

# UC Berkeley

## Working Papers

### Title

Aviation System Performance Measures

### Permalink

<https://escholarship.org/uc/item/2xw9204x>

### Author

Gosling, Geoffrey D.

### Publication Date

1999

Institute of Transportation Studies  
University of California at Berkeley

## **Aviation System Performance Measures**

**Geoffrey D. Gosling**

WORKING PAPER  
UCB-ITS-WP-99-1

NATIONAL CENTER OF EXCELLENCE FOR  
**NEXTOR**  
AVIATION OPERATIONS RESEARCH

**NEXTOR Working Paper WP-99-1**

January 1999  
ISSN 0192 4141

## **Preface and Acknowledgments**

This working paper documents research undertaken by the National Center of Excellence for Aviation Operations Research for the California Department of Transportation (Caltrans), under Contract Number 65A0010. Any opinions expressed herein do not necessarily reflect those of the California Department of Transportation.

The author acknowledges the many helpful comments and suggestions received during the course of the research from personnel in the Caltrans Aeronautics Program and New Technology and Research Program.

## Table of Contents

	Page
Preface and Acknowledgments	ii
Table of Contents	iii
List of Tables	iv
Executive Summary	v
1. Introduction	1
Role of the State in the Aviation System	2
The Need for a User Perspective	3
Intermodal Considerations	4
Structure of this Report	6
2. Measuring Transportation System Performance	7
User Perspective	8
Institutional and Legislative Context	8
Sacramento Conference	9
Framework for Transportation System Assessment	12
3. Aviation System Performance - Review of Recent Literature	16
Performance of the National Airspace System	16
National Plan of Integrated Airport Systems	17
State System Plans	20
Performance Measurement Techniques	24
4. Operator Perspectives	27
Delay	27
Cost	29
Facilities	31
Customer Satisfaction	31
5. Traveler and Shipper Perspectives	33
Cost	33
Service Quality	35
Accessibility	37
Customer Satisfaction	38
6. An Economic Perspective	41
Efficiency	42
Competition	43
Contribution to the State Economy	43
Externalities	44
7. Role of the State in Enhancing the Performance of the Aviation System	45
Funding Airport Development	45
Cooperative Airport Planning	46
Regulatory and Legislative Actions	47

**Table of Contents (cont.)**

	Page
7. Role of the State in Enhancing the Performance of the Aviation System (cont.)	
Surface Transportation System	47
Economic Development	48
Implications for Aviation System Performance Measurement	49
8. Proposed Performance Measures	50
Mobility and Accessibility	51
Reliability	57
Cost Effectiveness	57
Economic Well-Being	59
Sustainability	60
Environmental Quality	63
Safety and Security	64
Equity	65
Customer Satisfaction	66
9. Implementing Performance Monitoring	68
Sources of Data	69
Presentation of Performance Measures	70
10. Conclusions	71
References	72

**List of Tables**

Table	Page
ES-1 Proposed Aviation System Performance Measures	vii
2-1 Proposed Performance Measures - California Transportation Plan Update	15
3-1 Arizona Aviation System Performance Measures	21
3-2 Minnesota Aviation System Performance Measures	25

## **Executive Summary**

Within the transportation community, there is a growing recognition of the need to consider decisions addressing future investments in the transportation system from a multimodal perspective. This viewpoint has been given added weight by the passage of the Intermodal Surface Transportation Efficiency Act (ISTEA) in 1991, which not only recognized the importance of viewing the transportation system from an intermodal perspective, but also stressed the need to address the efficiency with which the system meets the transportation needs of its users. This approach was reinforced with the reauthorization of the surface transportation legislation in the 1998 Transportation Equity Act for the 21st Century (TEA-21), which added concepts of fairness in the distribution of resources to those of the efficiency of the transportation system. It is clear that to make investment decisions on a rational multimodal basis, it is necessary to be able to assess the performance of each of the modes in a consistent way, so that resources can be allocated across the modes in a way that maximizes their contribution to the overall performance of the entire transportation system.

Of course, in practice existing programs and institutional arrangements have tended to remain focused on a specific mode, and thus efforts to compare performance across modes, much less to allow this to shape investment decisions, are still in their infancy. However, the California Transportation Commission has embarked on an effort to approach its capital investment decisions from such a perspective, and recent state legislation (Senate Bill 45) requires that all Regional Transportation Plans (RTPs) shall address the coordination of aviation facilities and services with other elements of the transportation system. In addition, the RTPs in any region that contains a primary air carrier airport shall include an airport ground access improvement program. As part of the current update of the California Transportation Plan (CTP), the California Department of Transportation (Caltrans) commenced work on a System Performance Measures module of the CTP, the goals of which are to develop a set of measures to assess the performance of the multi-modal transportation system so as to support informed transportation decision making, and to establish a coordinated and consistent process for performance measurement throughout the state (Caltrans, 1998c).

This report addresses one aspect of that effort -- the definition of performance measures for the aviation system. This system, particularly the investment in airports, navigation aids, and air traffic management infrastructure, exists to serve its users, and indirectly to support the economic activities in which those users engage. Therefore, any attempt to measure the performance of the aviation system must consider the needs of the users and the extent to which the system satisfies those needs. From a broader perspective, the state is also interested in the extent to which the aviation system contributes to and supports the economic development of the state, as well as the adverse environmental impacts that result from aviation activities. Many of the current controversies surrounding major airport expansion or conversion proposals in the state focus not on the benefits to the users or the economy but on the impacts on the local communities or natural environment.

The report examines the range of considerations that arise in measuring transportation system performance, and summarizes the results of a recent conference that addressed performance measures for the state transportation system. It reviews the recent literature on measuring aviation system performance and discusses system performance from the perspectives of the aircraft operator and traveler or shipper, respectively. It then presents a third perspective, that of the effect of the performance of the aviation system on the larger economy, particularly that of California, as well as the impact on the environment. The report then shifts its focus to the state interest in monitoring transportation system performance, and discusses the role of the state in enhancing the performance of the aviation system, and how an effective performance monitoring system can contribute to that role.

Based on these considerations, the report presents a proposed set of aviation system performance measures, and discusses the steps necessary to implement an effective performance monitoring process for the state aviation system, including directions for further study to strengthen the role of performance measures in the development of the state aviation system.

The report identifies 74 potential aviation system performance measures in ten categories corresponding to the system performance outcomes defined in the CTP System Performance Measures module. These are divided into 48 potential measures that address the commercial aviation sector and 26 potential measures that address the general aviation sector, as shown in Table ES-1.

Table ES-1

**Proposed Aviation System Performance Measures**

Commercial Service	General Aviation
<b>Mobility and Accessibility</b>	
<i>Travel Time</i>	
<ul style="list-style-type: none"> <li>• Percent of air trips in markets served by nonstop flights</li> <li>• Percent of air trips in markets without nonstop service but served by connections through an airline hub or one-stop service</li> <li>• Percent of air trips in markets with at least six nonstop, one-stop or connecting flights per day</li> <li>• Number of international destinations served with nonstop flights with daily departures</li> <li>• Number of international destinations served with nonstop flights with at least three weekly departures</li> </ul>	
<i>Delay</i>	
<ul style="list-style-type: none"> <li>• Average delay experienced in traveling to and from the airport, measured as the average difference between actual access/egress highway travel times and free-flow travel times, weighted by the distribution of trip ends</li> <li>• Average delay experienced during the flight, expressed as the difference between actual flight times and scheduled flight times during periods of light traffic</li> </ul>	<ul style="list-style-type: none"> <li>• Average delay experienced in traveling to and from the airport, measured as the average difference between actual access/egress highway travel times and free-flow travel times, weighted by the distribution of based aircraft owner locations</li> <li>• Average delay per flight, estimated from the ratio of annual aircraft operations to the Annual Service Volume of the airport</li> </ul>
<i>Access to Desired Destinations</i>	
<ul style="list-style-type: none"> <li>• Percent of air trips in markets served by three or more carriers with nonstop, one-stop or connecting service</li> <li>• Percent of international departures in markets with at least two carriers</li> <li>• Percent of air trips for which the nearest commercial airport provides direct or connecting air service through one intermediate hub</li> </ul>	<ul style="list-style-type: none"> <li>• Percent of regional/statewide based aircraft at airports with available hangar space</li> <li>• Percent of regional/statewide based aircraft at airports with available tie-down space</li> <li>• Percent of regional/statewide itinerant operations at airports with a control tower</li> <li>• Percent of regional/statewide itinerant operations at airports with an instrument approach capability</li> </ul>



Table ES-1 (cont.)

Commercial Service	General Aviation
<i>Access to Desired Destinations (cont.)</i>	
<ul style="list-style-type: none"> <li>• Percent of air trips for which the nearest commercial airport provides direct jet service to the destination or to an intermediate hub with direct service to the destination</li> <li>• Average additional distance to access the nearest airport with direct air service to the destination, or connecting air service through an intermediate hub when the destination is not served directly, compared to the distance to the nearest commercial airport</li> </ul>	<ul style="list-style-type: none"> <li>• Percent of regional/statewide itinerant operations at airports with approach and runway lighting</li> </ul>
<i>Access to the Airport System</i>	
<ul style="list-style-type: none"> <li>• Percent of air trip ends within 45 minutes highway travel time of the nearest commercial service airport</li> <li>• Percent of air trip ends within 45 minutes highway travel time of the commercial service airport used</li> <li>• Average airport access/egress highway travel times under free-flow travel conditions, weighted by the distribution of trip ends</li> <li>• Percent of air trip ends within 5 miles of stops served by scheduled airport ground transportation services, including rail transit and express airport bus services</li> <li>• Percent of air trip ends in communities served by airport shared-ride van services</li> <li>• Percent of air passenger airport access/egress trips using shared-ride public transportation</li> </ul>	<ul style="list-style-type: none"> <li>• Percent of aircraft owners within 30 minutes of a general aviation airport, under free-flow travel conditions</li> <li>• Percent of population within 30 minutes of a general aviation airport with instrument landing capability, under free-flow travel conditions</li> </ul>
<b>Reliability</b>	
<ul style="list-style-type: none"> <li>• Percent of flights arriving more than 15 minutes late</li> <li>• Percent of flights arriving more than 30 minutes late</li> <li>• Average departure delay per flight</li> </ul>	

Table ES-1 (cont.)

Commercial Service	General Aviation
<b>Reliability (cont.)</b>	
<ul style="list-style-type: none"> <li>Standard deviation of highway airport access/egress travel times, weighted by the distribution of trip ends</li> </ul>	
<b>Cost Effectiveness</b>	
<ul style="list-style-type: none"> <li>Average fare paid per mile for intrastate air trips</li> <li>Average fare paid per mile for air trips <b>from</b> California to domestic destinations outside the state</li> <li>Average fare paid per mile for air trips <b>to</b> California from domestic origins outside the state</li> </ul>	<ul style="list-style-type: none"> <li>Average annual hangar space rental cost</li> <li>Average annual tie-down space rental cost</li> <li>Average cost per gallon paid for aviation gasoline</li> <li>Average cost per gallon paid by general aviation for jet fuel</li> </ul>
<b>Economic Well-Being</b>	
<ul style="list-style-type: none"> <li>Commercial airport productivity in terms of equivalent passengers per dollar of annual operating cost, including airline station costs and annualized cost of capital investments in airport and air traffic control infrastructure</li> </ul>	<ul style="list-style-type: none"> <li>General aviation airport productivity in terms of aircraft operations per dollar of annual operating cost, including annualized cost of capital investments and provision of air traffic control services</li> </ul>
<b>Sustainability</b>	
<ul style="list-style-type: none"> <li>Average percentage of household income spent on commercial air travel</li> <li>Average percentage of gross state product spent on commercial air transportation</li> <li>Average fuel consumption per ton-mile of all commercial flights originating in California</li> <li>Percent of airfield pavement at commercial service airports in California in fair condition, as reported in the FAA Airport Safety Data Program</li> <li>Percent of airfield pavement at commercial service airports in California in poor condition, as reported in the FAA Airport Safety Data Program</li> </ul>	<ul style="list-style-type: none"> <li>Average cost of owning and operating a private aircraft used primarily for personal flying</li> <li>Average cost of owning and operating a private aircraft used primarily for business purposes</li> <li>Percent of airfield pavement at general aviation airports in California in fair condition, as reported in the FAA Airport Safety Data Program</li> <li>Percent of airfield pavement at general aviation airports in California in poor condition, as reported in the FAA Airport Safety Data Program</li> </ul>

Table ES-1 (cont.)

Commercial Service	General Aviation
<b>Environmental Quality</b>	
<ul style="list-style-type: none"> <li>• Number of households exposed to aircraft noise levels exceeding 65 dB California Noise Equivalent Level (CNEL) near commercial service airports</li> <li>• Number of households exposed to aircraft noise levels exceeding 60 dB CNEL near commercial service airports</li> <li>• Tons per year of carbon monoxide (CO) generated by aircraft operations at commercial service airports in the state</li> <li>• Tons per year of volatile organic compounds (VOC) generated by aircraft operations at commercial service airports in the state</li> <li>• Tons per year of nitrogen oxides (NOx) generated by aircraft operations at commercial service airports in the state</li> <li>• Tons per year of sulfur dioxide (SO<sub>2</sub>) generated by aircraft operations at commercial service airports in the state</li> <li>• Tons per year of greenhouse gases generated by commercial aircraft operations departing from airports in the state</li> <li>• Vehicle-miles of travel per year by automobiles making trips to and from commercial service airports</li> <li>• Vehicle-miles of travel per year by diesel or gasoline powered buses or passenger vans making trips to and from commercial service airports</li> <li>• Vehicle-miles of travel per year by low-emission buses or passenger vans making trips to and from commercial service airports</li> <li>• Vehicle-miles of travel per year by trucks making trips to and from commercial service airports</li> </ul>	<ul style="list-style-type: none"> <li>• Number of households exposed to aircraft noise levels exceeding 65 dB CNEL near general aviation airports</li> <li>• Number of households exposed to aircraft noise levels exceeding 60 dB CNEL near general aviation airports</li> <li>• Tons per year of criteria pollutants (CO, NOx, VOC and SO<sub>2</sub>) generated by aircraft operations at general aviation airports in the state</li> <li>• Vehicle-miles of travel per year by automobiles making trips to and from general aviation airports</li> </ul>

Table ES-1 (cont.)

Commercial Service	General Aviation
<b>Safety and Security</b>	
<ul style="list-style-type: none"> <li>• Accident rate on commercial airline flights, expressed as the moving average five-year probability of being killed on a commercial flight taken at random from a California airport</li> </ul>	<ul style="list-style-type: none"> <li>• Accident rate to general aviation operations, expressed as the number of fatal accidents per flight hour</li> </ul>
<b>Equity</b>	
<ul style="list-style-type: none"> <li>• Ten-year moving average of federal Airport Improvement Fund grants at each commercial service airport, expressed as a ratio of the enplaned passenger traffic at the airport</li> <li>• Ten-year moving average of aircraft noise mitigation program expenditures by airport authorities in communities adjacent to the airport, expressed as a ratio of the number of households within the 60 dB CNEL contour</li> <li>• Ten-year moving average of airport ground access/egress traffic mitigation program expenditures by airport authorities, expressed as a ratio of the enplaned passenger traffic at the airport</li> </ul>	<ul style="list-style-type: none"> <li>• Ten-year moving average of state airport development grants to general aviation airports in each county, expressed as a ratio of the number of registered aircraft owners with addresses in the county</li> <li>• Ten-year moving average of state airport development grants to general aviation airports in each county, expressed as a ratio of the number of based aircraft at airports in the county</li> </ul>
<b>Customer Satisfaction</b>	
<ul style="list-style-type: none"> <li>• Air passenger satisfaction index</li> <li>• Air cargo shipper satisfaction index</li> </ul>	<ul style="list-style-type: none"> <li>• Aircraft owner satisfaction index</li> </ul>

## 1. Introduction

There is a growing interest in the transportation community in developing a more formal and coherent approach to measuring transportation system performance. This appears to be largely driven by two separate, but interrelated, concerns. The first is a desire to improve the effectiveness with which public investment decisions in the transportation sector are being made. This of course brings up the immediate question of what is meant by effectiveness, and how this can be measured. It is a natural step to then ask how well the transportation system is performing, and how any proposed investment would contribute to improving that performance. The second concern arises from a desire to improve the accountability of governmental programs, and to measure the performance of government agencies. Since the purpose of most transportation agencies is to develop, maintain or operate transportation systems, the measurement of the performance of those systems is one obvious way to assess the effectiveness of the responsible agencies. In California, the recent passage of Senate Bill 45 has shifted decision making for most local transportation projects to the regions. The trend to devolve investment decisions to lower levels of government has created a need to develop system performance measures that can be used by the state to monitor the effectiveness of decisions made at the local level.

Another important factor contributing to the increased attention being given to this topic is the growing recognition of the need to view the transportation system from a multimodal perspective. This viewpoint has been given added weight by the passage of the Intermodal Surface Transportation Efficiency Act in 1991, which, as its title suggests, recognized not only the importance of viewing the transportation system from an intermodal perspective, but also stressed the need to address the efficiency with which the system meets the transportation needs of its users. It quickly became apparent that to make investment decisions on a rational multimodal basis, one needs to be able to assess the performance of each of the modes in a consistent way, so that resources can be allocated across the modes in a way that maximizes their contribution to the overall performance of the entire transportation system. This approach was reinforced with the reauthorization of the surface transportation legislation in the 1998 Transportation Equity Act for the 21st Century (TEA-21), which added concepts of fairness in the distribution of resources to those of the efficiency of the transportation system.

Of course, in practice, existing programs and institutional arrangements have tended to remain focused on specific modes, and thus efforts to compare performance across modes, much less to allow this to shape investment decisions, are still in their infancy. However, the California Transportation Commission (CTC) has embarked on an effort to approach its capital investment decisions from such a perspective, and the California Business, Transportation and Housing Agency has led an effort to initiate statewide transportation system performance measurement. As part of the current update of the California Transportation Plan (CTP), the California Department of Transportation (Caltrans) commenced work on a System Performance module of the CTP (Caltrans, 1997; Caltrans, 1998c), the goals of which are:

- *To develop indicators/measures to assess the performance of California's multi-modal transportation system, to support informed transportation decisions by public officials, operators, service providers, and system users.*
- *To establish a coordinated and cooperative process for consistent performance measurement throughout California.*

This paper addresses one component of that effort -- defining performance measures for the aviation system.

### **Role of the State in the Aviation System**

In contrast to its role in the surface transportation system, the role of the state in the aviation system is not well understood by many in the air transportation sector, and even fewer outside of it. However, most states, and California in particular, have three critical roles. The first is the preparation of a state aviation system plan, that forms a key component of the national aviation planning process (FAA, 1989). A central function of the California Aviation System Plan (CASP) is to identify the aviation infrastructure requirements to meet the future needs of the state. The increasing emphasis on multimodal transportation planning gives this plan an added importance as the link between the aviation planning process and the planning process for the rest of the transportation system at the state level. The second role includes issuing airport operating permits and performing related safety inspections, coordinating land use planning by local governments, establishing and enforcing environmental regulations, including preparation of air quality conformance implementation plans, and conducting aviation education and awareness programs.

The third role is the allocation of those funds for aviation infrastructure investments that are under the control of the state. In California, as in some other states, some aviation tax revenues, predominantly from the sale of aviation gasoline, are used to fund the development of the state airport system. Because of the source of the funding, this is primarily restricted to general aviation airports. However, in recent years the Federal Aviation Administration (FAA) has been experimenting with a state block grant program, in which *federal* airport development funds are provided to the states for allocation to airports, rather than distributed directly to the airports themselves. While California is not currently participating in this program, the FAA plans to extend it in the future and it appears quite likely that within a few years, all discretionary federal funding for general aviation airports will be distributed in this way.

Because of these trends, the CTC has embarked on a process to incorporate all airport capital improvement programs within the state into the CASP Capital Improvement Program (CIP). This has required the regional transportation planning agencies to include all planned airport improvement projects within their regions, whether funded by the state or not, in their Regional CIP that they submit to Caltrans as input to the statewide CIP (Caltrans, 1998b). This process is conducted in parallel to the development of Regional Transportation Improvement Programs and the State Transportation Improvement Program that include capital improvement needs for all surface modes, and serves to place aviation investment decisions in the context of the wider transportation system, and in turn gives added emphasis to the need to develop aviation system performance measures that can support this process.

### **The Need for a User Perspective**

The aviation system, particularly the investment in airports, navigation aids, and air traffic management infrastructure, exists to serve its users, and indirectly to support the economic activities in which those users engage. Therefore any attempt to measure the performance of the aviation system must consider the needs of the users and the extent to which the system satisfies those needs. From a broader perspective, the state is also interested in the extent to which the aviation system contributes to and supports the economic development of the state.

The aviation system serves a diverse set of users, that can be broadly grouped into three categories:

- providers of air transportation services and other aircraft operators;
- air passengers and air cargo shippers;
- businesses that depend directly and indirectly on air transportation services.

Each of these user groups tend to approach the way they view the performance of the aviation system from somewhat different perspectives. For example, airlines may be very concerned about air traffic delays, because they impose a very real cost on their operations. Many air passengers, on the other hand, may be much more concerned about obtaining lower air fares than the delays they experience, and will willingly select an airline that has a lower on-time performance record if it also offers lower fares. These two groups may also view delays in very different ways. Airlines will be concerned about delays that cause flights to take longer than they otherwise would, since this translates into greater fuel burn, higher crew costs, and lower aircraft utilization, even if the flights still arrive on time due to adequate provision in the schedule to allow for delays. The passengers may be quite unaware of these delays, provided the flight arrives on time. However, a late arrival may cause significant disruption to their personal travel plans, involving missed connections, late arrival at meetings, or simply keeping greeters waiting at the airport. Of course, each group is ultimately affected by any delays in the system, whether apparent or not, since these delays add to the total costs of providing air transportation, which must be borne by the end users.

For air passengers and air cargo shippers, the flight is only one part of the total trip or goods movement. Thus for these users, the ground access portion of the trip or movement will be more important in their perception of the overall performance of the system than it will be for the airlines.

### **Intermodal Considerations**

The need to consider the performance of the aviation system within the context of the broader transportation system arises from two concerns. The first is that a passenger trip or cargo shipment rarely only involves air transportation. Air passengers desire to travel not from airport to airport, but from their trip origin to their final destination. This typically involves some surface travel at either end of the trip. For many trips to destinations within about 500 miles of the origin,



surface travel may be a viable alternative to air travel. The choice between air or surface modes will obviously depend on the performance of the alternative modes. In California, this is likely to become a crucial issue as the state continues to consider whether to develop a high-speed intercity rail system. Even where the major part of a trip is performed by air, the choice of which airport to begin and end the air trip depends on the service offered at alternative airports and the relative ability to access these airports by surface modes. This can be a particularly critical issue where one of both ends of the trip are located in communities at some distance from a major hub airport (Gosling, 1994).

Similar considerations apply to the shipment of commodities, for which air cargo may be a viable alternative. Not only must most air cargo shipments be transported to and from the airport by truck, but the option of moving the shipment entirely by surface modes will typically extend over greater distances than would normally be considered by most passengers. Indeed, the integrated air cargo carriers, such as FedEx and UPS, move some shipments entirely by truck over considerable distances where justified by the volume or as a supplement to the available capacity on their flights. Even for transoceanic shipments, there will be some commodities for which the decision whether to use air or sea will depend on how efficiently the goods can be moved to the port, loaded on the ship, transported to the destination port, unloaded and delivered to the final destination. A change in air freight rates, or in port handling or sailing times, may shift entire categories of shipment from one mode to the other.

The second concern is that capital invested in transportation infrastructure should produce a similar return in improved efficiency and productivity across all modes, although the extent to which this is achieved is often concealed by the fiscal and legislative procedures for generating and allocating the investment funds, which in the United States have historically treated aviation and surface transportation as entirely separate issues. However, the simple fact is that resources spent on airport development or air traffic control infrastructure are no longer available to expand the highway system or build new transit lines, and *vice versa*. Thus efforts to measure the performance of the different modes should help inform decisions about appropriate levels of investment and the associated revenue streams to support those.

## **Structure of this Report**

The remainder of this report addresses each of these issues in more detail. Chapter 2 discusses a range of considerations that arise in measuring transportation system performance, and summarizes the results of a recent conference that addressed performance measures for the state transportation system. Chapter 3 reviews the recent literature of measuring the aviation system performance. The following two chapters then explore system performance from the perspectives of the operator and traveler or shipper respectively. Chapter 6 provides a third perspective, that of the effect of the performance of the aviation system on the larger economy, particularly that of California and its regions. The next three chapters then shift the focus to the state interest in monitoring system performance. Chapter 7 addresses the role of the state in enhancing the performance of the aviation system, and discusses how an effective performance monitoring system can contribute to that role. Chapter 8 presents a proposed initial set of aviation system performance measures, and Chapter 9 explores the steps necessary to implement an effective performance monitoring process for the state aviation system. Finally, Chapter 10 presents the conclusions that can be drawn from the research performed to date, and suggests directions for further study to strengthen the role of performance measures in the development of the state aviation system.

## **2. Measuring Transportation System Performance**

Throughout history the performance of the transportation system has been both a source of concern as well as a stimulus to progress and economic growth. Steadily increasing speed and reducing costs not only led to increased interaction and trade in ideas and commodities, but fostered the specialization that has become the hallmark of the modern economy. At the same time, maintaining the physical infrastructure from the wear and tear of use and the ravages of the environment has required continual attention, while increasing demands on the transportation system generated by economic growth and an ever increasing population have brought problems of congestion and inefficient facilities and services. Each advance in transportation technology, from paved roads to canals, from the railway to the automobile and diesel truck, has initially provided quantum improvement in speed or cost, or both, followed later by congestion and deterioration of the physical facilities as the growth in use stimulated by that improvement has outpaced the provision of infrastructure.

Nowhere is this more clearly illustrated than by the evolution of the air transportation system over the past seventy years, and particularly the past four decades since the introduction of jet aircraft into airline service. Air travel has not only reduced long distance travel times from days to hours, but has become so cheap and ubiquitous that millions of people routinely fly thousands of miles for a vacation, while the ability to rapidly move personnel around the world has allowed businesses to evolve into global enterprises. Yet the steadily rising passenger and air freight volumes are threatening to overwhelm airport capacity and an outmoded air traffic control system, while recent advances in aircraft technology cannot be effectively utilized for lack of appropriate infrastructure.

This discussion suggests that the measurement of transportation system performance has been an issue of concern for a long time. In one sense this is true. Certainly such attributes as the speed and other operating characteristics of different modes have been extensively documented, together with attempts to understand their cost structure. However, concern with measuring the performance of an entire transportation system is relatively recent.

## **User Perspective**

With the creation and deployment of each new transportation technology has come an associated set of institutions that have evolved to build and operate the systems required to support the technology. These institutions naturally view their role as producers of transportation services, and their performance in terms of the amount of transportation service provided. Thus a transit operator might measure the number of revenue-miles of bus service, while a highway authority might consider the number of lane-miles in service or the vehicle-miles of travel on the system. Airport authorities usually monitor the number of aircraft operations or the number of passengers passing through the terminal, while airlines tend to measure their output in terms of either the number of seat-miles or number of passenger-miles flown.

While these are all valid measures of output from the perspective of the producer of transportation services, the user is typically more interested in viewing the performance of the system in terms of its success at delivering those services. Thus the performance of a transit operator might be viewed by the user in terms of the percentage of its bus operating hours that were within a specified number of minutes of the published schedule, while the performance of a highway authority might be expressed in terms of the proportion of the lane-miles under its jurisdiction that are at various levels of service during the peak hour. The airline industry has come to place great importance on on-time performance, and indeed the U.S. Department of Transportation has established an extensive and sophisticated reporting system to compare this performance over time and across carriers. Since transportation is generally an intermediate good that is valued not for its own sake, but because it allows other activities to occur, it is important that measures of system performance maintain the perspective of the user.

## **Institutional and Legislative Context**

Efforts to measure transportation system performance began to receive increased attention nationally with the passage of the Intermodal Surface Transportation Efficiency Act in 1991, partly due to the emphasis on intermodal coordination and partly to the requirement that state departments of transportation establish transportation management systems covering pavements, bridges, safety, congestion, public transportation and intermodal transportation. These management systems were intended to monitor the performance and condition of the system, and support decision making.

Although with one exception, these were later made optional, many states and metropolitan areas have continued with the implementation.

In 1993, the federal Government Performance and Results Act was passed with the goal of linking the strategic goals of federal agencies, including the Department of Transportation, to outcome based performance measures. This has resulted in an on-going effort in the Department of Transportation and its modal agencies to develop strategic plans and define and monitor appropriate performance measures. In California, the recently signed Senate Bill 45 requires "objective criteria for measuring system performance" as part of the state transportation improvement program. However as early as 1993, the California Transportation Plan (CTP) called for the development of performance assessment at the system levels. The current update of the CTP has designated this issue as one of the two priority areas of emphasis, and Caltrans has established a Transportation Assessment Steering Committee, in addition to the Policy Advisory Committee for the CTP as a whole.

### **Sacramento Conference**

In an attempt to better understand the role of transportation performance measures in the future development and operation of the state's transportation system, and to provide a focus for the work on the CTP update, the California Department of Transportation sponsored a two-day conference on *Performance Measures for California Transportation System Users and Investors* in October 1997 at the Sacramento Convention Center. The conference was organized by the UCLA Extension Public Policy Program in collaboration with the University of California Transportation Center, and brought together nearly two hundred participants representing state, regional and local government agencies, as well as the private sector and others interested in the future use of performance measures in the state.

The goals of the conference were stated as follows (Hill, 1997):

- To build a common frame of knowledge and language for addressing the process of discovering, developing and implementing a transportation performance measure system for California.
- To learn first hand about experience with the process of developing and implementing transportation performance measures at the national, state and regional levels from experts in the field.

- To understand how performance measures can improve policy formulation and decision making in the complex politically-charged world of transportation resource allocation.
- To help Caltrans develop a set of intermodal system-level transportation performance indicators that will become a part of the ongoing planning, management, and policy making process for transportation in California.

In order to accomplish these goals, speakers examined the past evolution of the use of transportation performance measures, the current legislative and institutional context, the uses to which performance measures have been or could be put, and prior experience in developing and implementing transportation performance measures at the national, state and regional levels. In the course of the presentations and discussions, several important issues emerged, on which there appeared to be a broad consensus.

One was the need to focus on *outcomes* rather than *outputs*, where *outcomes* address the consequences of the transportation facilities and services provided, and *outputs* address the transportation itself. Thus improving access to job markets or reducing transportation emissions are outcomes, whereas improving freeway level of service or increasing transit ridership are outputs. While output measures focus on the *efficiency* of the system performance, including both the production of transportation facilities and services as well as the level of service provided, outcome measures focus on the *effectiveness* of the system, in terms of the extent to which the users are able to achieve their goals. Outcome measures include such factors as accessibility, reliability, and externalities. It was noted that performance measures had evolved over time from a framework based on product or service standards to an orientation on providing customer satisfaction in product or service delivery. As part of this, there has been a shift in thinking toward viewing the user as a customer, rather than simply a participant in the system.

A second issue was the role of performance measures as decision tools, rather than decision rules. It was suggested that transportation performance measures should inform policy and funding debates by providing useful, comprehensive and relevant information, and not be used to allocate resources in a mechanistic way. It was pointed out that many important aspects of transportation system performance cannot be easily quantified, but should still be included in the decision process. While it was agreed that performance measures should not attempt to replace politics, it was

suggested that they could help provide a balance between political and technical considerations in decision making and provide a means to hold project sponsors accountable.

A third issue was the importance of the process of developing and implementing performance measures. Experience from other states and regions presented at the conference showed that the successful development of performance measures involved a difficult consensus building process that later proved invaluable to their acceptance and implementation. Several speakers noted that the development of useful measures should be an on-going process, as the initial efforts may not turn out to provide useful information, or may be found to be too difficult to measure. It may also be necessary to adapt the measures to changing needs. The experience of the Capital District Transportation Committee in Albany, New York, over a three and a half year process examining causality and clarifying values resulted in a recognition of the assets of the region, as well as a broad set of performance measures that addressed such higher values as access to choices, flexibility, land use, and environmental impact. The importance of involving political leaders and stakeholders in the process of developing the performance measures was raised by several speakers, in order to ensure that the measures are not ignored or misused. Other speakers stressed the importance of including the users and customers of the transportation system in the process. It was noted that user expectations vary with mode, route and location, and that a sophisticated set of performance measures will be needed to provide the detailed information desired by users. This will in turn require proactive efforts to seek out and involve the users.

While there was broad agreement on the foregoing issues, the conference identified other issues that were far from clear, and would need further careful study. One of the larger such questions was whether it would prove feasible to develop a consistent set of performance measures that could meet the needs of the various agencies and levels of government in the state. It was suggested that while they would need to be consistent in broad terms, the measures at the local level might differ in specifics from those at the state level, and might vary across regions, reflecting the differences between the rural and urban regions, as well as variations between the metropolitan regions. Concern was also expressed about the potential increase in data collection and reporting requirements at the regional and local levels to support the implementation of performance measures at the state level. It was noted that improved guidance and coordination of data collection could help avoid duplication of effort at different levels of government.

It was recognized that a very real tension exists between the desire for a simple set of measures that do not involve much additional data collection, and the desire for measures that adequately reflect the range of outcomes of concern, while retaining flexibility and adaptability. Several speakers cautioned that careful thought needs to be given to the source of the data that will be needed to implement any proposed measures, and how it will be collected and managed. Another important tradeoff that was recognized was that between generic measures that could be applied across modes and the need for measures that reflect the particular circumstances of each mode.

### **Framework for Transportation System Assessment**

While the work of the California Transportation Assessment Steering Committee (TASC) to define a framework of transportation system performance measures for the CTP is still in progress, the broad terms of that framework have emerged. A final report on the first phase of the development of the CTP system performance measures (Caltrans, 1998c) recognizes that effective performance measures must flow from a recognition of policy goals and objectives. Not only is it necessary to be able to monitor how well the policy objectives are being achieved, but the design of appropriate measures requires an understanding of why it is being measured.

The 1993 CTP (Caltrans, 1995) identified a number of strategies under three broad policies, that require transportation decisions to be made in a way that will:

1. Promote the economic vitality of California by providing for flexibility in choice and mobility of people, goods, services and information.
2. Provide all Californians with a safe, convenient, reliable transportation system.
3. Protect the environment and promote energy efficiency while improving mobility.

Within this framework the 1993 CTP proposed the following system performance objectives:

#### **Economic Vitality**

- Reduced travel time including intermodal transfers
- Reduced goods distribution costs per ton-mile
- Increased flow of goods to and through California airports, seaports, and manufacturing facilities



### **Safety & Security**

- Reduced accident and fatality rates per person-mile
- Increased user safety and security on and around transportation facilities

### **Mobility with System Efficiency and Cost Effectiveness**

- Reduced life-cycle costs of transportation facilities
- Increased travel options, including back-up systems, available in each corridor
- Increased housing densities and mixed land uses around public transit stations.

It is clear that these objectives give a stronger emphasis to outputs over outcomes, and are largely oriented to the surface transportation system, although the role of airports in goods movement is acknowledged, and several of the objectives can be applied to aviation facilities.

The TASC has adopted the following criteria for developing performance measures/indicators (Caltrans, 1998c):

- Whenever possible, use existing data sources and conform to existing performance activities at California's regional transportation planning organizations
- Measures/indicators must be easy to use and be simple to understand
- Measures/indicators, to the greatest extent possible, should be measurable across all modes.

It has also identified a set of desirable outcomes in two categories:

### **Effectiveness & Efficiency**

- Mobility/Accessibility - reaching desired destinations with relative ease within a reasonable time, at a reasonable cost with reasonable choices
- Reliability - providing reasonable and dependable levels of service by mode
- Cost-Effectiveness - maximizing the current and future benefits from public and private transportation investments
- Customer Satisfaction - providing transportation choices that are safe, convenient, affordable, comfortable and meet customer needs
- Economic Well Being - contributing to California's economic growth

## **Responsibility**

- Sustainability - preserving the transportation system while meeting the needs of the present without compromising the ability of future generations to meet their own needs
- Environmental Quality - helping to maintain and enhance the quality of the natural and human environment
- Safety & Security - minimizing the risk of death, injury, or property loss
- Equity - fair distribution of benefits and burdens.

For each of these outcomes, an initial set of performance indicators has been proposed, as shown in Table 2-1. These measures are intended to reflect system, program and project performance outcomes, and have been selected for use in:

- monitoring and reporting overall system performance
- estimating the performance impacts of programs
- estimating the performance repercussions of large transportation projects.

These have been defined at a very abstract level, with little attention thus far to how they can provide meaningful comparisons across modes, or indeed meet the goal of measuring the effectiveness of actions to improve the transportation system. For example, simply measuring the travel time and lost time as a measure of mobility ignores the costs of providing the facilities or implementing policies to affect this indicator. While benefit/cost calculations can be helpful at the level of individual project decisions, it is less clear how useful they are at the system level. While the costs of providing transportation services can be determined relatively easily (although appropriate treatment of private costs, such as vehicle operation, can be problematical), estimating benefits is an entirely different matter. Similarly, while the share of transportation related final demand in the gross regional product may be an interesting statistic in own right, it is less clear what the policy implications are if it goes up or down. Does an increase suggest that transportation costs have increased, diverting resources into the transportation sector and slowing economic growth, or does it suggest that new transportation opportunities have emerged that have stimulated economic growth through a greater reliance on the transportation system? It is clear that much further work needs to be done to refine these indications and integrate them into the policy and decision making process.

Table 2-1  
**Proposed Performance Measures**  
California Transportation Plan Update

System Performance Outcomes	Candidate Performance Measures
<b>Effectiveness and Efficiency</b>	
Mobility / Accessibility	Travel time; Delay (lost time); Access to desired locations; Access to the transportation system
Reliability	Standard deviation of average trip time
Cost-Effectiveness	Customer satisfaction index
Customer Satisfaction	User opinion survey
Economic Well Being	Share of transportation final demand in gross regional or state product
<b>Responsibility</b>	
Sustainability	Household transportation costs
Environmental Quality	Conformity / compliance; Livability
Safety and Security	Accidents rates; Crime rates
Equity	Income group share of mobility benefits

### **3. Aviation System Performance - Review of Recent Literature**

In spite of the increased attention being given to measuring the performance of the transportation system generally, the aviation system has thus far received fairly limited attention in the literature.

#### **Performance of the National Airspace System**

A recent study by the MITRE Corporation (Bolczak, *et al.*, 1997) documents efforts by the Federal Aviation Administration (FAA) to develop a system of performance metrics to enable it to allocate scarce resources where they will produce the most benefits, to continue to improve the services offered by the air traffic management (ATM) system, and to respond to the requirements of the Government Performance and Results Act of 1993. As noted above, this legislation requires federal government agencies to develop strategic and annual plans, long and short term goals, and metrics for measuring progress toward those goals.

The four categories of system performance indicators identified in the MITRE study were further expanded and refined in a subsequent FAA Performance Plan (FAA, 1998), which identifies eight performance outcomes:

- increase system safety
- decrease system delays
- increase system flexibility
- increase system predictability
- increase user access
- improve service delivery by increasing the availability of critical systems
- increase productivity
- create a model work environment.

The first five of these outcomes address the performance of the National Airspace System (NAS) from the perspective of its users, while the last three address the performance of the FAA in delivering ATM services. Within each of these eight areas, the FAA has defined a set of performance targets and measures.

Safety measures address both operational errors that occur when aircraft are allowed to violate established separation standards, as well as operational deviations that occur when aircraft

are allowed to penetrate airspace that has not been pre-coordinated for that aircraft's use. Delay measures address the time required to complete an operation beyond that planned or expected by the users of the system. Flexibility measures address the ability of the system to meet changing user needs and to permit users to adapt their operations to changing conditions. Predictability measures address the variation in the operation of the ATM system experienced by the users. User access measures address the ability of users to obtain air traffic control (ATC) services when needed, as well as the availability of the system resources and quality and level of service provided.

Delay has of course been recognized as an important measure of aviation system performance for a long time (Geisinger, 1989) and has been the focus of on-going efforts to enhance the capacity of the system (FAA, 1997b), although until recently the various efforts to monitor delays on an on-going basis have tended to result in a rather confused situation. This new approach of linking delays to expectations has some obvious drawbacks. While it may appear to reflect customer orientation, it is open to the problem that as long as users expect to experience heavy delays, these are not included in the indicator. However, they still impose very large costs on the system.

The flexibility with which national airspace users can operate within the system is currently constrained by a system of preferred routes that have been established for many of the most heavily traveled routes in the system, in order to reduce conflicts in congested airspace. The FAA flexibility performance measures will address both the amount of extra flight distance involved in using the preferred routes, as well as the proportion of flight segments flown off the preferred routes.

### **National Plan of Integrated Airport Systems**

The National Plan of Integrated Airport Systems (NPIAS) is prepared by the Federal Aviation Administration to identify airports that are eligible to receive grants under the Airport Improvement Program, and to estimate the future airport development costs that are eligible for federal funding under the AIP over the subsequent five-year period. The most recent update of the NPIAS was published in April 1995 (FAA, 1995) covering the period 1993 to 1997, and includes a section on the condition and performance of the airport system, addressing six aspects:

- Capacity

- Safety
- Aircraft Noise
- Pavement Condition
- Accessibility
- Financial Performance.

The treatment of each of these aspects varies in level of detail, reflecting the varying attention that it has received in past studies and the availability of comparable data. Aircraft delay is routinely tracked by both the FAA and the U.S. Department of Transportation. The NPIAS considers an airport to be severely congested when average delays exceed 9 minutes per operation. In 1992, seven airports were in this category, and this was expected to increase to 17 airports by 2002 if no new runways were constructed at those airports. The average delay per aircraft operation systemwide was estimated to be 7.1 minutes in 1992, and projected to increase to between 7.7 and 8.4 minutes by 2002.

The NPIAS notes the generally declining trend in aviation accident rates and states that it has not been possible to develop a statistically significant relationship between safety and airport capital investment levels, although it suggests that an increased emphasis that was given to the adequacy of airport marking, lighting and signage in airport inspections beginning in 1991 may have contributed to the subsequent reduction in the rate of runway incursions.

As of January 1993, 208 airports were participating in airport noise measurement and reduction programs under Part 150 of the Federal Aviation Regulations, of which 155 had Noise Exposure Maps in compliance with the requirements of the program and 135 had approved Airport Noise Compatibility Programs. The population exposed to high noise levels (presumably levels above 65 dB Day-Night Level) was reported as declining from about 7 million in 1975 to about 2.4 million by 1992. Due principally to the phase-out of Stage 2 aircraft, this was projected to decline to about 0.4 million by 2000.

Pavement condition information is collected as part of the FAA annual inspection of public-use airports. Runway pavements are classified as good, fair or poor, depending on the extent of unsealed cracks and joints, surface and edge spalling, and vegetation growing through cracks and joints. In 1993 some 68 per cent of all runways at NPIAS airports were rated good and only 7 per cent were rated poor. Runways at commercial service airports were in better

condition, with only 3 per cent rated poor. This represents an improvement in pavement condition over 1986.

The NPIAS measures airport accessibility in terms of the percentage of the population residing within 20 miles of a NPIAS airport. Using 1990 census data, there is a commercial service airport within 20 miles of 70 per cent of the population, while 98 per cent of the population live within 20 miles of some category of airport included in the NPIAS. Of course, the level of air service available at these commercial service airports varies widely, as does the use of air travel across the population. The 1993-1997 NPIAS also presents data for the distribution of air passenger origins and destinations with respect to travel time to the airport by highway and transit for three large metropolitan areas. Not surprisingly, a much higher proportion of air passengers can reach the airport by highway in a given time than by transit. However, the source of the data is not cited and it is unclear how transit is defined. Public transportation services at large airports typically include a range of public and private services, including door-to-door shared-ride vans and express buses to hotels and remote parking facilities. For many of these services, travel time estimates need to reflect service frequency, access time to the stop used, and any en-route stops or circuitry to pick up other passengers. On the other hand, there are cost differences between different access modes that may make some public modes appear much more attractive to the traveller than is suggested by a simplistic comparison of travel times.

Financial information for different categories of airport was estimated from the results of a survey of airport revenues and expenditures conducted by the American Association of Airport Executives. Survey responses were obtained from 196 airports, including 81 per cent of the large, medium and small hub airports. The data appear to suggest that expenditures exceed revenues for most categories of airport, although the results are distorted by the inclusion by some airports of construction costs rather than debt service while others included depreciation as an operating cost. Overall, in 1992 the 529 commercial service airports were estimated to have incurred capital expenditures of \$4.8 billion and operating expenditures of \$3.9 billion, and had revenues of \$8.6 billion, including federal and state grants. The 2,932 reliever and general aviation airports included in the NPIAS were estimated to have incurred capital expenditures of \$601 million and operating expenditures of \$420 million, and had revenues of \$1.05 billion,

including \$487 million in grants. Since it is unclear whether the apparent shortfall in revenue at commercial service airports is an artefact of the survey methodology or the accounting conventions used by the airports, and there is no attempt in the NPIAS to link the financial data to any operational performance data, it is not clear what useful conclusions can be drawn from this information. It is evident that the AIP grants play a major role in funding capital development, particularly at smaller airports. However, whether these airports would be able to fund their capital development needs some other way if the AIP funds were not available, or even whether they would incur those development costs in the first place, cannot be determined from the information in the NPIAS.

### **State System Plans**

A number of states have attempted to incorporate system performance measures into the state aviation system planning. The following sections discuss two of these, which serve as examples of the various approaches adopted.

#### Arizona

The 1995 Arizona State Aviation Needs Study (Arizona DOT, 1995) was based upon the application of performance measures for evaluating alternative scenarios. The study adopted fourteen performance measures, divided into three categories:

- facility performance measures
- service level performance measures
- economic performance measures.

The full list of performance measures is given in Table 3-1. A prior study (Arizona DOT, 1990) developed a more extensive set of 27 separate measures, tied directly to program goals.

The six facility performance measures reflect the extent to which the airports in the state conform to relevant planning and design standards, meet the needs of their users, and impact surrounding communities. However, the way the measures are defined illustrate some of the difficulties of developing meaningful performance measures. For example, system performance measure 4 counts the number of airports that generate noise contours greater than 65 decibels Day-Night Level (DNL) that extend off the airport property. There is no distinction between an airport



Table 3-1  
**Arizona Aviation System Performance Measures**

---

**Facility Performance Measures**

1. The extent to which system airports meet Arizona DOT Transportation Board minimum aviation development and planning standards
2. The number of airports with an annual demand less than 60 percent of runway annual service volume
3. The number of airports experiencing delay to aircraft operations; the maximum and average delay in minutes an aircraft experiences due to airside congestion
4. The number of airports that generate Integrated Noise Model noise contours greater than 65 dB Day-Night Level that extend off of airport property
5. The number of system airports without adequate utilities (electricity, telephone, water, sewer, and gas)
6. The number of airports with no close-in obstructions (within the 200 feet primary surface) and where all Federal Aviation Regulations Part 77 approach obstructions are marked (not including trees and roads)

**Service Level Performance Measures**

7. Percent of communities in the state with a population greater than 5,000 within 60 minutes of a commercial service airport
8. Percent of communities in the state with a population greater than 1,000 within 30 minutes of a general aviation airport
9. Percent of communities in the state with a population greater than 1,000 within 30 minutes of a general aviation airport that can accommodate large general aviation aircraft (Aircraft Runway Class B-II) and has Instrument Meteorological Conditions (IMC) capability
10. Percent of hospitals in the state within 30 minutes of a general aviation airport with IMC capability, on-site weather reporting, and jet fuel availability
11. The number of major recreational areas in the state within 30 minutes of a general aviation airport

**Economic Performance Measures**

12. The dollar cost average aircraft delay to Arizona airport system users
  13. Dollars of direct and indirect economic impact on the state from aviation
  14. The cost ratio of annual aviation infrastructure to total number of statewide annual enplaned passengers and annual aircraft operations
- 

SOURCE: Arizona Department of Transportation (Arizona DOT, 1995)

where the highest noise contour extending off the airport property is 66 DNL and one where it is 75 DNL, or ten times the noise. Indeed, since noise analysis typically generates noise contours in increments of 5 DNL, it is unclear whether “greater than 65 DNL” means 70 DNL and above or any noise level greater than 65 DNL. There is no discussion of how large an area is included within the 65 DNL contour, or whether in fact anyone lives within this area. Thus a program that reduces the extent of the noise contours at a particular airport such that the 65 DNL contour which previously included an area with 2,000 households now only includes a small area of public park would not change the system performance measure.

This demonstrates the importance of linking system performance measures to system goals. If the goal is to reduce the number of households exposed to excessive aircraft noise, then the system performance measure should count the number of households that experience a noise level above whatever threshold is defined as representing excessive noise. Since different people may consider different noise levels excessive, it may be more appropriate to define several performance measures that count the number of households exposed to a range of noise levels. This has another advantage, in that it allows the system performance measures to also reflect situations where the noise has been reduced below the target level.

It is also important that system performance measures are not defined in a way that implies a policy standard, where in fact no such standard has been agreed. Counting the number of airports with an annual traffic greater than 60 percent of their runway annual service volume conveys an implicit goal of ensuring that airports do not exceed this ratio. Yet it is unclear whether it is good or bad if an airport has an annual traffic level of 75 percent of its runway annual service volume. On the one hand, the users of the airport may experience some delay (although this is measured by another system performance measure). On the other hand, it shows that the infrastructure is being well utilized. Clearly there is a tradeoff between the policy goals of reducing delay and ensuring that runway facilities are utilized efficiently. Whether an appropriate balance is struck when traffic reaches 60 percent of annual service volume will depend on local circumstances.

The five service level performance measures attempt to reflect the accessibility of commercial and general aviation airports to communities of varying size, as well as hospitals and major recreational areas. Here too there are significant problems with the way the performance measures are defined. Measuring the percent of communities with more than 5,000 population that

are within 60 minutes of a commercial service airport means that 10 communities of 6,000 people that are 65 minutes from the nearest commercial service airport will have a much greater effect on the measure than a city of half a million people that has two commercial service airports within 45 minutes. There are also concerns about how one measures travel time from a “community” in large metropolitan areas where travel times to an airport may vary significantly from the closest to the farthest point in the community and by time of day. As discussed elsewhere in this paper, accessibility to airports with commercial air service should also reflect the nature of the air service that is provided. Many travelers will prefer to use more distant airports with better air service than nearby airports that only provide a limited number of feeder flights to a major hub.

Finally, the three economic performance measures attempt to reflect the costs involved in using the airport system, the economic impacts on the state from the aviation system, and the expenditures on aviation infrastructure in relation to the volume of traffic handled. These are all valid aspects of the performance of the aviation system. However, as discussed later in this paper, developing appropriate measures of these issues requires careful thought. The costs of delay are only one (and typically a fairly minor) part of the total cost of making an air trip or shipping air freight. While it is desirable to reduce these costs (as it is to reduce any costs), what matters more is the consequence of any particular decisions on the total costs. Adding airport capacity to reduce delays, if the cost of that infrastructure is greater than the cost of the delays that are avoided, is clearly not in the interests of the users of the system. Therefore it is important to put the costs that result from the operation of the system in the context of the costs of providing airport infrastructure. This also has the merit that provision of infrastructure involves decisions in which states have a role, while the provision of air service or the pattern of general aviation activity is largely outside their control.

Measuring annual aviation infrastructure expenditure, while certainly an indicator that states may want to track, is not really measuring the performance of the system on either an output or outcome basis. Rather it is a measure of the inputs required to allow the system to continue to provide air transportation. A reduction in the annual investment in infrastructure may reflect a failure to provide the system with adequate resources to operate efficiently, or it may reflect a greater efficiency in the way that the system infrastructure is being developed and used. It is one of the roles of system performance measures to identify which situation is in fact the case. By

focusing on operational efficiency and user costs, the system performance measures can be used to determine whether appropriate levels of investment are being made.

### Minnesota

The State of Minnesota Aeronautics Program has developed a set of 11 measures that it uses in its annual Agency Performance Report (Minnesota, 1996). These are also tied to program goals, and are shown in Table 3-2. While these combine organizational performance with system performance, they are heavily oriented toward the services provided by the program. It is clear that several of the performance measures are shaped by the ease of collecting the data rather than whether they indicate how well the goal is being met. Thus attendance at pilot safety seminars is a measure of program output. The outcome that is desired is to reduce the aviation accident rate. Likewise, increasing the distribution of promotional literature may or may not increase the understanding and awareness of the role of aviation in Minnesota. Even if it does, while this may be worthy goal of the Minnesota Aeronautics Program, it does not really measure the performance of the aviation system, but rather it provides political support for actions that hopefully will improve the performance of the system.

Measuring the availability and condition of airport pavements, airfield lighting and navigation aids does provide measures of the safety and reliability of the aviation system. Airfield pavement condition can also affect aircraft operating costs, due to repair costs resulting from damage from loose pavement material. However, defining appropriate ways to include these factors in aviation system performance measures will require that some thought be given to ways to aggregate the measures across different facilities.

### **Performance Measurement Techniques**

Development of a system of performance measurements requires careful attention to the choice of measures and the fit between the goals and objectives of the system and the measures adopted. A review of tools and techniques, with particular orientation toward measures of organizational performance and Total Quality Management programs, was prepared for the U.S. Department of Energy (1995). However, to the extent that measures of performance of the aviation system are only of interest within the context of organizations that are responsible for taking

Table 3-2  
**Minnesota Aviation System Performance Measures**

Goal	Performance Measure
Number of aircraft accidents is reduced	Number of aircraft accidents
Airport owners, aircraft owners, and pilots are provided information and resources to operate more safely	Average number of airport deficiencies per inspection
	Total attendance at pilot safety seminars
	Number of weather products requested by pilots on computer weather terminals
Air travel accessibility provides opportunity for economic development and supports community vitality	Percent of projects receiving capital improvement funding
Life of capital investments in airports is maximized through effective maintenance programs	Airport condition ratings
	Airport lighting system ratings
Reliability is improved and utility of the state aviation system is increased	Percent of time navigation aids are operational
	Percent of airports with scheduled air service that have a precision landing system
Awareness of career opportunities in the aviation industry is improved	Number of students participating in aviation education activities
Understanding and awareness of the role of aviation in Minnesota is enhanced	Number of general public contacts that receive promotional literature

SOURCE: Minnesota Department of Transportation (Minnesota DOT, 1996)

decisions that affect the performance of the system, the distinction between the performance of the system and the performance of the organization becomes blurred. The choice of performance measures for the California aviation system provides a means not only to judge how well the aviation system is meeting the needs of the state, but also to assess how effectively the California Department of Transportation is performing its various roles in the planning and operation of the

system. This of course is complicated by the division of functions between state agencies on the one hand, and both local and federal agencies on the other. This suggests that the development of an effective set of aviation system performance measures needs to consider not only which organizations have decision authority over the factors that influence each measure, but the means by which Caltrans can influence those decisions.

The Department of Energy report notes the distinction between doing the right things and doing things right, and suggests that successful performance measurement systems adhere to the following principles:

1. Measure only what is important. Do not measure too much; measure things that impact customer satisfaction.
2. Focus on customer needs. Ask customers if they think this is what should be measured.
3. Involve the workers in the design and implementation of the measurement system. Giving them a sense of ownership leads to improvement in the quality of the measurement system.

While these principles address organizational performance, the first two are also clearly applicable to measuring performance of the system itself. In the context of the state aviation system, defining the customers of the planning process requires some careful thought. This issue is addressed in the next two chapters.

## 4. Operator Perspectives

One important group of users of a transportation system are the operators of the vehicles that use the system to satisfy their own transportation needs or to provide transportation services to others. In the case of the aviation system, these users fall into three broad categories:

- air carriers
- general aviation
- military.

*Air carriers* provide commercial air transportation services, and include both scheduled and non-scheduled airlines providing passenger and air cargo services, as well as the integrated package express companies. This category includes airlines operating smaller aircraft, which are often referred to as commuter or regional airlines. *General aviation* comprises a broad category of aircraft operators who provide air transportation for their personal or corporate use, including executive transportation, aerial surveillance, recreational flying, and flight training. *Military aviation* includes the regular armed forces, national guard, and Coast Guard.

Not surprisingly, these users are directly affected by the performance of the aviation system in enabling them to operate their aircraft in the way that they wish, and frequently think of themselves as **the** users of the system. However, their needs vary widely, reflecting the very diverse flying activities and type of aircraft operated, as well as the type of facilities used.

In the case of general aviation, the owners of the aircraft and the pilots are often the same. Thus the distinction between the aircraft operator and the pilot is semantic. However, other general aviation aircraft operators employ professional pilots, and the relationship between the pilot and the operator is similar to that of air carriers or the military. Whether the user is considered to be the aircraft operator as an entity or the pilot actually flying the aircraft, both are affected by the performance of the system.

### **Delay**

Air carriers are the operators most affected by congestion and delay in the national airspace system for two reasons. First, they tend to have a large proportion of their operations at the larger,

and therefore busier and more congested, airports and associated terminal airspace. Second, delays can seriously disrupt their carefully scheduled operations. Even non-scheduled airlines have to be concerned about efficient utilization of their aircraft and flight crews, as well as meeting duty time limitations set by the Federal Aviation Regulations.

From the perspective of a scheduled air carrier, there are two ways to measure delay. The first is the difference between the time that flight actually takes and the time that it would have taken if there were no congestion due to other aircraft or route deviations to avoid adverse weather. The second is the difference between the scheduled departure and arrival time and the actual times. Since airlines generally build some slack into their schedules to allow for some amount of delay, the second type of delay is generally less than the first. Indeed, an aircraft can incur some delay during its flight and still arrive early, if there is enough allowance in the schedule for anticipated delays. For obvious reasons, most other categories of operator only experience the first type of delay, although some corporate flight departments operate in part according to a published schedule within the organization.

Delays are typically measured in terms of aircraft-minutes. However, it is clear that a minute of delay to a Cessna 172 is not the same thing as a minute of delay to a Boeing 747. Likewise, a delay of 20 minutes to one flight may not be regarded by the operator as equivalent to delaying two flights by 10 minutes each. Thus while delays are rightly viewed as important measures of performance of the system, developing appropriate ways to measure delays is not a trivial matter. This is complicated by the very definition of delay. While the actual duration of a flight can be determined reasonably accurately, as long as the departure and arrival times are recorded somewhere, estimating the time that the flight would have taken absent congestion or adverse weather is not so simple. If the winds experienced by the aircraft during its flight are blowing stronger one day than another, and in consequence the flight takes longer to reach its destination, should that be considered a delay? Should the flight time with no delay be based on following the most direct sequence of air routes, or flying the great circle route (which will always be shorter). If the practice of the air traffic control service is to route traffic between two points along a more circuitous sequence of airways for reasons of traffic flow management, should the additional time be considered part of the delay, or not?



In practice, the nominal flight times used to compute delays are determined from a statistical analysis of the actual flight times over a large sample of flights, based on some criterion such as the 10th percentile as the baseline. An alternative approach, typically used to study delay at a particular airport or region, is based on use of a simulation model that can directly measure delay as it is incurred in the simulation. However, the results obtained from this process are highly dependent on the assumptions made in generating the inputs to the simulation analysis, particularly the times at which the arriving aircraft enter the simulation. Obviously, in the real world aircraft do not just appear at a point in space, and the time they reach any given point is the result of a complex upstream process, that may well be influenced by the factors being studied in the simulation.

### Delay Data

The availability of accurate delay data has been a significant problem in the past. While in principle aircraft actual departure and arrival times could be recorded, in practice they often were not. However, most large air carriers now automatically record these times using switches on the aircraft and transmit the data to a central database using the Air Carrier Addressing and Reporting System. It has become standard practice to record the time leaving the gate, taking off, landing and arriving at the gate (termed out-off-on-in, or OOOI). These times not only give the total time from gate-to-gate (also termed block-to-block, or block time), but the amount of time spent on the ground at either end.

Recognizing the need to make these data more readily available, the FAA has recently developed the Consolidated Operations and Delay Analysis System (CODAS), which incorporates the OOOI times reported by the airlines, as well as the scheduled departure and arrival times and various other information (FAA, 1997a).

### **Cost**

Another concern of aircraft operators is the cost of using the various facilities that comprise the national airspace system. While many of the costs of a given flight are intrinsic to the aircraft technology, some result from the performance of the system and some are set as a matter of policy. Naturally, delays incur costs in terms of additional fuel that is burned and crew time that must be paid for. Some maintenance costs may also increase as a result of the longer time spent airborne or taxiing. Other costs result from inefficient utilization of aircraft and possibly ground crew and

equipment. Fuel burn may also increase if aircraft are not able to fly at their optimum flight level or speed, due to the need to be separated from other traffic.

Fees charged for use of the national airspace system facilities represent another cost. Landing fees are generally paid to airport authorities, based on the certificated maximum landing weight of the aircraft, while the use of other airport facilities, such as gates or aircraft parking areas often incurs additional fees. In the United States, the cost of providing air traffic control services has traditionally been covered partly by general tax revenue and partly by taxes on aviation, including fuel taxes and a tax on airline tickets. These latter charges are not borne directly by the aircraft operators, but indirectly such as when they purchase fuel. Since the airlines collect the full price of the ticket from the customer and have to then pay the tax to the treasury, they often speak as if they were paying the tax, although of course this is no different than any business having to collect and pay any taxes that are imposed on goods or services that it sells. This approach to paying for the national airspace system is currently being questioned, and it appears likely that aviation taxes will be reduced or eliminated and replaced with a new system of direct user charges that are more closely linked to the use made of the system.

One effect of such a change would be to increase the attention being given to the performance of the aviation system facilities by aircraft operators. If operators are being charged for air traffic control (ATC) services by the flight hour or per operation, they can be expected to put pressure on the ATC service to take steps to reduce costs where this does not degrade performance, and improve service where the cost of doing so is less than the value of the improved service.

#### Cost Data

Data on facilities costs at the airport level are not readily available in a comprehensive way. While of course airports know what they charge their users, these data are not typically reported to any public agencies on a regular basis. The Airports Council International conducts periodic surveys of the landing charge fees at its member airports, but the resulting data is considered confidential. Other charges, such as facility rental rates, are so situation specific that meaningful comparative data would be difficult to collect, and is rarely attempted. From time to time the Caltrans Aeronautics Program conducts surveys of aircraft tie-down and hangar rates at general

aviation airports in the state, although this information was last collected some nine years ago and there are currently no plans to obtain this information on a regular basis.

While the cost of developing, operating and maintaining the national airspace system (NAS) is readily available at the national level from the FAA budget, determining how those costs are distributed across the many facilities presents formidable problems of cost allocation, particularly at the level of the individual airport or navigation aid. In any event, since the funding to support this comes partly from the general fund and partly from an array of user taxes that flow into the Airport and Airway Trust Fund, the question of how much it costs each operator to use the NAS may not be meaningful.

### **Facilities**

The nature and type of facilities available at each airport, and indeed the availability of airports themselves, are an important concern to aircraft operators. Whether an airport has lighting or an instrument approach aid will determine whether it can be used at night or during bad weather. The length of the runways and strength of the taxiways will determine which aircraft can use it, and the availability of supporting services, such as aircraft maintenance, will influence decisions on where to base aircraft. The proximity of a suitably equipped airport to the residence of the aircraft owner or the final destination of those aboard a visiting aircraft will affect the accessibility of the aviation system. This is a particular concern in the more remote parts of the state, where access distances to a suitable airport may be significant.

### Facilities Data

Fortunately detailed information on available facilities at each airport is readily available from pilot information publications. Less easily available is information on the serviceability or quality of those facilities. The results of regular airport inspection programs generate some information on such issues as pavement condition and the condition of airfield lighting and signing.

### **Customer Satisfaction**

Aircraft operators, particularly general aviation pilots, form one set of customers of the state aviation system. How well does the system meet their needs? While objective measures of system performance such as cost or delay may provide indicators that would suggest the likely level of

satisfaction, or at least the potential for dissatisfaction, it may be worth attempting to measure this directly through a user survey. Rather than trying to define some overall measure of satisfaction, it may be worth using the survey to identify specific aspects of the aviation system that users would like to see changed or improved.

## **5. Traveler and Shipper Perspectives**

While some of the concerns of aircraft operators, particularly delays, are also of concern to air travelers and shippers, and of course ultimately the costs borne by commercial operators in using the system get passed on to the end users, those users have a different perspective on the performance of the system. Some of this is influenced by the way in which the costs get passed on. For example, if landing fees are higher at one airport than another, the airline serving that airport may reflect this in higher fares from that airport, but most likely will not. In addition, issues such as service quality and accessibility are primarily concerns of the consumer of air transportation services, not the producer.

### **Cost**

The cost of air transportation is one of the most, if not the most, important consideration to a traveler or shipper. This cost includes not only the direct cost of purchasing the ticket or shipping the cargo, but also the cost associated with accessing the airport. For medium haul flights, these can be a significant part of the total cost of the trip. For a two-day trip in the California corridor, the cost of driving to the airport, parking for two days, and renting a car at the other end of the trip could easily exceed the air fare. Similarly, if inconvenient flight schedules require a traveler to spend an additional night away on a trip, the hotel and meal costs could add as much as \$200 or more to the cost of the trip.

One aspect of measuring air fares that has become much more significant since airline deregulation is the wide range of fares and the rise of yield management systems that attempt to impose restrictions on who can use each fare class, in order to obtain the most revenue from a given passenger while still offering heavily discounted fares to attract price-sensitive travelers. Thus it is no longer meaningful to ask how much it costs to fly from, say, Los Angeles to Chicago. The fare will depend on the day of travel, the duration of the trip, and how far in advance the ticket was purchased. One can still ask what is the average fare paid, across any segment of the market, but almost no-one will have actually paid that fare.

Measuring the cost of air freight is no easier. Freight rates vary by commodity, volume shipped, and any special handling required. The market is very competitive, and large shippers can

negotiate discounts from the published rates. The rise of the integrated carriers, such as Federal Express and UPS, and their expansion from the express package market into larger and heavier shipments further complicates the issue, since the rates paid include pickup and delivery. Thus comparative data for shippers using conventional airlines should take account of the cost of delivering the shipment to the airport or freight forwarder, any fees charged by the forwarder, and delivery at the destination.

### Cost Data

Data on the fares paid by passengers on scheduled airlines are available from information reported by the airlines to the U.S. Department of Transportation as part of the 10 percent origin-destination survey. This is not strictly a survey, but rather a sample of the itinerary and fare paid by roughly every tenth passenger (in principle the information from every ticket with a ticket number ending in zero should be reported). The data are aggregated by the reporting airline to give the count of passengers traveling on a given itinerary at a given fare in each quarter). These data can be used to calculate the average fare paid in a given market, as well as the distribution of fares paid, subject to the limitation of the sample. There are many technical complications in working with the data, caused by such issues as code sharing in which one flight may have two or more flight numbers for different airlines or a regional airline may designate its flights with the two-letter code of a major airline, but these are fairly well understood.

Average fare data for each airline at the national level can be determined from the financial data reported by the airlines to the U.S. Department of Transportation. However, because average fares vary widely from market to market, these data are virtually useless for analysis at a state or regional level.

Information on ground access costs is much harder to obtain. Some airports perform air passenger surveys that obtain data on mode use, and may (although rarely do) ask about costs paid. One difficulty is that many of the costs have not yet been paid at the time the passenger is surveyed, and so the respondent may not know the amount anyway. Typically, costs are estimated for each mode based on published rates and charges that are tracked by the airport authority for other reasons (such as operating traveler information desks). However, these surveys are usually quite infrequent. For example the Metropolitan Transportation Commission performs a survey at the three Bay Area

airports every five years. The airports maintain other data on an on-going basis, although there is no effort to coordinate this, or even to allow others to access it. As part of research for Caltrans into airport ground transportation information systems, the Institute of Transportation Studies developed a database on airport ground access mode use on a monthly basis at six California airports for 1993 and 1994 (Gosling & Lau, 1995; Gosling, 1996). However, this was not continued beyond the end of the study. There is a pressing need for the creation of an on-going database on airport ground access information at airports throughout California (and indeed across the nation). While this could easily become a valuable part of statewide Intermodal Transportation Management Systems, there has been very little effort to date to pursue this.

Data on air cargo costs is even more limited. There is no air cargo survey comparable to the passenger origin-destination survey. Average freight revenue per ton-mile is available at the national level for each carrier from the financial data reported to the U.S. Department of Transportation. Some information on air cargo costs can be obtained from the Commodity Flow Survey performed intermittently by the U.S. Department of Commerce, and described by Tsao (1998). Costs for delivery and pick-up of air freight are typically internal to the shipping organization, and are not reported anywhere. Very few surveys of truck drivers have ever been attempted, and such surveys run into the difficulty that the driver may not know what it costs to operate the truck, or even what is being picked up or delivered.

### **Service Quality**

The most important aspect of service quality is the frequency of service in the market in question. This determines the ability of travelers to fit the air trip into their desired schedule, as well as their ability to make flight connections in markets where direct service is not available. Other factors include the number of carriers in the market and the type of aircraft operated. The number of carriers not only affects the likelihood that travelers can fly on a preferred airline, or one on which they can obtain frequent flier benefits, but also the competition in multicarrier markets may stimulate better service or lower fares. Jet aircraft generally provide a better comfort and ride quality than turboprop aircraft, while wide-body aircraft provided more storage for cabin baggage and may be perceived as more comfortable than narrow-body aircraft, particularly for longer flights.

Measuring service quality experienced by the traveler within the airport terminal is also a challenging task. There is fair amount of literature on measuring airport landside level of service (e.g. Brink & Maddison, 1975; Transport Canada, 1979; Ashford, 1988; Muller & Gosling, 1991), but little effort has been made in the U.S. to do this on a consistent basis across airports.

### Delays

The levels of airport delay are another aspect of service quality. Apart from the value of the passenger time involved in delays, the disruption to travel plans that results from missed or canceled flights can be significant. As levels of airport delay increase, the airlines tend to provide more allowance for these delays in their schedules, in order to maintain adequate on-time performance. Although this reduces the frequency of late arrivals, all passengers incur the added travel time involved. Even if the flight arrives early, because the delays were less than allowed for in the schedule, this additional time is often not usable by the travelers, particularly if they are connecting to another flight, are being met at the airport, or have scheduled meetings or other business based on their expected arrival time.

Although air passengers incur the delays experienced by their flight due to congestion in the system, most travelers have no real idea how long the flight would have taken if there were no congestion, and thus tend to focus only on the on-time performance. However, while they may not be aware of this, they do incur the cost of this delay in the sense of having to spend longer in the system than they would otherwise. Thus it may be useful to distinguish between congestion delay and on-time performance.

### Service Quality Data

Data on airline flight schedules, including the type of aircraft used is available from the Official Airline Guide (OAG), which is published in various formats, including computer disk. Some flight schedule data can also be inferred from the data reported to the U.S. Department of Transportation for the Airline On-Time Performance Reporting System. Calculating flight frequencies from schedule data is tedious, unless automated tools are available. Some on-line aviation data providers offer the OAG data and analysis tools to work with it. However these are typically quite expensive to use, due to the data access fees that must be paid to the publishers of the OAG.



The U.S. Department of Transportation maintains an on-line database on airline on-time performance, which can be used to measure trends in this aspect of delay. The underlying database tracks arrival and departure times at the level of individual flights, and can be used to examine the distribution of delays of varying length. However, this does not take account of the additional travel time involved when airlines increased scheduled flight times to improve their on-time performance.

Routine information on other aspects of service quality, including airport terminal level of service, is not collected or reported. Some proprietary air passenger surveys are performed by private market research groups, that sometimes include questions about airport level of service.

### **Accessibility**

The accessibility of an airport is largely a function of the local highway system. However, at larger airports public transportation services become important and an appropriate measure of accessibility become more problematical. While it may be sufficient to measure highway access in terms of peak and off-peak travel times, measures of public transportation services need to address issues of service area and frequency. Combining measures of the service offered by each mode into a single indicator is difficult enough for a specific location. Developing an appropriate indicator for the entire market served by an airport is even more difficult. Ndoh and Ashford (1993) present a framework for evaluating airport access level of service, but it is based heavily on surveys of user perceptions and no work has been done to correlate the level of service scale values derived from the methodology with objective measures of the attributes of the landside system.

Another important aspect of accessibility is the role of the level of service offered by the ground access system in airport choice, when passengers can choose between several airports. This becomes particularly relevant in smaller communities at some distance from larger metropolitan regions, where the traveler may have to choose between using a feeder airline (typically a turboprop flight operated by a regional carrier) to access a nearby regional hub airport, or traveling by surface mode (typically driving) directly to a nearby larger airport. With the advent of code-sharing relationships between the regional airlines and their major airline partners, the fares for such feeder flights may be fairly modest if the traveler is continuing on the code-share major airline, but very expensive if another airline is used. The potential development of a high speed rail system in

California offers the prospect that the level of accessibility of major airports from smaller communities in the state could be significantly enhanced by ensuring that adequate links are created between the rail system and major hub airports in the state.

Of course, access to a specific airport is only one aspect of accessibility to the air transportation system, which also depends on the air service offered at alternative airports that could be used by the traveler. In large metropolitan areas served by multiple air carrier airports, the difference in air service between the primary airport and other airports causes many travelers to use the primary airport, although it may not be as convenient as one of the secondary airports. In the case of smaller communities, the number of destinations served from the local airport is often quite limited and fares are often significantly higher than from the larger hubs where there is more competition.

#### Access Data

Data on the California state highway system can be obtained from the Intermodal Transportation Management System (ITMS) maintained by Caltrans (Booz-Allen & Hamilton, 1996), or from regional highway travel time databases maintained by the metropolitan planning organizations or the congestion management agencies. Information on the services offered by other modes is currently not included in the ITMS, but may be maintained by the airport authorities, particularly if they operate ground transportation information systems. As noted above, including this information in the ITMS could significantly enhance its value to the state. While the ITMS includes information on public transit, this mode is used by very few airport travelers. Most public transportation at airports is provided by private operators, such as shuttle van or airport express bus companies.

#### **Customer Satisfaction**

The foregoing considerations address aspects of the system performance that can be objectively measured. However, as with aircraft operators, there is also the perspective of how satisfied the users of the system are with the service they receive. The CTP Final Report on Transportation System Performance Measures (Caltrans, 1998c) proposed developing a customer satisfaction index based on passenger surveys. Some airports, including San Francisco International, already perform surveys on a regular basis to assess passenger satisfaction with

specific aspects of the airport. There are two approaches possible to obtaining such survey data. One would involve surveying passengers at the airport or on their flight. The other would involve conducting a household survey.

Surveying passengers on a sample of flights provides a more representative sample than trying to survey passengers at the airport, where many are in a hurry to catch their flight or leave the airport and are unwilling to take the time to answer questions. Most airport surveys are performed in the boarding lounges, where passengers are generally more willing to participate. However, there are concerns about potential bias arising from the amount of time before flight departure that different types of passenger arrive at the boarding lounge. On the other hand, in-flight surveys require the cooperation of the airline, which may be difficult to obtain. While conducting airport surveys may appear to be the easiest approach, particularly if there are existing surveys being performed that could be utilized, it would be necessary to get each airport or regional agency conducting the surveys to agree on a standardized methodology and question wording. Since each agency performing a survey has its own information needs, this might be difficult to achieve.

Household surveys are a well-established source of transportation planning information. They have the advantage that they can obtain data on trips taken at other times of year from the date of the survey, and can address trips by a range of modes, not just air travel. They can also obtain information on the entire round trip. Two disadvantages are that for many households it may have been some time since they last took an air trip and their recollection of the details may be poor, and of course a household survey will generally not obtain information on trips by visitors to the state.

This suggests that the best strategy might be to undertake a statewide in-flight survey in conjunction with a household travel survey. The household travel survey could be designed to obtain information on all modes of intercity travel, including private vehicles. In addition to questions on customer satisfaction with the transportation system, the surveys could also obtain other information of use in intermodal planning, including the frequency of making intercity trips and travel mode choice issues. The in-flight survey would require airline cooperation and could be conducted on a random sample of flights departing from California airports throughout the year, in order to reflect seasonal patterns of travel. Discussions could be held with the airlines to identify what information they might obtain from such a survey that would be of use to them, and thus help obtain their cooperation.

Developing a satisfaction index from such survey data involves two issues. The first is what aspects of the system performance to assess and the second is how to weight the responses to each aspect into a single index. This issue is no different for the other modes, and the approach should be consistent across each mode, although the specific aspects may vary from mode to mode.

## 6. An Economic Perspective

The foregoing chapters view the performance of the aviation system from the perspective of its direct users -- aircraft operators, air travelers and shippers. However, in another sense, the entire population of the state are users of the aviation system, whether they take flights themselves or not. Air transportation has become an essential element of the present day economy, and particularly the high technology and tourism sectors that are so important in California. There appears every reason to believe that aviation will remain an essential element of the economy in the twenty-first century and may well increase in importance.

The air transportation system contributes to the state's economy in a number of ways, foremost by allowing the necessary movement of people and goods. The lower the cost of doing this, the more competitive California firms become and the more money households have to spend on other things, stimulating those aspects of the economy in the process. Of course, if the cost of air transportation declines, many firms and consumers will decide to consume more air travel than before in order to take advantage of business and personal opportunities that have become more affordable. Whether this would tend to cause the rate of economic growth to increase or slow down compared to the existing cost structure is not clear. Certainly, lower air fares encourage more visitors to experience California's many tourist attractions, from Disneyland to Yosemite Park.

A recent study for the U.S. Bureau of Transportation Statistics (Garrison, Gillen & Williges, 1997) examined the impact of improvements in air transportation during the four decades from 1955 to 1995 on recreation and tourism. The findings suggest that a major beneficial impact of improvements in transportation infrastructure and services is that they allow people not just to do things in the same way at less cost, but to do entirely new things or the same things in novel ways. Certainly, the availability of increasingly affordable air travel has provided a major stimulus to California's convention and tourism industry. However, while these changes may be easy to identify in hindsight, and even this is not clear given all the other factors involved, developing system performance indicators that are sensitive to these outcomes will be a major challenge.

A similar case study could be performed on the way that the development of the overnight air express industry has changed the manufacturing and distribution sectors. The ability to guarantee delivery the next day has reduced the need to hold large inventories as a buffer to cover

the lag between production and delivery, or to provide a wide range of options to customers. Now if a store does not have the product in the particular configuration the customer wants, it can be shipped from a central warehouse and delivered directly to the customer the next day. Indeed, it may not even exist when the order is placed, but can be manufactured in the desired configuration and delivered within a matter of days.

### **Efficiency**

A key measure of the performance of the aviation system is the amount of resources that are consumed to produce each unit of output. Since these resources are no longer available for other purposes, it is important to ensure that they are being used in a way that produces the most output possible. In order to be able to combine the various resources consumed by a project or activity into a single measure, they are typically expressed in terms of their cost. While most projects have a fairly good handle on their direct costs, estimating indirect or external costs can be more difficult. Part of the problem is determining exactly what to consider and part is deciding how to measure it. For example, an important externality of airport activity is aircraft noise. The further one gets from an airport, the less the noise impact. How much should one measure? With some caveats, federal policy on airport planning and funding noise mitigation measures has adopted the criterion of 65 dB Day-Night Level (DNL). However, many communities near airports feel quite strongly that they are adversely impacted at lower levels. Even after deciding which noise impacts to include and which not, there remains the question of how to value these impacts, or whether they can be meaningfully expressed in monetary terms at all.

Another important resource is the time that must be spent by each traveler in the course of the trip. In many markets schedule convenience becomes an important issue. Is it better to have more flights with smaller, and consequently more expensive, aircraft or fewer flights by larger aircraft? This will depend on the relative values of schedule delay compared to travel time, and indeed between in-vehicle time and waiting time.

Notwithstanding the foregoing difficulties, measuring the economic efficiency of the aviation system, and the effect of proposed policies or projects on that efficiency, is clearly important, not only to decisions on how to allocate resources within the aviation system but also on how to allocate resources between aviation and other transportation modes, or indeed between

transportation and other activities. Since it is generally regarded as nearly impossible to do this effectively without appropriate price signals to decision makers and consumers, one important measure of the economic efficiency of the system is the extent to which the prices charged for air transportation services reflect the true resource costs of producing them.

### **Competition**

An important aspect of aviation system performance is the extent of competition in providing air service at airports throughout the state. While there may be a small reduction in efficiency from having multiple providers in the same market, the expectation is that this is more than offset by the improvements in efficiency, innovation, and pricing that are driven by the need to attract passengers and shippers in a competitive environment.

Beyond any improvement in efficiency, or protection against monopolistic pricing, competition provides choice to the air traveler or shipper, which has a value beyond its effect on the cost of service. Different airlines provide differentiated services, even if only the use of different hub airports and participation in different frequent flier programs. Since individual preferences vary, it can be expected that the more varied the range of services provided, the higher the proportion of passengers or shippers who will feel satisfied that their needs have been adequately met.

### **Contribution to the State Economy**

While the contribution of the aviation system to the state economy is clearly very significant, that alone is not particularly helpful to the development of system performance measures. The issue is not whether to do away with aviation, but rather how different changes at the margin vary in their contributions to the economy. Therefore indicators are required that are sensitive to these marginal changes.

A common approach to measuring the economic impact of activities such as airports is to count up the number of employees who work there and estimate the amount of spending they contribute to the economy, combined with the direct spending by airport-related businesses. In many cases, these spending levels are then increased by a multiplier to allow for secondary spending by the recipients of the initial spending. The fallacy of this approach can be seen by asking what the impact on the state economy would be if a new technology were to allow airlines to

cut their airport labor force in half while continuing to provide the same air services. According to the usual approach this would result in a large reduction in the economic benefits of aviation. However, in reality, the consequent reduction in the airlines' cost of doing business must have a significant positive impact on the cost of providing air services, and hence in the contribution of aviation to the state economy.

Since aviation has become a fundamental part of our society and economy, the relevant question is not what would happen if it did not exist, but rather what return will be obtained from the next incremental commitment of resources to aviation facilities and services, in comparison to using those resources in other ways. Therefore, aviation system performance indicators need to address both the marginal contribution of expanded aviation activity to the growth of the state economy and the resources required to achieve and sustain that increase in activity. The former is a much more difficult question than the latter, and most likely cannot be answered with any confidence at the present level of understanding of the causality inherent in the system. However, the importance of the question to policies affecting airport development suggests that this is deserving of significantly increased research attention.

### **Externalities**

Aviation brings both economic benefits and adverse environmental impacts, including aircraft noise and air pollution. Major airports also generate large volumes of ground access traffic, that add to the congestion of adjacent streets and highways. Just as the state has an interest in promoting the economic benefits of aviation, it also has an interest, and indeed a legislated responsibility, to ensure that these environmental impacts are reduced as much as possible, and that airport development conforms to established environmental standards. Particularly in regions that are not in attainment of the national ambient air quality standards, emissions from aviation activity, including aircraft, airport ground operations, and vehicles traveling to and from the airport, are an issue of increasing concern.



## **7. Role of the State in Enhancing the Performance of the Aviation System**

Since it is axiomatic that any system performance measures should reflect the goals that have been defined for the system, the development of statewide aviation system performance measures should focus on the role of the state in enhancing the performance of the aviation system, otherwise they simply become an exercise in wishful thinking or gratuitous information. The Policy Element of the California Aviation System Plan (Caltrans, 1998a) defines the goals of the state aviation system planning process and identifies the policies by which these goals are pursued. However, the role of the state in aviation is broader than the system planning process and falls into four broad categories:

1. Funding airport development
2. Facilitating cooperative airport planning
3. Regulatory and legislative actions
4. Development and operation of the surface transportation system.

### **Funding Airport Development**

The California Department of Transportation administers the state Aeronautics Capital Program which provides a fairly modest source of development funds for smaller airports in the state, derived from the state tax revenues on aviation fuel (Caltrans, 1998b). This role would become much more significant if California were to become a block grant state under the federal Airport Improvement Program and responsible for administering the allocation of federal as well as state airport development funds. It would also increase dramatically if the state legislature ever decided to end the state tax exemption for jet fuel used by commercial air carriers or redirect taxes currently being paid by the aviation industry from the state General Fund to aviation programs.

Another aspect of the state role in airport development is the coordination between state and other funding, including airport ground access projects developed with highway and rail funding programmed through the State Transportation Improvement Program (STIP). In order to provide a comprehensive assessment of state airport development needs, the California Transportation Commission (CTC) is now requiring each regional planning agency to include all airport capital

improvement programs within its region in its input to the state aviation Capital Improvement Program (CIP), whether or not financed by state funds (Oldham, 1998). In 1990, the aviation CIP was taken out of the STIP and is now an independent program that is adopted by the CTC on the same schedule as the STIP. Recent legislation (Senate Bill 45) divided the STIP funding into two programs, a Regional Improvement Program that is allocated to counties on an entitlement basis and an Interregional Improvement Program that is programmed by Caltrans, and required that all Regional Transportation Plans (RTPs) address the coordination of aviation facilities and services with other elements of the transportation system. In addition, the RTPs in any region that contains a primary air carrier airport shall include an airport ground access improvement program. Partly as a result of these changes, the CTC has begun to take an increasing interest in the state's airport development needs (Oldham, 1998).

### **Cooperative Airport Planning**

A second important role is coordinating the airport system planning process at the state level. The interrelated nature of the state's airport system requires cooperative planning both between airports in each region as well as across regions. With most of the airports operated by independent municipal or county authorities, there is an understandable tendency for each airport to pursue an separate development agenda and often to regard other airports in its region as competitors for the traffic. The performance of effective airport system planning at a regional level by the metropolitan planning organizations and regional transportation planning agencies is hampered by a lack of suitably qualified and experienced staff, and by those with appropriate knowledge and experience having to perform other duties in addition to airport system planning. Through the Regional Transportation Planning Agency Airport System Planning Committee, Caltrans Aeronautics Program is able to play a critical role in coordinating efforts between the regions and in working with the Federal Aviation Administration Regional Office to ensure that federal airport development and planning funds are allocated in a way that considers the needs of the entire state.

## **Regulatory and Legislative Actions**

Although regulation of air transportation and airport operations is largely a federal function, the state has become involved in a number of ways, including aircraft noise and airport land use planning. Caltrans also performs airport certification and inspection on behalf of the Federal Aviation Administration.

Another significant state role is played by the California Air Resources Board in setting emission standards for a broad range of activities, including airports, and preparing the State Implementation Plan for compliance with the federal Clean Air Act Amendments. These actions are likely to have a greater impact on airport development and operations in the future, as additional emission reductions from other sources become harder to achieve.

A potential legislative role, although one that has not been exercised to date, concerns the institutional structure of airport authorities within the state. These are mostly municipal agencies. In both the Bay Area and Southern California, this has resulted in multiple airports within the region being operated by different authorities, and with the metropolitan planning organizations having a relatively weak role in shaping the development of the system. There is also the problem that many of the airports impact surrounding communities that are within different jurisdictions from the municipality operating the airport. The effective development of the state aviation system may require legislative action to establish a more effective institutional structure to ensure that the broader interests of the regions and state are not compromised by narrower local interests, whether on the part of the jurisdictions owning the airports or the adjacent communities.

## **Surface Transportation System**

The surface transportation system forms the essential intermodal interface to all aviation activity. As the developer and operator of the state highway system, Caltrans plays an essential role in facilitating airport development. Conversely, airport development imposes additional traffic demands on the local highway system. Although public transportation services are generally operated by local agencies, the state continues to play a key role in developing and promoting new approaches as well as providing state funds and coordinating the disposition of federal funds through the State Transportation Improvement Program (Oldham, 1998).

The recently created California High Speed Rail Authority is currently developing a plan for a statewide high speed rail system, to present to the electorate for authority to issue bonds to finance the public component of the proposed system. While it remains to be seen whether the electorate will support such a plan, it would clearly be short-sighted for the aviation system planning process in the state to ignore this possibility. Indeed, such a system could benefit the airline industry in the face of growing traffic levels and increasingly constrained airport facilities, by allowing the utilization of scarce airport capacity for higher revenue longer haul traffic. It could also allow the development of new airports at locations some distance from the metropolitan areas by providing high speed surface links to the urban centers. However, the achievement of such visionary solutions to California's future air transportation needs will require strong and well-informed state leadership.

### **Economic Development**

Perhaps the strongest case for a strong state role in aviation is the importance of the aviation system to the economic health of the state. While aviation has traditionally formed an important component of the state's manufacturing sector, it is less clear how closely this depends on the aviation system within the state. The factors that cause the aerospace industry to locate in the state have more to do with the climate and labor force skills than with the condition of the state's airports. Of course, these industries require good air transportation services, but so does any high technology industry. To the extent that they need to be located on, or adjacent to, airfields in order to test and deliver their products, there is no shortage of suitable sites.

A far more significant linkage exists between the aviation system and the state's tourist industry. The convention and tourist industry as we know it today would not exist without good and affordable air service. Increases in the cost of air travel will not only reduce the number of visitors to the state, but will reduce the money they have to spend while they are here. Capacity constraints at the state's gateway airports will encourage airlines to shift service to other gateways, with potentially adverse consequences for foreign tourist travel. The exact dynamics of this process are not well understood, but the risks appear to be very real.

Beyond these specific sectors, air transportation forms an essential component of almost all economic activity. Factors that increase the cost of air travel or air cargo, or reduce the service

quality adversely impact the state's competitiveness and discourage firms from locating in the state. Outside the major metropolitan areas, the quality and availability of air service may have an even greater effect on the distribution of economic activity in the state.

### **Implications for Aviation System Performance Measurement**

It is clear that, in California at least, the state is far from a minor player on the aviation system stage, although many of its roles are the responsibility of other agencies than Caltrans. However, the California Aviation System Plan provides a framework to articulate these roles and facilitate an integrated approach to the development of the aviation system within the state, that places aviation within the context of the broader transportation system. For this to occur, it is essential to be able to monitor the performance of the aviation system in terms of established goals, and to be able to identify issues of concern in a timely way as well as to assess the effectiveness of the strategies being pursued to address these concerns.

## **8. Proposed Performance Measures**

This chapter presents an initial set of proposed aviation system performance measures within the framework defined by the Final Report on Transportation System Performance Measures as part of the 1998 California Transportation Plan (Caltrans, 1998c). As with all the measures proposed in the Final Report, it is recognized that as experienced is gained in implementing the initial performance measures, the set of measures will evolve. This evolution could take the form of changes in the way the measures are defined, addition of new measures, or elimination of measures that are found to be less useful than originally thought.

One important consideration in defining the initial set of aviation system performance measures is whether to only address aspects of the aviation system over which Caltrans has some direct influence, or include all aspects that are of interest to users of the California aviation system and those affected by it. The latter approach has been adopted on the grounds that in the last analysis what matters to the people of the State of California should matter to the agencies of its state government. If monitoring these performance measures identifies issues of concern that Caltrans or any other relevant agency in state government does not have the authority or the means to influence, then at the very least the elected officials need to be made aware of these issues so that they can in turn decide whether legislative action is required to address the issues. Even where these issues fall within the jurisdiction of the federal government, state agencies can, and do, work through the California Congressional delegation to ensure that the interests of the state are addressed. In fact, taking such an approach is essential if the aviation system performance measures are to address the full transportation needs of the state.

The following proposed aviation system performance measures have been organized according to the nine system performance outcomes defined in the Transportation System Performance Measures Final Report. Separate performance measures have been proposed for commercial air service and general aviation. Since these two sectors have quite distinct characteristics, it follows that their performance measures will need to be designed to reflect the different roles of each sector in the overall transportation system.

### Commercial Air Service

As discussed earlier, the performance of the aviation system can be viewed from the perspective of either the travelers and shippers, or the commercial air service operators. Air travelers are primarily concerned with the cost of air service and the quality of the service available in terms of the frequency of flights to their destination. However, other considerations also arise, including preference for specific carriers and the ease of accessing alternative airports. While air cargo shippers are also concerned about cost, service frequency and accessibility, measuring these factors in the context of air cargo shipments is more difficult, particularly in view of the growing role of the integrated express package carriers. Air carriers are primarily concerned with the availability of adequate capacity and facilities to accommodate their operations efficiently. Thus the proposed performance measures reflect these different perspectives.

### General Aviation

The two principal aspects of the performance of the aviation system that concern owners and operators of general aviation aircraft are the cost of using the system and access to appropriate facilities. While there are several components to the cost of operating an aircraft, the two major elements that are influenced by the way the system is configured and managed are the cost of renting storage space for the aircraft at the airport where it is based and the cost of fuel. Access to appropriate airport facilities includes the availability of aircraft storage space at a convenient airport and the provision of adequate air traffic control services and navigation aids. Thus the proposed measures have been developed to reflect the performance of the aviation system from the perspective of operators of general aviation aircraft.

### **Mobility and Accessibility**

The aviation system performance measures in this category have been grouped to address the four broad transportation system performance measures proposed in the CTP Transportation System Performance Measures Final Report.

### Travel Time

While door-to-door travel times could certainly be calculated for air trips, the wide range of trip lengths and travel patterns would make this a formidable undertaking. It is also not clear what

use such a measure would have, since flight times are largely determined by the aircraft technology in use and the surface component of the trip is addressed separately under accessibility. However, travel times do depend on whether direct flights are available and the time that must be allocated to a trip depends in part on the frequency of service. Therefore these two aspects are recommended as a more meaningful measure of travel time than the actual door-to-door time itself.

In the case of general aviation, all point-to-point flights are essentially direct and can depart when required. In the case of many general aviation activities, such as recreational flying or aerial observation, travel time is not even a relevant consideration.

The following measures are proposed:

- C1.1 Percent of air trips in markets served by nonstop flights
- C1.2 Percent of air trips in markets without nonstop service but served by connections through an airline hub or one-stop service
- C1.3 Percent of air trips in markets with at least six nonstop, one-stop or connecting flights per day each way
- C1.4 Number of international destinations served with nonstop flights with daily departures
- C1.5 Number of international destinations served with nonstop flights with at least three weekly departures

The foregoing performance measures attempt to balance the desire to capture the complexity inherent in air travel service quality with the work involved in assembling the relevant data and explaining the resulting measure. For example, travelers can get to any destination if they are willing to change planes enough times. Thus the critical question is how often are an excessive number of connections required. What is considered excessive for a trip from San Diego to New York might not be considered excessive for a trip from Bakersfield to Birmingham. Similarly, three daily departures in a market by each of two airlines is not the same thing as six daily departures by a single airline. Which is preferred by a traveler depends on a number of factors, and quite likely will vary from traveler to traveler.



## Delay

In the context of mobility, delay refers to the difference between actual travel times and travel times under optimal conditions. In the case of the air transportation system, there are two components to delay, that experienced getting to and from the airport and that experienced flying to the destination.

Most general aviation airports are sufficiently uncongested that delay to general aviation aircraft is not a significant issue. Even so, it may be useful to include this in the aviation system performance measures, both to provide comparative information across airports and to provide an early warning in case the situation begins to deteriorate. Since planned and even actual flight time information is not routinely available for general aviation activity, it is necessary to estimate delays from standard airport demand/capacity relationships. Also, since survey data is generally not available for access/egress trip ends for general aviation activity, the distribution of the registered addresses of the owners of aircraft based at the airport can be used as a surrogate.

The following measures are proposed:

- C2.1 Average delay experienced in traveling to and from the airport, measured as the average difference between actual access/egress highway travel times and free-flow travel times, weighted by the distribution of trip ends
- C2.2 Average delay experienced during the flight, expressed as the difference between actual flight times and scheduled flight times during periods of light traffic
- G2.1 Average delay experienced in traveling to and from the airport, measured as the average difference between actual access/egress highway travel times and free-flow travel times, weighted by the distribution of based aircraft owner locations
- G2.2 Average delay per flight, estimated from the ratio of annual aircraft operations to the Annual Service Volume of the airport

The inclusion of measures of average aircraft delay deserves some discussion. While delay reporting systems, such as the FAA's Consolidated Operational Delay Analysis System, provide a means to compute delay statistics on an on-going basis, careful consideration has to be given to how the delay is defined. For example, if a flight is held at the gate at Denver due to bad weather at San Francisco, should that delay be included in the average delay for San Francisco. Also, how are

flight cancellations to be addressed? Does a canceled flight have zero delay or infinite delay? Another important factor is the distribution of the delay. While the average delay may be fairly modest, it is the relatively few flights that incur large delays (typically during periods of bad weather) that cause the greatest concern both to operators and their passengers. While a distribution can be shown graphically for a given airport, combining this information into a single distribution at the statewide level may be misleading if in fact almost all the severe delay occurs at only a few airports. Perhaps the most useful aspect of computing the average aircraft delay is that the data acquisition, management and computational procedures required can be easily adapted to perform much more comprehensive analysis when required.

### Access to Desired Destinations

The concept of convenient access to desired destinations in the context of the air transportation system hinges on the definition of convenient. The development of airline hub and spoke networks mean that essentially all destinations can be reached by making a modest number of connections, typically no more than two. While this does increase travel time and may well increase the cost, these aspects are addressed by other performance measures.

What may be relevant system performance measures for access to desired air service are the number of carriers serving the market and difference in air service between the closest airport and the nearest airport with direct service to the destination or to an intermediate hub if the destination is not served directly.

In the case of general aviation, the issue is not so much the destination, since all destinations are directly accessible, but rather limitations on the choice of airport that result from differences in the facilities available at the airports. While it would be possible to simply measure the percentage or number of airports with specific facilities, this ignores the distribution of activity between the airports. Therefore it may be more appropriate to measure the percent of based aircraft or activity in a region that occurs at airports with specific facilities. The existence of a nearby airport is of limited use to an aircraft owner if there is no available space to base the aircraft there. Thus one aspect of the ability of the general aviation airport system to meet the needs of aircraft owners is the availability of aircraft parking or hangar space.

The following measures are proposed:

- C3.1 Percent of air trips in markets served by three or more carriers with nonstop, one-stop or connecting service
- C3.2 Percent of international departures in markets with at least two carriers
- C3.3 Percent of air trips for which the nearest commercial airport provides direct or connecting air service through one intermediate hub
- C3.4 Percent of air trips for which the nearest commercial airport provides direct jet service to the destination or to an intermediate hub with direct service to the destination
- C3.5 Average additional distance to access the nearest airport with direct air service to the destination, or connecting air service through an intermediate hub when the destination is not served directly, compared to the distance to the nearest commercial airport
  
- G3.1 Percent of regional/statewide based aircraft at airports with available hangar space
- G3.2 Percent of regional/statewide based aircraft at airports with available tie-down space
- G3.3 Percent of regional/statewide itinerant operations at airports with a control tower
- G3.4 Percent of regional/statewide itinerant operations at airports with an instrument approach capability
- G3.5 Percent of regional/statewide itinerant operations at airports with approach and runway lighting

### Access to the Airport System

All airports are accessible by the state and local highway system. Travel times under free-flow conditions depend on the distribution of trip ends with respect to airport locations, which are the result of land-use development patterns largely exogenous to the development of the aviation system. However, airport location and development decisions could affect the access distances faced by users of the system. In the case of commercial service airports, the availability and use of

shared-ride public transport access services is an important measure of performance of the intermodal transportation system.

The following measures are proposed:

- C4.1 Percent of air trip ends within 45 minutes highway travel time of the nearest commercial service airport
- C4.2 Percent of air trip ends within 45 minutes highway travel time of the commercial service airport used
- C4.3 Average airport access/egress highway travel times under free-flow travel conditions, weighted by the distribution of trip ends
- C4.4 Percent of air trip ends within 5 miles of stops served by scheduled airport ground transportation services, including rail transit and express airport bus services
- C4.5 Percent of air trip ends in communities served by airport shared-ride van services
- C4.6 Percent of air passenger airport access/egress trips using shared-ride public transportation
  
- G4.1 Percent of aircraft owners within 30 minutes of a general aviation airport, under free-flow travel conditions
- G4.2 Percent of population within 30 minutes of a general aviation airport with instrument landing capability, under free-flow travel conditions

The proposed measures provide a limited perspective on the level of service provided by the airport ground access system, ignoring such issues as the relative costs of different modes and the frequency of service. Since this involves the intermodal transportation system, it is likely to be an important consideration for a comprehensive set of state performance measures. This omission is not intended to suggest that these factors are less important than those addressed in the foregoing measures. Rather it is a reflection of the difficulty in defining appropriate measures for which data is readily available. Even recent efforts to simply develop statistics on mode use at selected airports (Cunningham & Gerlach, 1996; Shapiro *et al.*, 1996) have resulted in a confusing amalgam of incomplete data and inconsistent definitions. This would appear to be a critical topic for future research.

## **Reliability**

While the standard deviation of flight time can be calculated from available flight delay data, in a scheduled service this is of less interest to the traveler than knowing how often flights arrive late and by how much. In general, delays do not depend on the duration of the flight, but rather on the traffic conditions at the destination airport. While departure delays are of less concern to the travelers than arrival delays (although one often results in the other) they are of concern to aircraft operators, since they affect how much slack remains in the flight plan to accommodate additional downstream delay. Also they may be an indicator of airport capacity problems at the origin airport. The standard deviation of highway airport access/egress travel times may be a useful measure of how much allowance for unexpected delay travelers need to make.

The following measures are proposed:

- C5.1 Percent of flights arriving more than 15 minutes late
- C5.2 Percent of flights arriving more than 30 minutes late
- C5.3 Average departure delay per flight
- C5.4 Standard deviation of highway airport access/egress travel times, weighted by the distribution of trip ends

## **Cost Effectiveness**

Although cost effectiveness ratios are an appropriate technique for evaluation alternative projects, it is less clear how the concept can be applied to *system* performance. While the costs of developing and operating the system can be estimated, albeit with some difficulty, estimating the benefits of the entire system is extremely problematical. Differences in techniques for estimating benefits at a regional or local level will make any comparisons completely meaningless and preclude the development of statewide values.

However, efforts to monitor trends in system costs are a useful exercise that not only directly address an issue of primary concern to system users, but can provide a basis for a more thoughtful assessment of the relative cost-effectiveness of alternative investment strategies by comparing user costs and other system performance measures across modes and projects. While airline fares and freight rates are not technically a cost in an economic sense, they do represent a major cost of using the system to the traveler and shipper and act as a surrogate for the various cost

elements faced by the airlines. More importantly, this information is critical to the effective conduct of regional and state aviation system planning, and even statewide intermodal transportation planning, and thus can help to provide a link between the system performance measurement process and other system planning activities.

Two major costs faced by general aviation aircraft owners that are affected by airport development policies and funding are aircraft parking or hangar fees and the cost of fuel. These two cost elements form the major source of revenue for most general aviation airports, and thus reflect the efficiency with which the airport system is operated. In addition, taxes on aviation fuel form the source of revenue to support airport infrastructure development programs at the state and federal level. Thus these taxes are in effect payments for the use of state and federally funded airport infrastructure, and it is desirable to be able to monitor the relative contribution of these taxes to the total costs faced by aircraft owners.

The following measures are proposed:

- C6.1 Average fare paid per mile for intrastate air trips
- C6.2 Average fare paid per mile for air trips **from** California to domestic destinations outside the state
- C6.3 Average fare paid per mile for air trips **to** California from domestic origins outside the state
  
- G6.1 Average annual hangar space rental cost
- G6.2 Average annual tie-down space rental cost
- G6.3 Average cost per gallon paid for aviation gasoline
- G6.4 Average cost per gallon paid by general aviation for jet fuel

The choice of the above measures reflects an attempt to address the more important issues with a reasonable number of measures, while recognizing that aircraft operators do not all desire the same type of facility, nor view the tradeoff between cost and services equally. Expressing the measures in terms of the percent of based aircraft or itinerant operations is an attempt to reflect the choices available to aircraft owners, as well as those actually made. Thus the higher the percentage of based aircraft at airports with available storage space, the greater the likelihood that owners can

base their aircraft at their preferred airport. The higher the percentage of itinerant operations at airports with control towers, the more likely it is that any given operation can choose a convenient airport with air traffic control services.

The use of average fuel cost as a system performance measure reflects two issues: the fact that fuel flowage fees form a significant source of revenue at many airports, and the effect of economies of scale on the cost of providing fuel. Thus these costs are not only a reflection of a major component of aircraft operating cost, that is driven in part by factors outside the control of the aviation system, but also a reflection of how efficiently the system provides fuel to aircraft operators as well as how airports recover their operating costs.

Missing from the above measures is any explicit measurement of air cargo service quality from the shipper perspective. As with airport access, the difficulty is lack of appropriate data. Unlike passenger fares, there is no readily available data on air freight costs below the level of the carrier. As discussed by Tsao (1998), the only public data on shipment patterns results from national surveys conducted intermittently and with sample sizes that limit their applicability below the level of the state. Efforts to conduct regional surveys of air cargo activity have met with mixed success. This too is an area that could benefit from further research to develop suitable measures of performance.

### **Economic Well-Being**

Final demand is an appealing measure for economic well-being, since it represents the total expenditure of households on goods and services, after adjusting for government purchases, investments and net exports. Of course, what determines well-being is not aggregate consumer spending, but consumer spending per household, although this is a fairly trivial adjustment. However, the use of input-output analysis as a measure of the contribution of the transportation system to economic well-being is more problematical. What matters is not the share of transportation final demand in gross regional or state product, but rather the productivity of the transportation sector in meeting the travel and shipment needs of the other sectors. The share of final demand accounted for by the transportation sector could decline for two reasons. One would be if households found that they needed to spend more of their income on other goods and services (such as housing or food) and in consequence had to reduce their travel expenditure. This would be

bad. On the other hand, the transportation share could also decline if other sectors of the economy found that they needed to spend less on transportation to produce the same output, and in consequence prices fell and households purchased more of those goods and services. This would be good, partly because households presumably derive greater value from these new spending patterns (or they would not have changed) and partly because some of the productivity gains will translate into growth as more money flows into households, which then spend more, leading to higher levels of final demand.

Fortunately, productivity can be measured directly without having to resort to input-output models. From the standpoint of the state aviation system, the critical issue is the productivity of the airport system. However, this must be viewed more broadly than simply the inputs provided by the airport authorities, and also consider the airport-related inputs by the airlines as well as the air traffic control system. One difficulty that needs to be addressed is the requirement that different components of airport traffic, such as cargo versus passengers or international versus domestic passengers, require different facilities and resources. While this is a classic problem of joint costs, a relatively simple approach is to define each component of the traffic mix in terms of "equivalent passengers," although developing appropriate equivalency factors will require some research.

In the case of general aviation, the relevant output measure is aircraft operations. However, appropriate techniques for measuring the contribution of general aviation to economic growth are even less clear than for commercial aviation, and deserve further research.

The following measures are proposed:

- C7.1 Commercial airport productivity in terms of equivalent passengers per dollar of annual operating cost, including airline station costs and annualized cost of capital investments in airport and air traffic control infrastructure
  
- G7.1 General aviation airport productivity in terms of aircraft operations per dollar of annual operating cost, including annualized cost of capital investments and provision of air traffic control services

## **Sustainability**

Measuring the average percentage of household income devoted to air transportation expenditures can be done in one of two ways, either directly through household spending surveys or indirectly by estimating the total expenditure on air transportation within the state and the



proportion of this incurred by California households. Expenditures on commercial air travel can be separated into the cost of trips originating in California and the cost of those originating elsewhere. The cost of California originating trips should be adjusted for trips originating in the state by nonresidents or paid for by businesses, as well as trips originating elsewhere but paid for by California households.

In the case of general aviation, the relatively low number of households owning aircraft may make the direct survey approach not only statistically invalid, but potentially misleading. A significant change in aircraft ownership and operating costs could still be less than the margin or error in the estimates of automobile ownership and operating costs on an average household basis. It may be more useful to estimate the aircraft ownership and operating costs per aircraft owner rather than per household. In either case, adjustments will need to be made for corporately owned aircraft and business use of individually owned aircraft.

Neither approach accounts for two important aspects of the ability of future generations to meet their transportation needs, which lie at the heart of concerns for sustainability. The first is the dependence of the transportation system on oil-based fuels and the potential implications for future trends in the real cost of transportation, while the second is the issue of deferred maintenance and renewal of the transportation infrastructure.

The use of direct household expenditure as a measure of sustainability also ignores two other issues. The first is trends in transportation costs faced by businesses, which may show very different patterns from those faced by households, yet still ultimately impact both household income and spending. The second is changing household spending priorities as real incomes rise or relative prices of goods and services change. It is well known that higher income households spend a higher proportion of their income on services, including air travel. Thus as average real incomes rise, one would expect an increase in the proportion spent on air travel. Similarly, if the relative cost of air travel changes relative to other goods and services, housing for example, one would expect households to adjust the proportion of their income spent on air travel.

The following measures are proposed:

- C8.1 Average percentage of household income spent on commercial air travel
- C8.2 Average percentage of gross state product spent on commercial air transportation

- C8.3 Average fuel consumption per ton-mile of all commercial flights originating in California
- C8.4 Percent of airfield pavement at commercial service airports in California in fair condition, as reported in the FAA Airport Safety Data Program
- C8.5 Percent of airfield pavement at commercial service airports in California in poor condition, as reported in the FAA Airport Safety Data Program
  
- G8.1 Average cost of owning and operating a private aircraft used primarily for personal flying
- G8.2 Average cost of owning and operating a private aircraft used primarily for business purposes
- G8.3 Percent of airfield pavement at general aviation airports in California in fair condition, as reported in the FAA Airport Safety Data Program
- G8.4 Percent of airfield pavement at general aviation airports in California in poor condition, as reported in the FAA Airport Safety Data Program

The issue of airport maintenance deserves some comment. While the standard of maintenance of the airport facilities, such as pavement condition, is a matter of considerable concern to airport managers, it is less clear how it should be reflected in system performance measures. In a free market for airport services, aircraft owners will presumably choose to base their aircraft at an airport that provides them with their desired combination of cost and quality of facilities. Some owners will put up with cracked and deteriorating pavement in order to take advantage of lower airport fees. Others will want well-maintained facilities and be prepared to pay the higher fees associated with this. As long as aircraft owners can find space at their preferred airport, the degree to which airports are maintained may be an issue to be resolved by the market.

There are two caveats to this. The first is that conditions should not be allowed to deteriorate to the point where a safety hazard is created. The other is that maintenance should not be deferred to the point where the need to reconstruct the facilities costs more than maintenance to preserve an acceptable condition would have.

## **Environmental Quality**

While conformity with existing environmental standards is one measure of the performance of the transportation system, there is a need for measures that provide an indication of progress toward achieving conformity and improved performance beyond the established standards.

The following measures are proposed:

- C9.1 Number of households exposed to aircraft noise levels exceeding 65 dB California Noise Equivalent Level (CNEL) near commercial service airports
- C9.2 Number of households exposed to aircraft noise levels exceeding 60 dB CNEL near commercial service airports
- C9.3 Tons per year of carbon monoxide (CO) generated by aircraft operations at commercial service airports in the state
- C9.4 Tons per year of volatile organic compounds (VOC) generated by aircraft operations at commercial service airports in the state
- C9.5 Tons per year of nitrogen oxides (NO<sub>x</sub>) generated by aircraft operations at commercial service airports in the state
- C9.6 Tons per year of sulfur dioxide (SO<sub>2</sub>) generated by aircraft operations at commercial service airports in the state
- C9.7 Tons per year of greenhouse gases generated by commercial aircraft operations departing from airports in the state
- C9.8 Vehicle-miles of travel per year by automobiles making trips to and from commercial service airports
- C9.9 Vehicle-miles of travel per year by diesel or gasoline powered buses or passenger vans making trips to and from commercial service airports
- C9.10 Vehicle-miles of travel per year by low-emission buses or passenger vans making trips to and from commercial service airports
- C9.11 Vehicle-miles of travel per year by trucks making trips to and from commercial service airports
  
- G9.1 Number of households exposed to aircraft noise levels exceeding 65 dB CNEL near general aviation airports
- G9.2 Number of households exposed to aircraft noise levels exceeding 60 dB CNEL near general aviation airports

- C9.3 Tons per year of criteria pollutants (CO, NO<sub>x</sub>, VOC and SO<sub>2</sub>) generated by aircraft operations at general aviation airports in the state
- G9.4 Vehicle-miles of travel per year by automobiles making trips to and from general aviation airports

### **Safety and Security**

Although aviation accident rates are very low compared to other modes of transportation, they are of great concern to air travelers. While users of the air transportation system is well protected against typical crimes that occur in other public modes, potential terrorist attacks on airports or aircraft remain a concern. Although aviation safety and security is largely the responsibility of the federal government, the state has a role in improving the safety of the general aviation sector through airport improvements and pilot education programs.

Because of the low number of commercial airline accidents, it will be necessary to use systemwide accident rates and a multi-year average rate to avoid wide year-to-year fluctuation in the performance measure. The issue of whether California commercial service airports are more or less safe than other U.S. airports can probably not be determined with any statistical confidence from accident data.

The following measures are proposed:

- C10.1 Accident rate on commercial airline flights, expressed as the moving average five-year probability of being killed on a commercial flight taken at random from a California airport
- G10.1 Accident rate to general aviation operations, expressed as the number of fatal accidents per flight hour

The choice of proposed measures addresses the *outcome* of interest, the accident rate, rather than the existence and condition of physical facilities, which represent the means by which safety is improved. While improving safety-related facilities *should* reduce accident rates, the desire to measure the extent to which this is the case is precisely why the performance measures should address the *ends* and not the *means*. This is not to say that data on the physical facilities should not be collected. Indeed they should. But these data are *not* measures of system performance in the sense used in this paper.

Another consideration is the need for consistency in measuring safety across different modes. Measures of aviation facilities, such as the number of control towers or instrument landing systems, that have no parallel in other modes, do not allow a meaningful cross-modal comparison of system performance.

## **Equity**

The concept of travel time benefits by income group is problematical in the context of the air transportation system. In the first place, the use of air travel varies widely by income group, and thus any benefits will naturally tend to accrue to higher income groups, even if all income groups are treated equally in matters of public policy (or even if policies favor lower income groups, such as by subsidizing public transportation access to airports). Secondly, it is not clear that user benefits from the air transportation system arise primarily from travel time savings, which are likely to be very modest compared to other aspects of the system performance. In fact, perhaps the most significant development in air transportation during the past twenty years that has broadened the access to air travel among lower income groups has been the development of yield management systems that have resulted in deeply discounted fares for people willing to make reservations well in advance and stay away over a Saturday night.

However, there are two aspects of achieving a fair distribution of benefits and burdens from transportation investments that are particularly germane in the context of the air transportation system. The first is the geographical distribution of airport development funding between large metropolitan areas and smaller communities. The second is the difference in the distribution of the benefits of air transportation, that are spread broadly across the region served by an airport, and the adverse impacts of aircraft noise, traffic congestion, and other externalities that fall disproportionately on the communities adjacent to airports. While it is not obvious from a policy perspective whether investments should be based on need or contribution to the underlying revenues, the aviation system performance measures can at least report the distribution. Since investments at individual airports tend to involve large amounts at irregular intervals, it would seem appropriate to average the investments over a long enough period to span more than one investment cycle.

The following measures are proposed:

- C11.1 Ten-year moving average of federal Airport Improvement Fund grants at each commercial service airport, expressed as a ratio of the enplaned passenger traffic at the airport
- C11.2 Ten-year moving average of aircraft noise mitigation program expenditures by airport authorities in communities adjacent to the airport, expressed as a ratio of the number of households within the 60 dB CNEL contour
- C11.3 Ten-year moving average of airport ground access/egress traffic mitigation program expenditures by airport authorities, expressed as a ratio of the enplaned passenger traffic at the airport
  
- G11.1 Ten-year moving average of state airport development grants to general aviation airports in each county, expressed as a ratio of the number of registered aircraft owners with addresses in the county
- G11.2 Ten-year moving average of state airport development grants to general aviation airports in each county, expressed as a ratio of the number of based aircraft at airports in the county

### **Customer Satisfaction**

Customer satisfaction is necessarily a subjective matter that is best measured by survey techniques. Several airports already conduct air passenger surveys with this objective. However, the definition of customer satisfaction indices will need to be closely coordinated with the measures being developed for other modes, in order to ensure cross-modal consistency in the resulting measures. The development of appropriate survey-based satisfaction indices will be a complex undertaking, the details of which will require significant further research.

The following measures are proposed:

- C12.1 Air passenger satisfaction index
- C12.2 Air cargo shipper satisfaction index
  
- G12.1 Aircraft owner satisfaction index

Customer satisfaction with a transportation system involves many aspects, and the only reliable way to know how individuals balance the different factors is to ask them. Trying to infer their satisfaction by measuring the physical system is at best speculative, and at worst may lead to entirely false conclusions. For example, expanding facilities may reduce congestion but increase passenger walking distance and cost, and thereby lead to an overall reduction in satisfaction.

## **9. Implementing Performance Monitoring**

The previous chapter presents a proposed initial set of aviation system performance measures. There remain three issues that must be addressed to design an effective performance monitoring system:

1. What specific data to collect on a routine basis;
2. Where to obtain the data;
3. How to present the data in a form useful to decision makers.

Since the development of a formal performance monitoring process for the aviation system is a new undertaking for the State of California, and indeed for most, if not all, other states, it can be expected to be an evolutionary process. As the results of initial efforts become available to decision makers, it will become clearer which measures are most useful and which additional measures are needed. Also, as experience is gained in assembling and presenting the data, it will become easier to expand the range and sophistication of the performance measures used. This suggests that initial efforts should focus on developing a fairly limited set of measures that capture the more obvious aspects of the aviation system performance, that can be expanded later as resources permit and experience is gained.

Even so, capturing the scale and complexity of the California aviation system is no trivial task, and careful thought needs to be given, not only to what measures to use, but at what level of detail to assemble the data and present the measures. Individual communities will naturally tend to want to see the performance measures presented in a way that allows them to identify the performance of the system at the particular airports serving their community, and how this compares with other communities across the state. However, for the purposes of formulating state policies, it is necessary to be able to aggregate the measures from individual communities or airports to a regional and statewide level. In many cases this a nontrivial task. For example, while it is relatively easy to measure the number of destinations served with nonstop flights from an individual airport, how does one combine these measures into the equivalent regional or statewide measure? Certainly, the total of individual measures for each airport is a meaningless number, and



the average across all airports ignores the fact that improvements in the measure in one community do not make a reduction in service experienced by another community any less of concern.

### **Sources of Data**

The computation of a set of performance measures requires access to appropriate data on a routine basis. Ideally, the required data would already be collected for other purposes, so that no new data collection activity is required. Naturally, some analytical processing of the data will usually be required to extract the information in the form required, and to compute the measures. However, this can usually be automated, once the process to compute a given measure has been developed and tested. In some cases, it may be necessary to set up new procedures to obtain data from agencies that routinely collect it, but formerly did not report it to anyone on a regular basis. For example, airport authorities routinely collect large amounts of data on their operations and finances for internal use.

An extensive amount of data on commercial airline operations is available from reports that are filed by each airline with the U.S. Department of Transportation on a quarterly, and for some data monthly, basis. The Federal Aviation Administration maintains detailed records of activity at those airports where it operates control towers. In the case of nontowered airports, the airport management usually attempts to estimate activity. These estimates have been supplemented by periodic measurement of activity at selected airports using acoustical counters, under a program operated by the Caltrans Aeronautics Program.

Another potential source of data on the surface access component of the aviation system is the Intermodal Transportation Management System. However, to be able to effectively utilize the information in this system, it will be necessary to integrate it with information about the distribution of air passenger trip ends, air cargo shipping patterns, and the distribution of general aviation aircraft owners. This will require a significant research effort, both to identify the relevant data sources, develop procedures to standardize data from different sources, and integrate it with the surface transportation system performance data.

Caltrans should not underestimate the commitment of resources that will be required to develop and maintain a meaningful set of aviation system performance measures. The temptation will be to simply measure what is readily available, or define the performance measures in a way

that allows them to be easily calculated from information that is already collected. However, simple measures that do not shed any useful light on the policy issues of concern are worse than no measures at all. They establish the pretense of measuring performance, without actually doing so. While there is no merit to a system of performance measures that is more complex than necessary, there is equally no merit to a system of performance measures that are so simplified that they cannot detect the very changes that matter. Finding the correct balance will require both experimentation and considerable thought as to what aspects of the system need to be measured.

### **Presentation of Performance Measures**

To be useful to decision makers, the aviation system performance measures need not only to be updated on a regular basis, but to be presented in a format that allows trends over time to be readily identified. This suggests an annual publication that presents the performance measures for the most recent year, together with the values for each measure over the prior years. Such time series can be usefully presented in both tabular and graphical format. Tabular data provides the actual values of each measure, while graphical presentations allow trends to be easily identified and relative changes to be better understood. The publication should present the measures at local, regional and state levels.

## 10. Conclusions

Monitoring the performance of the aviation system in the state should form a critical input to both the balanced development of the state's multimodal transportation system and the continuing state aviation system planning process. The choice of aviation system measures should reflect the needs of the users of the system, both aircraft operators and consumers of commercial air transportation services, and provide a basis to guide the investment and policy decisions that shape the development of the aviation system. With the current trends toward viewing decisions on aviation system investments within the broader context of capital improvement programs across all transportation modes, shifting federal airport capital funding allocation decisions to the state level through block grants, and moves to replace aviation taxes with user fees, the definition of aviation system performance measures should be consistent with those used in other modes.

However, it is equally important that the performance measures for the aviation system are defined in a way that assists the state in defining appropriate policy or investment strategies. Thus while travel time is obviously an important measure of performance of any transportation system, simply comparing the average speed of air trips beginning or ending in the state with the average speed on the state highway system, for example, provides decision makers with little useful information. Trends over time may be more useful, although care must be taken to ensure that apparent changes are not simply the result of shifts in the composition of the market, such as an increased proportion of international or personal travel.

While it would be ideal to be able to directly measure the contribution of the aviation system to the economy of the state, there is currently little agreement on how this could be done, much less any attempt to assemble the necessary data. Therefore the best that can be done in the near term is to define a series of measures that are believed likely to serve as indicators of the economic benefits generated by the aviation system, and that could in due course serve as inputs into a more complex measure that better captures the impact on the state's economy.

## References

- Arizona Department of Transportation, 1990 Arizona State Aviation Needs Study, Technical Report, Phoenix, Arizona, 1990.
- Arizona Department of Transportation, 1995 Arizona State Aviation Needs Study, Phoenix, Arizona, 1995.
- Ashford, Norman, "Level of Service Design Concept for Airport Passenger Terminals: A European View," Transportation Research Record, No. 1199, 1988.
- Bolczak, Catherine N., *et al.*, National Airspace System Performance Measurement: Overview, MITRE Technical Report MTR 97W0000035, Center for Advanced Aviation System Development, McLean, Virginia, August 1997.
- Booz-Allen & Hamilton, Inc. Team, California Intermodal Transportation Management System - ITMS User's Guide, Prepared for California Department of Transportation, Sacramento, California, April 25, 1996.
- Brink, Marjorie, and Donald Maddison, "Identification and Measurement of Capacity and Levels of Service of Landside Elements of the Airport," Airport Landside Capacity, Special Report 159, Transportation Research Board, Washington, D.C., 1975.
- California Department of Transportation, 1993 California Transportation Plan, Sacramento, June 1995.
- California Department of Transportation, System Performance Measures Project Discussion, California Transportation Plan, Transportation System Performance Measures, Issue Paper # 1, Transportation System Information Program, Working Draft, Sacramento, October 1997.
- California Department of Transportation, The California Aviation System Plan - Policy Element, Sacramento, January 1998.
- California Department of Transportation, California Aviation System Plan: Capital Improvement Program, Aeronautics Program, Sacramento, California, January 1998.
- California Department of Transportation, 1998 California Transportation Plan - Transportation System Performance Measures Final Report, Sacramento, August, 1998.
- Cunningham, Lawrence F., and James H. Gerlach, Ground Access Assessment of North American Airport Locations, Report No. CDOT-DTD-R-97-2, Prepared for the Colorado Department of Transportation, University of Colorado at Denver, Final Report, September 1996.

- Garrison, William L., David Gillen and Christopher R. Williges, Impacts of Changes to Transportation Infrastructure and Services: How Improvements in Air Transportation Infrastructure and Services Enabled Innovations in Recreational Activities, 1955-1995, Research Report UCB-ITS-RR-97-4, Institute of Transportation Studies, University of California, Berkeley, July 1997.
- Geisinger, Kenneth, Airline Delay: 1976-1986, Report No. FAA-APO-88-13, Federal Aviation Administration, Washington, D.C., March 1989.
- Gosling, Geoffrey D., Development of a Recommended Forecasting Methodology for Aviation System Planning in California, Research Report UCB-ITS-RR-94-7, Institute of Transportation Studies, University of California, Berkeley, July 1994.
- Gosling, Geoffrey D., "Analysis of Changes in Airport Ground Access Mode Use," Rebuilding Inner City Airports, Proceedings of the 24th International Air Transportation Conference, Louisville, Kentucky, June 5-7, 1996, American Society of Civil Engineers, New York, 1996.
- Gosling, Geoffrey D., and Samuel W. Lau, Evaluation of a California Demonstration of an Automated Airport Ground Transportation System, Research Report UCB-ITS-RR-95-3, Institute of Transportation Studies, University of California, Berkeley, May 1995.
- Hill, Mary C., Performance Measures for California Transportation System Users and Investors, Summary of a Two Day Conference Held in Sacramento on October 6-7, 1997, UCLA Extension Public Policy Program, Los Angeles, California.
- Minnesota Department of Transportation, 1996 Agency Performance Report, Final Format, November 1996.
- Muller, Carlos, and Geoffrey D. Gosling, "A Framework for Evaluating Level of Service for Airport Terminals," Transportation Planning and Technology, Vol. 16, No. 1, 1991.
- Ndoh, N.N., and N.J. Ashford, "Evaluation of Airport Access Level of Service," Transportation Research Record, No. 1423, October 1993.
- Oldham, Charles C., The California Aviation Capital Improvement Process, Paper presented at the Fourth National Aviation System Planning Symposium, Houston, Texas, March 25-27, 1998.
- Transport Canada, A Discussion on Level of Service Condition and Methodology for Calculating Airport Capacity, Report TP2027, Ottawa, Canada, April 1979.
- Tsao, H.-S. Jacob, The Role of Air Cargo in California's Goods Movement, White Paper prepared for the California Department of Transportation, Institute of Transportation Studies, University of California, Berkeley, March 1998.

Shapiro, Phillip S., *et al.*, Intermodal Ground Access to Airports: A Planning Guide, Report No. DOT/FAA/PP/96-3, Prepared for the Federal Highway Administration and Federal Aviation Administration, Bellomo-McGee, Inc., Vienna, Virginia, December 1996.

U.S. Department of Energy, How to Measure Performance: A Handbook of Techniques and Tools, Prepared by the Training Resources and Data Exchange (TRADE) Performance-Based Management Special Interest Group, Oak Ridge Institute for Science and Education, October 1995.

U.S. Federal Aviation Administration, Planning the State Aviation System, Advisory Circular No. 150/5050-3B, Washington, D.C., January 1989.

U.S. Federal Aviation Administration, National Plan of Integrated Airport Systems (NPIAS) 1993-1997, Report to Congress, Washington, D.C., April 1995.

U.S. Federal Aviation Administration, Documentation for the Consolidated Operations and Delay Analysis System, Office of Aviation Policy and Plans, Washington, D.C., September 1997.

U.S. Federal Aviation Administration, 1997 Aviation Capacity Enhancement Plan, Washington, D.C., December 1997.

U.S. Federal Aviation Administration, Air Traffic Services Performance Plan - Fiscal Years 1998-2000, Washington, D.C., October 1998.