly one-half to 1 million population. An example of such a system could be the west side of Los Angeles with Santa Monica and West Los Angeles on the north and Los Angeles International Airport and El Segundo on the south, encompassing segments of I-405 and I-10 about 10 miles and 5 miles in length. The objective is to install a network density on the freeways and non-freeway arterials such that it is representative of what would be deployed on a regional basis in the future, and assuming success of previous demonstration stages.

The network envisaged would be 200 lane miles, having a cost of approximately $500 million. It is assumed that the vehicles would be produced by major automobile manufacturers, and purchased by the public.

The subregional demonstration would be designed in Phase III for completion in 1997, with construction in the 1998-2000 period. The scale of the demonstration is such that the vehicle market would be at least 10,000 per year and potentially larger.

A system such as this one configured as a dense electrified network contained in a relatively small area of the entire SCAG region, however, raises concerns regarding its economic feasibility. Prior to such a demonstration moving forward would require market studies and other analyses and tests to validate it feasibility.

Other Demonst[illegible]on Possibilities Outlined in [illegible]ya Vista Work Scope

Two additional demonstration possibilities are outlined in the **Playa** Vista work scope.

Thin Reaional Alternative. As an alternative to the previously detailed subregional demonstration, a **"thin"** regional network will be explored, in which the objective would be to install enough powered roadway so that a trip can be made anywhere in the region, for example one lane in each direction on I-5 over an 80 mile span, and one lane in each direction on I-10 over a similar distance. Again as in the subregional network the goal would be to obtain a few hundred lane miles of powered roadway, and maximize the number of vehicles that could use it.

Near-Term Demonstration. In parallel with the demonstrations described previously, which would take place in the 1992-2000 period, many opportunities for simple effective demonstrations using buses or HOV facilities may arise for which the technology is already available, *or* nearly available. Bus systems, whether using the MOV under development, or full size electric transit buses, may represent near-term opportunities to display and demonstrate the technology. Examples of this include (1) shuttle bus systems in the vicinity of LAX traveling among the airport terminals, hotels, rental car agencies and long term parking facilities or (2) HOV facilities. These kinds of opportunistic demonstrations will be continuously looked for in parallel with the staged demonstration described previously.

Marina Freeway Demonstration Possibility

Before any widescale deployment of the RPEV technology in a freeway setting, the concept should be tested operationally on a short segment of the region's freeway network. A likely candidate location is the 2 mile segment of the Marina Freeway (State Route 90) from Culver Boulevard to Slauson Avenue. This freeway segment is located in close proximity (essentially adjacent) to the Playa Vista site. The Marina Freeway is a good candidate for initial RPEV treatment because of its relatively low traffic volumes (in relation to other nearby freeway *sections).* Construction of electrified lanes could take place with minimal disruption to traffic flow.

Initially, one lane in each direction (about 4 lane miles) should be installed. Testing of RPEVs from the Playa Vista site on this segment should occur over a period of at least two years. Specific tests of the inductive coupling system at freeway speeds should be undertaken. Particular attention should be given to segmented power switching and the development and testing of the mechanism(s) for recovering roadway electric energy costs. A monitoring program should be designed to closely evaluate system use, operational characteristics, problems and opportunities for subsequent deployment of the technology.

Another Freeway D[redacted]ation Opportunity

Another opportunity *for* demonstrating the RPEV technology in a freeway setting deserves further investigation for its feasibility. It would involve applying the technology to the 8 mile segment of the f-15 reversible freeway section in San Diego County that is being utilized by PATH for demonstrating the highway automation technology.

Busway Electrification Demonstration Project

One proposal has been previously developed to demonstrate the extension of roadway electrification technology to freeway speeds, utilizing a limited access facility on which transit buses, vans or other light duty vehicles could be demonstrated. A preliminary program description of a prototype busway electrification demonstration project is contained in "Highway Electrification and Automation -- Planning Implications for Southern California", Southern California Association of Governments (December 1984). The project proposed a Phase I $500,000 1 year feasibility study, with a multiphased effort over a period of about 8 years, to electrify and provide certain automation capabilities on a busway/HOV facility in the Los Angeles region. Total cost for the program was estimated in the $70 to $80 million dollar range. The initial system would encompass 12 to 15 miles of electrified roadway, 60 to 100 electric transit buses, and 100 to 200 electric automobiles or vans, all of which would be operated on a limited access facility with some semi-automatic operation capabilities.

Alternative Sites

During Phase I of the proposed busway study at least 4 alternative sites will be examined for development of demonstration opportunities. The following are three examples of possible demonstration sites:

Name	Length	Description
El Monte Busway	11.25 mi.	East-west facility, existing, Parallel to San Bernardino Freeway, two lanes each way.
Santa Ana Guideway	30.3 mi.	Southeasterly from downtown LA to Santa Ana, parallel to Santa Ana Freeway, one lane each way.
Harbor Guideway	11.36 mi.	North-south from downtown LA to Route 91 in vicinity of Gardena, parallel to Harbor Freeway, one lane each way.

Program Phases and Funding

The original concept of the project envisioned a 5 phase program starting in FY 85 and ending in FY 92. This approach to phasing is still valid, but the basic evaluation of vehicles and some of the associated technical studies have currently been incorporated in the Playa Vista Project work plan. It is estimated that total funding for this project would be approximately $75 million. The following phasing plan and possible funding sources are adapted from the initial 1984 design:

Phase	Year	Possible Funding Sources
1 Research & Feasibility	1	Caltrans or Local Agency
2 Prototype Development & Test	2-4	Caltrans, FTA, FHWA, EPRI/DOE
3 Engineering & Specs.	5-6	FTA, FHWA, Caltrans, DOE
4 Construction & Fabrication	6-7	FTA, FHWA, Caltrans
5 Operational Demo.	6-8	FTA, FHWA, Caltrans

This earlier report was prepared prior to any actual roadway testing of the technology, and does not reflect the most recent research and development of the technology as well as its economic feasibility. However, a recently completed PATH project (Chira-Chavala, et al 1992) at the Institute of Transportation Studies of the University of California-Berkeley performed a case study of the feasibility of implementing roadway-powered electric vehicle technology on the El-Monte Busway.

The study's objective was to assess the feasibility of early deployment of the RPEV technology in existing high-occupancy-vehicle (HOV) facilities in California. Initially, functional requirements of the RPEV system *for* the El-Monte Busway *were* specified. Six scenarios of possible electrification scales were then defined for the feasibility evaluation. An inductive coupling system design was developed for this case study, including the roadway inductor design, power conditioner and distribution system, the vehicle inductor design, and the vehicle itself. The impact of the proposed system on the utility industry was also evaluated. Finally, a plan for the public demonstration of the technology was proposed. Implementation of the technology could occur in three incremental phases. Phase I demonstration of the technology could start with the implementation of a Downtown Shuttle bus service using static chargers exclusively. For Phase II, this shuttle service could be expanded from the CBD to the El-Monte Busway terminating at the El-Monte Busway Terminal, using static chargers exclusively. Phase II would consist of implementation of dynamic roadway electrification along the El-Monte Busway.

Phase I could start as early as 1993 and be prepared for public demonstration by 1995; activities in Phase II could begin in 1995, with a public demonstration date in 1998. Finally, Phase III could be initiated in 1996, with a public demonstration date *in 2000.* These approximate demonstration dates include the time for needed research to address technical uncertainties that remain.

The projected hardware cost, including hardware and installation, but not the engineering, for implementing the Downtown Shuttle bus service of Phase I would be approximately $4.0 million. The incremental hardware cost for Phase II is projected to range between $2.7 million and $5.4 million. The incremental hardware cost for Phase III is projected to be approximately $74 million taking into account the fact that the acquisition of new electric buses would mean that the transit agency will not have to replace existing diesel buses when their service life expires. The total for the whole demonstration project would range between $80.7 million and $83.4 million.

9.4 ONGOING RPEV RESEARCH NEEDS

Throughout the development of this study various questions have been raised concerning the viability of the roadway powered electric vehicle and its applicability in the urban environment. The following sections contain a brief discussion of ongoing RPEV research needs that should be pursued at the government, university, transportation laboratory and private sector levels.

Market Potential for RPEVs and Evs in the Los Angeles Area

Market research surveys need to be conducted in the Los Angeles area and any other area considering RPEVs or Evs. These surveys should attempt to quantify the public's willingness to accept both RPEVS and Evs. Design of the questions and supporting documentation of the strengths and weaknesses of both technologies is of critical importance. Results of these surveys can help to refine assumptions used in the modeling of RPEV market potential and system utilization.

Highway Network Analysis of Different RPEV Network Configurations Market Penetration Assumptions, Battery Ranges, and Alternative Spacings

Further highway modeling should be undertaken of different RPEV network configurations in the Los Angeles Area and any other areas considering the technology. This modeling should continue to investigate different types of network configurations (ie. outlying intra-region long distance highway links and inter-region highway links); different levels of market penetration, based on market research studies; different battery range assumptions, including assumptions with different ranges of hybrid vehicles in mix; and, alternative spacings of the roadway inductor (ie. varying lengths of spacings between roadway inductor segments).

ng/Retrofit Feasibility and RPEV Market Iation

Studies need to be undertaken on the feasibility of manufacturing RPEVs or of retrofitting Evs with the RPEV technology. The studies also need to consider the steps necessary to bring RPEVs online in a given market area. Similar studies have been conducted by the Electric Vehicle Development Corporation for Evs. These studies can serve as a starting point for similar studies that will be needed for full market integration of the RPEV technology.

Electric Use and Cost Recovery (Vehicle/System)

Studies should be undertaken to characterize electricity use, including system losses, under various roadway inductor and vehicle use configurations. The mechanisms for determining energy use (both inductor systemwide and within individual vehicles) need further study. Also, work is needed to determine the manner of allocating electric use costs to system users.

Roadway Inductor Construction, Install[redacted] Costs

Continuing research is needed to determine the optimum method for constructing and installing the roadway inductor modules. Different lengths of roadway inductor segments (currently 120 ft. length) need to be investigated. The benefits of constructing modules near the site (to minimize transportation costs) need to be looked at. Furthermore, techniques need to be developed to facilitate installation of roadway segments in an expeditious, cost effective manner. The prime result of these studies should be to achieve a significant reduction in roadway inductor costs.

Long Term Impacts of Highway Use on Roadway Inductor and Pavement Structure (Highway Test Segment)

Questions have been raised by Caltrans and others concerning the long term impacts of highway use on the roadway inductor and pavement structural integrity. Studies need to be undertaken, over an extended time frame, to ascertain whether the roadway inductor segments can withstand the rigors of extensive highway use. Also, investigations are needed to determine how roadway resurfacing will occur, so as not to damage the roadway inductor segments. Design, construction, and testing of roadway inductor segments and pavement structures is seriously needed.

RPEV Opportunity Charging Possibilities (Intersections, Bus Bays, Parking Lots)

Other possibilities have been raised for using the RPEV technology to help extend the range of vehicles. Opportunity charging possibilities exist at intersections where vehicles are stopped for brief periods; at bus bays where buses are stopped to load or unload passengers; and, at parking lots where vehicles are parked for extended periods. Studies should be conducted to examine these opportunities, and determine the synergistic effect they would play in conjunction with large scale highway system deployment of the RPEV technology.

Arterial Applications for the RPEV Technology

Initial RPEV work considered application of the technology on arterials. While this study chose not to consider any arterial network configurations, there may be potential in selected arterial applications and situations, like a local bus network (ie. original downtown Santa Barbara bus system). The Playa Vista project will provide an opportunity for demonstrating the technology in this setting.

RPEV Bus vs. Battery EV Bus vs. Electric Catenary Bus

Comparative studies are needed to look at the costs and benefits of three bus configurations (RPEV, Battery EV and Electric Catenary). Some work has been done in this area by the Los Angeles County Transportation Commission and Southern California Rapid Transit District, as part of their Electric Bus Feasibility Project. As the RPEV technology becomes more cost effective, it may provide a viable alternative to the other modes.

Long and Short Term EMF and EMI Effects (Vehicle/Wayside)

Recent measurements have been conducted of electromagnetic fields (EMF) produced by the RPEV technology, both within the vehicle and along the wayside. Further work is needed to verify the results of these studies in the long term. Similar studies are needed of electromagnetic interference (EMI) effects observed in the PATH design. These effects are reflected primarily in acoustic noise in conventional vehicles over the powered roadway and with sensors in the conventional vehicles.

Time-Staging and Deployment Sequencing in the Metropolitan Area

Once a final highway network(s) is (are) agreed to for the Los Angeles area, studies need to be undertaken to determine time-staging and deployment sequencing of construction activities. Time-staging studies need to consider integration of the emerging vehicle fleet with construction timing of various highway segments. Development sequencing studies also need to consider installation of the roadway segments so as to minimize traffic disruption. Related studies of what development sequencing to follow to overcome the chicken and egg phenomenon of induced development should additionally be researched.

Cost-Effectiveness of Alternative EV and Hybrid Vehicle Assumptions

Further comparative studies are needed to examine the cost-effectiveness of the RPEV versus alternative EV and hybrid vehicles, under different vehicle mix and operating characteristics assumptions. Questions have been raised about RPEV cost effectiveness, if significant improvements occur in Evs (battery range improvements) and hybrid vehicles (range extension with battery and small engine). These questions can only be answered when policy makers have the results of comparative studies which address the costs and benefits of the different technologies.

Ongoing Testing and Refinement of the Inductor and Pickup Technology

Significant advancements have been made in RPEV inductor and pickup technology in recent years, although only about $7 million has been spent in total since its inception. Further studies are planned over the next few years. These and additional studies and tests should be undertaken to further refine the technology.

Dynamic Vehicle Applications (Auto/Van/Bus/MOV/Truck

Testing of the RPEV technology has only occurred with a bus and electric G-van. In the case of the G-van, the RPEV was a retrofit of an existing vehicle. The bus, however, was built as an electric vehicle, though its structure was comparable to that of a diesel bus. Design and testing of the technology in automobiles, vans, buses, multiple occupant vehicles and trucks should continue, both as retrofits to existing vehicles and in vehicles designed from the ground up. Involvement of the auto industry in this effort should be fostered.

9.5 DEVELOPMENT OF AN EVALUATION PLAN

For each of the demonstration projects that come to fruition, an evaluation plan needs to be designed and executed from the onset of the demonstration. Each evaluation plan needs to start with the assembling of baseline data of facility use, environmental conditions and socio-economic base. Goals and objectives for each demonstration should be clearly stated, so as to allow for the evaluation of effectiveness. Each aspect of the technology should be clearly documented (ie. vehicles, roadway inductor, power conditioner, etc.) so as to properly characterize the results of the demonstration. Any changes to the technology during the course of the demonstration should also be detailed. Cost effectiveness criteria should be developed and data collected to verify the application of the criteria under differing conditions and situations. Institutional and social impacts should be documented, including public and governmental officials' perceptions prior to institution of the demonstration versus those at the completion of the demonstration. The degree of intergovernmental or interorganizational coordination should be documented, so that these efforts can serve as a guide for subsequent demonstrations. No demonstration should be undertaken unless a formal evaluation plan has been developed, funds made available for its implementation and an objective body identified to carry out the evaluation plan.

10.0 DEMONSTRATION OPPORTUNITIES FOR AUTOMATION

The technology for vehicle automation is not as far advanced as the technology for roadway electrification. Options for automation have been investigated by various authors over the past 30 years. The Mobility 2000 work group on advanced vehicle control systems identified the following intelligent vehicle highway system (IVHS) technologies:

- lateral guidance or automatic steering;
- longitudinal control, including obstacle detection or avoidance, headway keeping, automatic braking, platooning;
- communication among vehicles and between vehicles and a central control facility;
- driver warning, vision enhancement and assistance systems;
- automatic trip routing and scheduling;
- control of merging of streams of traffic;
- and, transitioning to and *from* automatic control.

The demonstration options for automation will be handled in a more general way than for electrification. Time frames for implementing the various automation technologies will be postulated. General cost information for research and application, where information exists, will be detailed. An assessment will be made of the potential benefits to be derived from highway automation. Social and institutional benefits of automation will be expanded upon. Finally, strategies will be developed for demonstration of automation technologies.

10.1 FEASIBLE TIME FRAMES FOR IMPLEMENTING AUTOMATION TECHNOLOGIES

The first systematic approach to defining a work program and time table for implementing automation technologies was completed in 1990 following the National IVHS Workshop sponsored by government, universities and industry as part of Mobility 2000. The second more current approach to development of a systematic program for research and development for AVCS is part of work performed by IVHS America. This work is documented in the Strategic Plan for Intelligent Vehicle-Highway Systems in the United States, including its definition, characteristics and requirements, current status, and plan elements, and is summarized below. Of particular importance are the operational testing and deployment plans.

AVCS combine sensors, computers, and control systems in vehicles and in the infrastructure to warn and assist motorists or to intercede in the driving task. AVCS is not a single operational concept, but a broad range of capabilities that will be translated into products and systems in an evolutionary progression. Although

AVCS is regarded as the most long-terms of all IVHS functional areas, research and development work has been on-going in one form or another for more than three decades. Some examples of AVCS-type technologies such as anti-lock brakes, traction control, active suspension, and four-wheel steering, are currently available as either standard or optional equipment on motor vehicles. Other AVCS technologies are under development for non-automotive applications, such as factory automation, military and aerospace vehicle systems, and computers. Motorist warning, perception enhancement, and assistance/control systems are under active research, development, and testing in the U.S., Japan, and Europe.

Vehicle-highway automation, the AVCS technologies assumed throughout this study, for specialized freeway lanes have received attention from both the public and private sectors. The California PATH program is currently pursuing vehicle-highway automation work, having already completed research, development, and small-scale testing. Larger-scale testing under realistic operating conditions is planned during'the next several years. That work will take the initial steps toward demonstrating the feasibility of increasing the vehicle density in a traffic lane, and thus allowing increases in effective freeway capacity.

Operational Testing

Due to its greater safety consequences, AVCS operational testing endeavors differ from other AVCS functional areas of investigation. AVCS products and systems will require a significant amount of simulation and test track evaluation prior to conventional public road operational deployment. Some AVCS components, such as driver warning and perceptual enhancement devices which do not rely on infrastructure elements, will not require special facilities for testing. However, those AVCS components that do rely on infrastructure elements will require special roadway facilities for testing.

The Strategic Plan divides AVCS operational testing into the following three time-frames: Near Term (5 -year timeframe, Middle Term (lo-year timeframe), and Longer Term (20-year timeframe). In the near term, the following AVCS products will likely be ready for large-scale testing:

- Backup warning
- Adaptive cruise control
- Traction (ice) warning and control
- Vehicle performance monitoring (on-board diagnostics)
- Longitudinal collision warning
- Lane change and merge warnings

In the middle term, AVCS products will evolve which have a greater degree of vehicle motion control. Some additional products that are expected to be tested include:

- Lane and road departure warning
- Steering control
- Side collision warning
- Automated lane change system
- Automated collision avoidance (steering or braking)
- More advanced vision enhancements
- Short-headway vehicle following control
- Rural intersection hazard warning
- Head-on collision warning

In the longer term timeframe, the AVCS concepts to be tested would incorporate many of the elements previously listed. With such a long lead time, all elements cannot be anticipated today since AVCS technology is rapidly changing. Automated highway concepts, such as long or short heady automated platoons, will be evaluated for safety, human factors, and effectiveness in reducing congestion.

Deployment

Near term deployment of AVCS systems and products would likely include the following:

- Stand-alone, electronic control systems such as anti-lock braking, electronic engine and transmission controls, and traction control under acceleration

- Simple vehicle performance monitoring (tire inflation and reduced traction)

- Warning systems for side and near obstacles

- Adaptive cruise control (maintaining a safe distance from the vehicle ahead)

Middle term deployment of AVCS systems and products would be expected to include the following:

- Warning systems for distant obstacles (frontal collision), lane departure, lane change and merge, and roadway conditions

- Electronic control systems for brake application and steering

- Vehicle performance monitoring for items such as tire condition, traction, braking capability, andacceleration capability

- Automated collision avoidance

- Vision enhancement for drivers in night and conditions of rain and fog

Longer term deployment of AVCS systems and products would be expected to include the following:

- Warning systems for intersection hazards
- Automated vehicle operation on specially equipped roadways

10.2 POTENTIAL COSTS FOR IMPLEMENTING AUTOMATION

Determining potential capital, operation, and maintenance costs for implementing highway automation is not an easy task. Cost studies on the various automation components are meager mainly because of the technology's early stage of research and development. Nonetheless two sources of information regarding potential costs for highway automation implementation are available and will be summarized in this section.

The first study is entitled "Systems Studies of Automated Highway Systems (SSAHS)" and is approximately ten years old. Although more recent studies have dealt with various aspects of automation technologies, none have systematically addressed all of the components in this study. The following referenced cost although dated, should not be relied on for current planning. They do, however, present benchmarks for reference purposes. General cost information can be estimated based on extrapolation of information contained in the SSAHS study.

The second study is part of the "Strategic Plan for Intelligent Vehicle-Highway Systems in the United States" prepared by IVHS America and was published in 1992.

systems Studies of Automated Highway Systems(SSAHS):

Capital Cost Elements

Three capital cost subsystems make up the automation package:

Wayside -- This subsystem includes all of the command, control and communications equipment to enable the vehicles to communicate with a central command center. The equipment is either located within the right-of-way, along the wayside, or at an external command center.

Guideway -- This subsystem includes diagnostic and referencing equipment located within the roadway or adjacent barrier medians. The equipment facilitates the lateral and longitudinal positioning of the vehicle. The relative costs for this component would likely be greater than those noted due to the addition of costs for on and off ramps and separated rights of way.

vehicle -- This subsystem includes all diagnostic, communications and control equipment located within the vehicle. The equipment enables the vehicle to interact with other vehicles, the guideway and the wayside.

Figure 51 details the automation wayside, guideway and vehicle equipment considered in the SSAHS study for the "Smart" vehicle concept.

Figure 51

"Smart" Individual Vehicle Concept
Capital Cost Substations And Equipment Breakdown

Wayside

- o Network Controller
    - Hardwire or Microwave Communications
    - Computers (Medium Capacity)
    - Controls and Displays
    - Antennas
- 0 Sector Controller
    - Hardwire or Microwave Communications
    - Computers (Medium Capacity)
    - Controls and Displays
    - Antenna Systems

Guidewav

- o Diagnostics
    - Micro Computers
    - Lateral Benchmarks
    - Longitudinal Benchmarks
    - Interconnect Cables
- o Longitudinal Reference
    - Guideway Benchmarks
- o Lateral Reference
    - Guideway Benchmarks

Figure 51 (cont.)
"Smart" Individual Vehicle Concept
Capital Cost Sub-Systems And Equipment Breakdown

Vehicle

- Diagnostics
  - Accelerometer
  - Brake Sensor
  - Tire Pressure Sensor
  - Computation and Communication Integrity Tester
  - Fuel, Fluid, Pressure & Temperature Sensors

- Communications
  - Antennas

- Longitudinal Control
  - Micro Computers
  - Throttle and Brake Actuators
  - Benchmark Detectors .
  - Velocity Sensors
  - Cabling
  - Controls and Displays
  - Car Following Sensors

- Lateral Control
  - Micro Computers
  - Steering Actuators
  - Cabling
  - *Sensors*

- Collision Avoidance
  - Micro Computer
  - Brake Actuators
  - Throttle *Override*
  - Sensors

SOURCE: System Studies of Automated Highway Systems, Final Report

Convert-A-Lane Cost Estimates

The SSAHS Study included a convert-a-lane option that most closely resembles the automation scenario in the Southern California study. This option uses an existing lane(s) within the right-of-way (a take away situation) to incorporate the automation technological improvements. The cost for a convert-a-lane option in 1980 dollars was estimated at $1,950,000 per lane mile for the Smart AHS in an urban setting. These costs were derived by using the AGT-SOS System cost Model, which estimates capital, operating and maintenance costs. General Motors was the prime contractor for this study, under contract to the Transportation Systems Center in Cambridge, Massachusetts, and funded by the Urban Mass Transportation Administration. This model is now obsolete and could not be adapted for this study. Development of an integrated cost model was beyond the scope of this study.

For comparative purposes urban life cycle costs from the SSAHS Study for a smart vehicle phased automation concept system within the Northeast Corridor are detailed as follows:

User Costs:	
Capital	$ 203,400,000
Inspection & Maintenance	293,500,000
Energy	269,500,000
Operating & Maintenance Tolls	216,100,000
System Costs:	
Capital	$1,057,200,000
Operating & Maintenance	189,100,000
Deployment Characteristics:	
Person Trips	7,413,000,000
Vehicle Miles	39,990,000,000
Vehicles	1,479,000
AHS Use %	11.05

SOURCE: System Studies of Automated Highway Systems, Final Report

Also for comparative purposes the urban equivalent uniform annual and specific costs from the SSAHS Study for a smart vehicle phased automation concept system within the Northeast Corridor are detailed as follows:

Cost:

User	100,500,000
System	127,400,000
Total	205,800,000

Cost Per Vehicle Mile ($/Mile):

User	0.090
System	0.115
Total	0.185

Costs Per Person Trip ($/Trip):

User	0.488
System	0.619
Total	0.999

SOURCE:
System Studies of Automated Highway Systems, Final Report

Incremental costs from the SSAHS Study for vehicles with AHS smart vehicle technologies was estimated to range from $2,000 to $2,500 in 1980 dollars. These costs include lateral and longitudinal controls, communications and automatic braking.

Strategic Plan for Intelligent Vehicle-Highway Systems:

The cost estimates made in 1991 dollars for private sector involvement assume that the products will be technically feasible, will show adequate public benefit, and will eventually be marketable items. The following listing of AVCS cost estimates provides near term (5 years), mid-term (10 years), and long-term (20 years) estimates for annual corporate (design and tooling), consumer (AVCS vehicle purchase), and infrastructure (construction, maintenance, and operation) costs.

	Near-term	Mid-term	Long-term
		$ 96	
Corporate	$ 32	$1,800	$ 160
Consumer	$500		$5,500
Infrastructure	$ 0	$ 60	$ 700
AVCS total	$532	$1,956	$6,360

SOURCE:

Strategic Plan for Intelligent Vehicle-Highway Systems in the United States, IVHS America, May 1992

10.3 POTENTIAL BENEFITS OF AUTOMATION

The principal benefits of vehicle automation in the highway environment are improved safety and improved regional mobility. The safety issue was not addressed in this project's investigation of highway automation. Regional mobility impacts are the subject of Chapter 6 of this report. *To* a limited degree, emissions impacts of highway automation were assessed and the results appear in Chapter 7 of this report.

10.4 SOCIAL AND INSTITUTIONAL IMPACTS OF AUTOMATION

Social and institutional impacts of automation technologies have been touched on previously in Chapter 5.2. Perhaps the most comprehensive treatment of social and institutional impacts is contained in the Society of Automotive Engineers compendium, "Automated Highway/Intelligent Vehicle Systems: Technology and Socioeconomic Aspects" (1990). Within this compendium, one paper, "Social and Institutional Considerations in Intelligent Vehicle-Highway Systems" (Underwood), presents a comprehensive assessment of impacts or considerations. This paper is based on a Delphi survey of 32 experts in the automotive, electronics and communications fields. The Delphi panelists expressed their views on a number of questions within four consideration categories: (1) the driving forces for implementation, (2) the barriers to market penetration, (3) constructive government policy initiatives, and (4) the expected socio-technical impacts from adoption of the systems. The following ten groupings of IVHS features were assessed within the context of the four consideration categories:

1. Automatic tolls and road pricing
2. Automatic vehicle location
3. Automatic vehicle navigation
4. Motorist information
5. Cooperative route guidance
6. Collision warning
7. Collision avoidance
8. Speed and headway keeping
9. Automated highway
10. Automated guideway

Groups 6 through 10 come under the more general heading of Advanced Vehicle Control Systems (AVCS).

The following sections summarize the views as expressed in the Delphi survey.

Driving Forces For Implementation

The Delphi participants listed the following driving forces for implementation of IVHS technologies:

1. Increasing Traffic Congestion
2. Desire for Improved Safety
3. Motorists' Desire for Comfort and Convenience
4. Public Demand for Travel Information as They Become Aware of It
5. Declining Cost of Technology and Operation
6. Incremental Process Toward Development and Adoption of Advanced Systems
7. Commuters' Preference for Highway Over Rail
8. Novelty of the Technology
9. Promise of Shorter Trip Times by Traveling on Designated Lanes

Increasing traffic congestion, in conjunction with the public's general resistance to further highway construction will continue to be the public's key consideration pushing for implementation of automation technologies. Closely trailing will be the public's desire for improved traffic safety, being fueled by the ever increasing costs for auto insurance. These two factors should be the major driving forces for implementation of AVCS technologies.

Barriers to Market Penetration

The Delphi participants listed the following barriers to market penetration of implementation of IVHS technology:

1. Cost to the Consumer
2. Obtaining Technical Reliability of a Trusted System
3. Lack of Demand and Consumer Resistance and Acceptance
4. Government and Manufacturing Liability Risks
5. Possible System Ineffectiveness (Getting the Desired Results)
6. Setting of Appropriate Standards (Equipment and Broadcasting/Communications)
7. Planning for Transition to New and More Advanced Technologies
8. Cost to Federal and State Governments
9. Human Factors in System Design
10. Penalizes User (Drivers Must Travel at a Slower Pace)
11. Limited Applicability of the Systems

The overwhelming concern regarding AVCS technologies (collision warning, collision avoidance, speed and headway keeping, and automated highway) was system reliability. Also of concern and significance is the institutional reaction to system failures. The principal issue is determining who will be held responsible and liable for damages as a result of system failure. Settlement of the liability issues was the second highest ranking barrier over most AVCS categories.

Constructive Government Policy Initiatives

The Delphi participants listed the following constructive government policy initiatives for implementation of IVHS technology:

1. Limit the Liability Borne by Manufacturers and Government
2. Establish Effective Standards
3. Provide Federal Funding or Incentives for Research and Development
4. Department of Transportation Leadership, Initiative and Commitment
5. Provide the Necessary Public Infrastructure
6. Provide Federal Funding for Construction and Operation
7. Provide Federal, State and Local Legislation to Implement
8. Dedicate Lanes and Roadways for Priority Use by Vehicles with Cooperative Technology

Government regulators at the Federal and State levels need to address the nagging question of how to limit liability borne by manufacturers and government. This issue was the subject of a separate SAE paper "Liability and Insurance Implications of IVHS Technology" (Syverud). Prior experience with other pathbreaking technologies (commercial aviation, nuclear power and satellites) suggest that matters of liability risks for the more advanced stages of automation technology (collision avoidance, speed and headway keeping, automated highways and automated guideways) be addressed in Federal legislation.

Another critical matter that will require Federal and State cooperation is the provision of funding or incentives for research and development of highway automation systems. Federal DOT leadership in this area has begun to emerge with the passage of transportation legislation in late 1991. As with prior major new highway initiatives, Federal funding, in large part, will be required if a major highway automation effort is to be successful.

Expected Socio-technical Impacts

The Delphi participants listed the following expected socio-technical impacts associated with the implementation of IVHS technology:

1. Reduced Congestion
2. Improved Safety
3. Increased Comfort and Convenience for the Motorist
4. Increased Driver Acceptance of Automated Control
5. Increased Automobile Commuting
6. Smoother Flow of Traffic on Toll Roads

The greatest perceived socio-technical benefit to highway automation is a reduction in congestion. This is borne out by the comparison of baseline 2025 highway congestion levels with those resulting from implementation of the 2025 automation network (see Chapter 6 and 10.03 "Mobility Benefits" discussions).

Improved safety has long been touted as a key benefit to highway automation. The specific technological elements that will improve driver safety are: collision warning, collision avoidance, speed and headway keeping, automated highway and automated guideway. Analysis of traffic accident and injury statistics indicate that between 85 to 90 percent of all accidents are the result of "improper driving". Even accounting for some failures in automation technologies due to their complex nature and newness, these systems should substantially reduce head-on and angle collisions as well as run-off-the-road accidents.

Automated highway systems should offer greater driver comfort and convenience. They will allow the driver greater knowledge of the highway environment, through improved communications about driving conditions (weather, accidents, traffic). They will facilitate the drivers entering and exiting traffic flow in a safe and expeditious manner. They will make getting from one destination to another easier through optimum trip planning. Finally, they will help minimize the stress associated with congested freeway driving, by improving driver and vehicle safety (real and perceived).

Once drivers become familiar with the operation of automated highway system technologies, they should find them substantially more reliable than current automobile travel. This will depend in part on the success of technical development work to improve the reliability of automation system components. Further research in this area is of critical importance.

One impact of highway automation that may have possible negative consequences is the possibility of increased automobile commuting resulting from improvements in traffic flow and safety. The question of induced travel resulting from introduction of highway automation is one that needs further study.

In controlled access situations, like restricted lanes on toll facilities, smoother traffic flow should result from the introduction of automated systems. Once vehicles become a part of platoons and begin to operate with minimal vehicle spacing, traffic should flow in a smooth manner.

Socio-technical Impacts of different individual AVCS technologies are summarized in the following subsections based on the Delphi survey responses.

Collision Warning -- These in-vehicle systems alert the driver when on a collision course with another vehicle or object.

- Increased safety and less accidents
- Increased risk taking by drivers
- Increased consumer trust or reliance on non-human systems
- Motorists will likely drive faster

Collision Avoidance -- These systems incorporate automatic braking with collision warning through use of radar, sonar, infrared and/or laser detection devices.

- Increased safety and less accidents
- Increased litigation in the event of system failures

Speed and Headway Keeping -- These systems combine throttle control with braking capabilities in order to assure safe distances between vehicles on the roadway.

- Increased efficiency in traffic flow
- Vulnerability to control breakdown
- Improved safety

Automated Highway -- These systems combine lateral and longitudinal control features of the previous systems with the communications technologies to enable vehicles to travel on their own without continuous control from the motorist.

- Increased safety, fewer accidents
- Increased efficiency in traffic flow
- Less air pollution
- Debates over whether to allocate resources to equipping lanes and roadways
- Increased freedom of mobility for most people, decreased sense of mobility for some people
- Changing employment opportunities in the transportation sector
- Possible induced travel and locational changes

Automated Guideway -- These systems include totally automated vehicles operating along a guideway with exclusive right of way, like automated guideway transit or urban shuttle service.

- Similar benefits to automated highway
- More reliable trip times
- Huge (costly) guideway building program

10.5 STRATEGIES FOR DEMONSTRATION OF AUTOMATION TECHNOLOGIES

Automation technologies are still in their relative infancy as is the readiness of the public to accept the full range of automation strategies detailed herein. Some tests of automation technologies are underway in the US and other countries. In California the only test currently in operation involves the experiments with both lateral and longitudinal control by the PATH program at Richmond Field Station and in the San Diego area on the 8 mile stretch of the I-15 reversible lanes, respectively. Figure 51 depicts the type of vehicle being used in the I-15 study and Figure 52 portrays a prototypical command and control system for the automated roadway system. No actual automation demonstrations are underway in California.

The crafting of demonstrations of automation technologies needs to await the results of further research and development work. Until that time it is premature to move forward with any demonstrations within the southland. A possible future demonstration site in the Los Angeles area might be the El Monte Busway on I-10 between El Monte and downtown Los Angeles. This facility has previously been suggested as a possible demonstration site for the roadway powered electric vehicle.

Figure 51
AUTOMATION TECHNOLOGY SYSTEM:
I-15 TEST FACILITY (SAN DIEGO, CA)

PATH

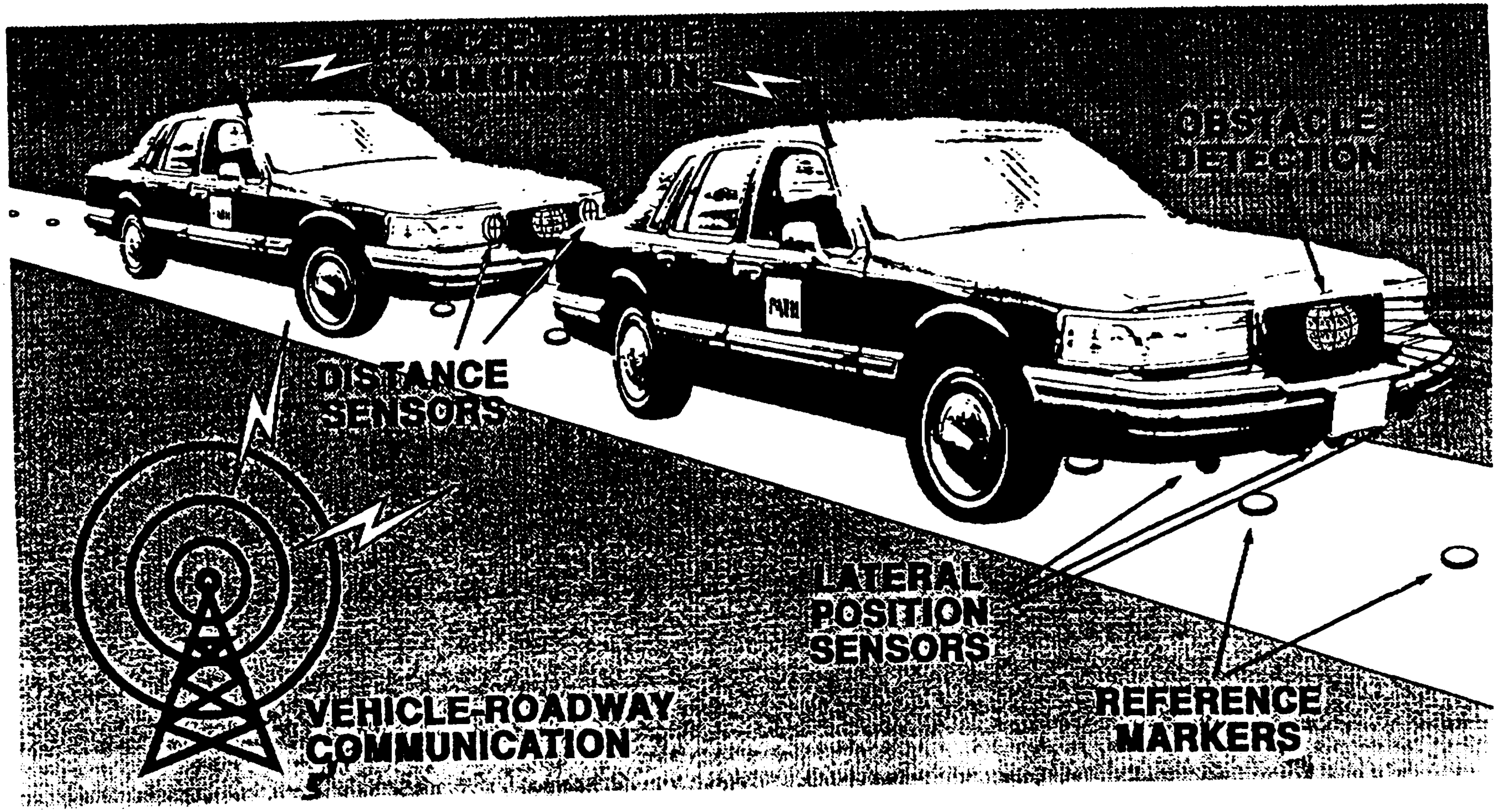
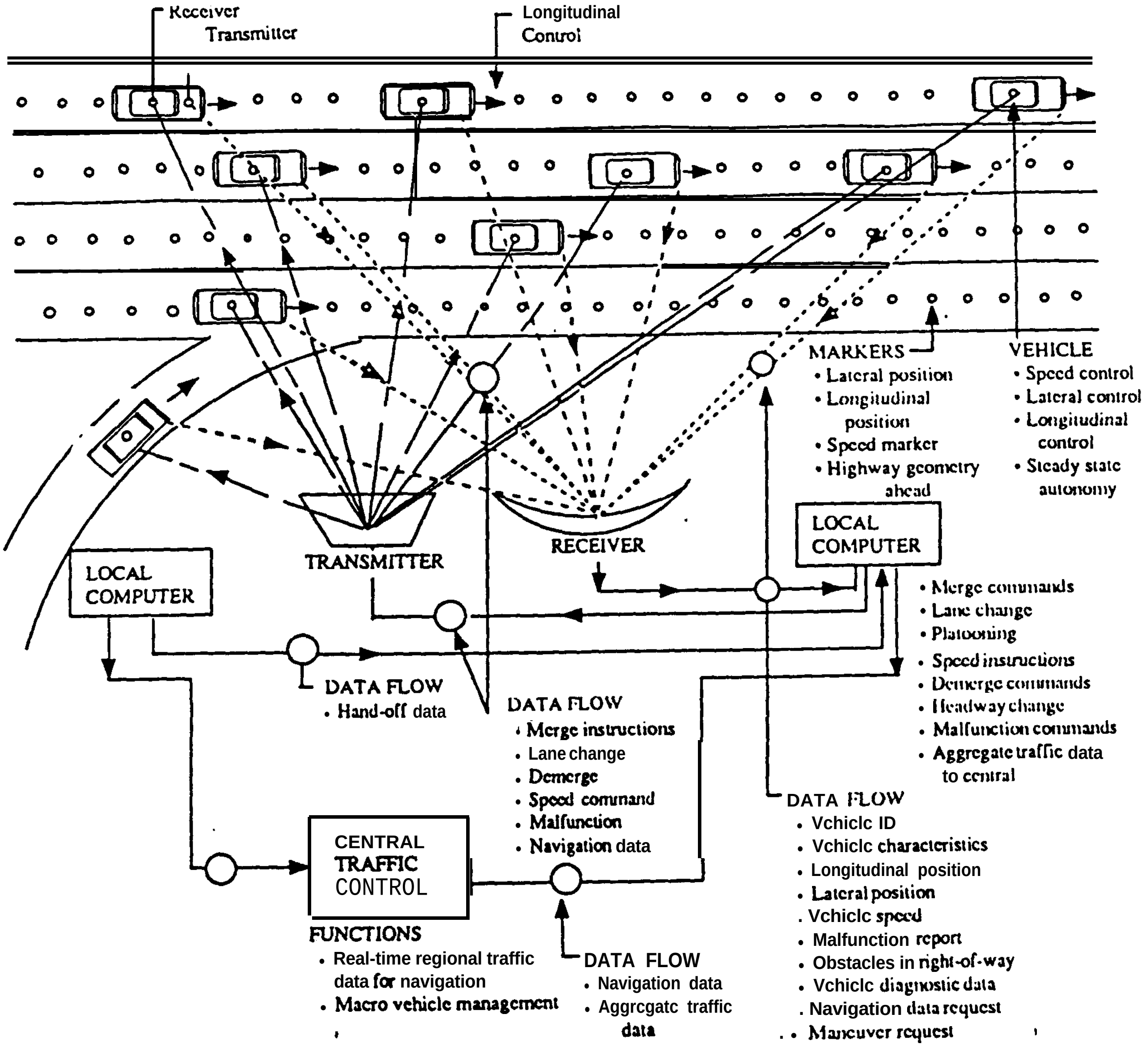


Figure 52

COMMUNICATION, COMMAND
AND CONTROL CONCEPT
FOR HIGHWAY AUTOMATION



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