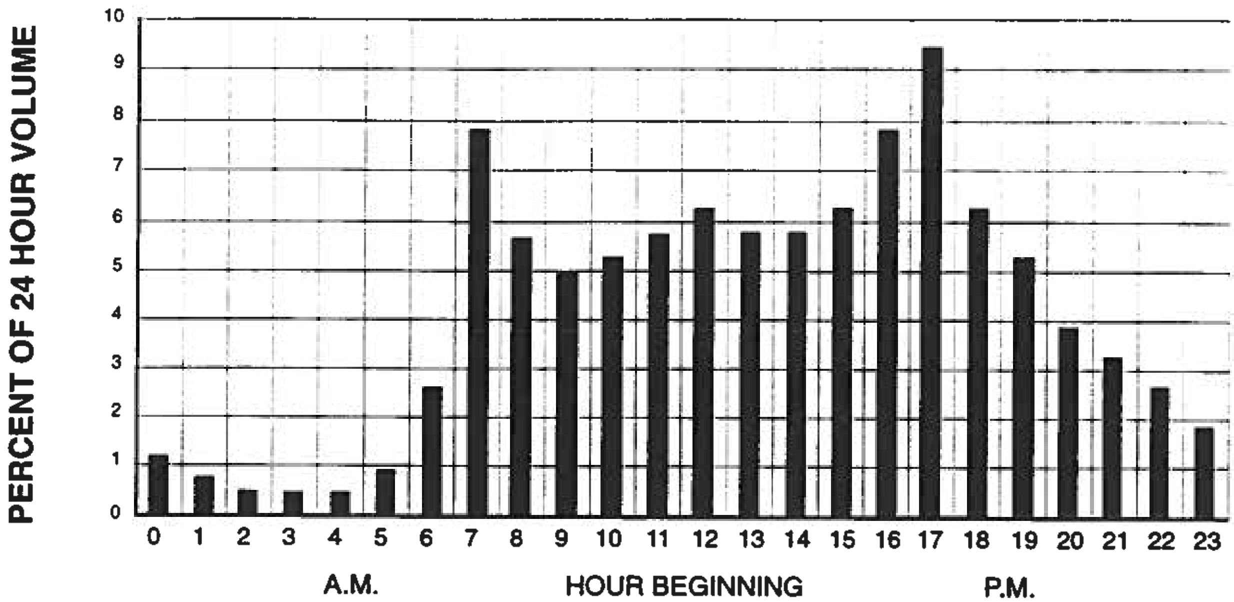
Chapter Two—Experience in Measuring Performance

Basic Factors in Measuring Operations on Arterial Streets

Most simple performance measures address "quality of service." Quality of service is typically described by terms such as "Congestion", "Level of Service" and "Safety". A summary of qualitative measures is presented in Table 2.1. Congestion is described by comparative values of travel time (e.g. the speed at which traffic is flowing) or delay (the expected and perceived time waiting in a queue or traveling to a destination). Level of service is a composite index which qualitatively describes different operating conditions based on speed, traffic flow and interruptions, driver comfort and freedom to maneuver, and safety. Safety is also a perceived measure, but quantified based on the number of accidents or frequency of accidents, by type, relative to traffic volume at a given location.

Transportation operational performance parameters describe quantitatively how well or efficiently the travel demand is processed by the facility. Composite qualitative measures such as "Level of Service", implicitly describe travel efficiency by using a descriptive index which relates demand (traffic volume) and capacity of a facility. Typically qualitative measures have relatively few index levels (six, A through F, for Level of Service). Each index level is descriptively broad, and is not sensitive to most changes in system performance. Changes in traffic signal timing, which may improve traffic flow and travel time by as much as ten percent will not often be reflected in Level of Service indices. Similarly, these indices are often interpreted and perceived differently. Average operating conditions on an urban route are perceived differently than are average operating conditions on a rural route, even though the indices are based on common relative values. Level of Service describes an operational condition for a designated location and time period. A roadway may operate at Level of Service C, average conditions, during one time of day, one season of the year or at one location along a route, as travel demand varies.

Operational performance of a facility varies proportionately with changes in travel demand. Travel demand varies hourly, with demand peaking during morning and evening commute to work periods. See Exhibit 2.1. Peak hour travel demand measured in vehicles, may represent 8 to 15 percent of the total travel on a given route over a twenty-four hour period. As a percentage of total daily travel, peak hour travel is generally a lower percentage on urban arterials and a higher percentage on rural arterials. Travel demand measured in terms of persons, rather than vehicles, varies more significantly by time of day and location. On rural routes with limited public transit, person travel demand is comparable to vehicle demand adjusted for vehicle occupancy. On urban arterials, public transit service is more pervasive and frequent, capturing a higher ridership. Consequently, urban arterial person peak hour travel is higher and accounts for a larger percentage of total daily person travel than on suburban and rural arterial routes. Travel demand also varies significantly by weekday and seasons, as shown in Exhibits 2.2 and 2.3.



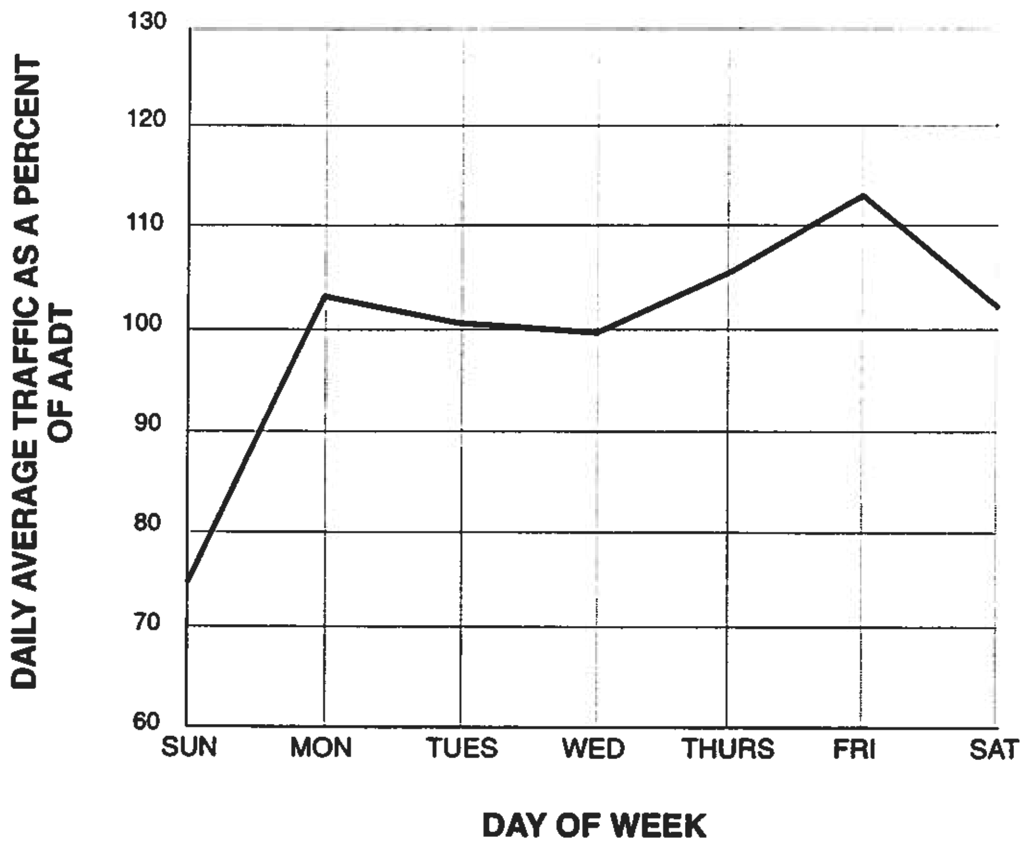
VARIATIONS IN TRAFFIC

Source: Institute of Transportation Engineers Manual of
Traffic Engineering Studies

TYPICAL PATTERN OF HOURLY TRAFFIC VARIATIONS -- WEEKDAY, URBAN AREA

SRA Strategic Regional Arterial Planning Study

Exhibit 2.1



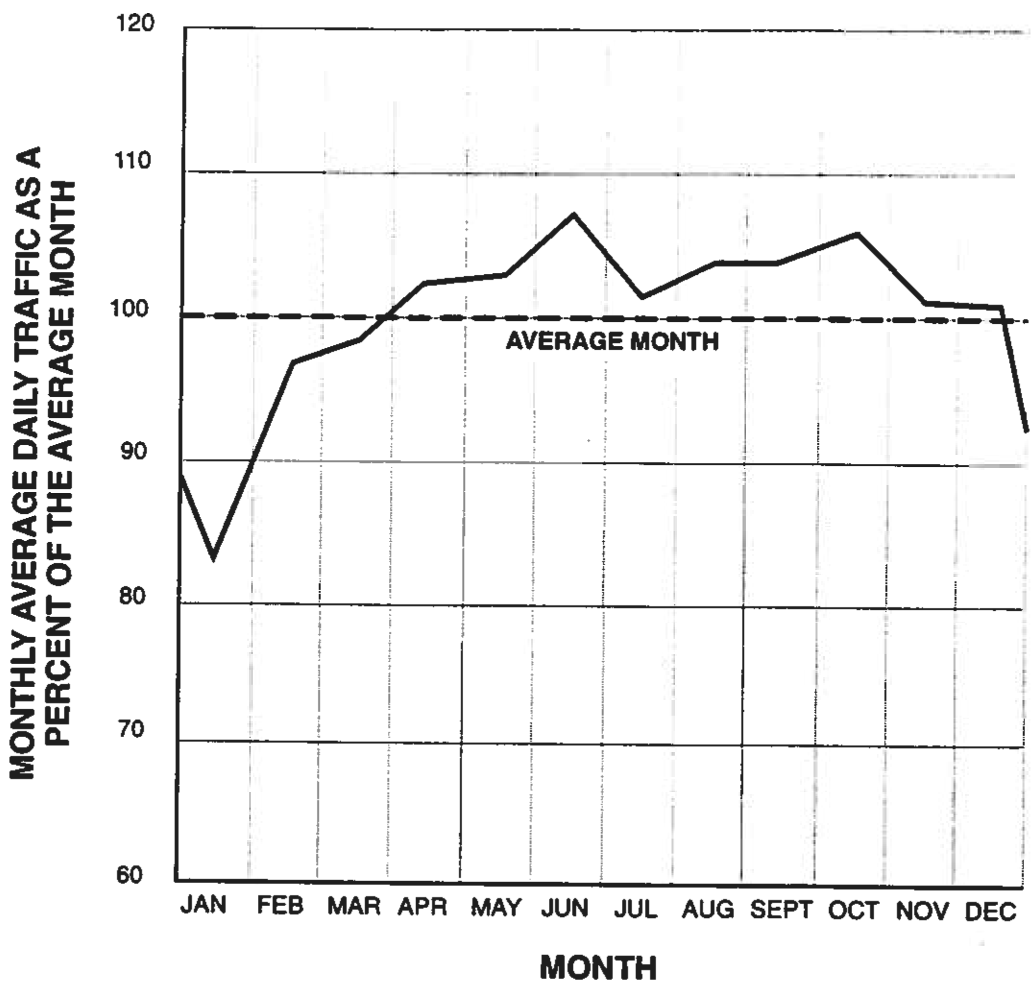
Source: Institute of Transportation Engineers Manual of Traffic Engineering Studies

EXAMPLE OF WEEKLY TRAFFIC VOLUME VARIATIONS -- URBAN AREA

T104274.13.A4 Exhibit 2.2.1 6-5-97 lg

Strategic Regional Arterial Planning Study

Exhibit 2.2



Source: Highway Capacity Manual, 1994

EXAMPLES OF MONTHLY TRAFFIC VOLUMES VARIATIONS SHOWING RELATIVE TRAFFIC VOLUME TRENDS, URBAN AREA

SRA Strategic Regional Arterial Planning Study

Exhibit 2.3

Table 2.1
Measures of the Quality of Transportation Service

Measure	Parameter	Describe/Define Applicability
Travel Time	Minutes	• Minimize overall • Dependent on origin/destination
Travel Speed	Miles per hour	• Maximize overall • Slower speeds are acceptable in urban areas, higher speeds in rural settings
Travel Rate	Minutes per mile (inverse of travel speed)	• Minimize overall • Higher rates are acceptable in urban areas, less so in rural settings
Delay	Seconds per vehicle	• Minimize overall • Longer delays are more acceptable in urban areas, less so in rural settings
Density	Vehicles per mile	• Minimize overall • Longer delays are more acceptable in urban areas, less so in rural settings
Level of Service	A–F	• Acceptable LOS: – Rural—B or C – Suburban—C or D – Urban—D or E
V/C (or Load Factor)	Ratio of traffic demand in vehicles per hour to capacity	• Minimize • Criteria vary by area type
Lane Occupancy	Ratio = LO = $\frac{\sum_{i=1}^{N}(\frac{L_i}{S_i})}{T}$ L = vehicle length S = vehicle speed T = sampling interval N = number of vehicles within interval T	• Another measure of demand to capacity • Higher lane occupancy is more acceptable in urban settings.

Table 2.1
Measures of the Quality of Transportation Service

Measure	Parameter	Describe/Define Applicability
Accident Rate Severe Accident Rate	Accidents per MEV (for intersections) or Accidents per MVM (for extended highway segments) Fatal and injury accidents per MEV (or MVM)	• Minimize overall • With higher volumes (urban areas), higher accident rates tend to occur
Percent of Bus-Miles with Standees	Percentage	• Minimize (passenger view point) • Maximize (bus service view point)
Average Bus Load	Percentage of seating capacity	• Maximize (bus service view point)
Bus Coverage	Population within ¼ mile of route	• Maximize overall
Transit Transfer Time	Minutes	• Minimize overall
Frequency	Buses per hour	• Higher number in urban area
Driver Effort	Ratio $N_{+} = [\Delta_s x \Delta_{\tau+} x \Delta_\theta]/D$ $\Delta_s = \Sigma$ Speed Δ's $\Delta_{\tau+}$ = Incremental time $\Delta_\theta = \Sigma$ Direction Δ's D = Total distance	• Higher ratio more acceptable in urban settings
Galvanic Skin Response	Electrical Conductance	• Minimize overall • Measures tension (more tension expected in urban settings)

Weekday travel demand variations are less pronounced on urban arterials and more pronounced on rural arterials. Seasonal travel demand follows the same curvilinear trend on both rural and urban routes, with the exception of tourism sensitive facilities where seasonal peaks are more pronounced. Consequently, operating performance measures must vary proportionately with the range of temporal variations in travel demand.

Measures of travel demand are listed in Table 2.2. Travel demand refers to the number of persons or vehicles which use a facility over a specified time period. This quantifies the actual users, but not the potential users. The volume of actual users is derived from counts of vehicles or persons passing through a specific location and is expressed in terms such as vehicles or persons per time interval. Travel based units are computed from actual counts of vehicles at one or more locations for a specified length of road and expressed in terms of vehicle-miles traveled. For transit, travel based units are computed based on transit vehicle and passenger occupancy counts for a specified route length, and are expressed in terms of passenger- miles traveled. Other demand measures relate to length of travel, time or directional variations in travel demand. The most simplistic and accurate measures of travel demand are actual counts of vehicles by direction of travel and by time period.

Travel supply measures capacity, the expected number of vehicles or persons that a facility can process over a specified interval of length and time under prevailing conditions. Transportation supply is a theoretical capacity adjusted for specific physical and operational characteristics. Physical characteristics which control available capacity are the number of travel lanes, width of the lanes, presence or absence of shoulders or medians, curvature, and grades or slopes. Operational characteristics which control available capacity are speed limits, traffic signals, other traffic regulatory controls, intersections and driveways, mix of vehicles, pedestrian crossings and presence of on-street parking. For transit, passenger capacity of the vehicle, frequency of service, and spacing of passenger boarding/alighting locations also affect supply. Several common measures of roadway capacity are presented in Table 2.3. Each of these measures quantifies the practical capacity of the roadway for prevailing conditions at a particular location. These measures are location dependent and do not interrelate system wide variations which typically prevail on metropolitan area arterial routes.

Table 2.2
Measures of Demand for Transportation Service

Measure	Parameter	Describe/Define Applicability
Corridor Throughput	Total vehicles or persons (in a given time period)	Compare to capacity or trip-carrying capability of the corridor or network
Average Daily Traffic	Vehicles per day	
Average Daily Person Trips	Persons per day	
Average Trip Length	Miles per trip	
Average Auto Occupancy	Persons per vehicle	
VMT	Vehicle-miles of travel	
PMT	Person-miles of travel	
K	Percent of daily traffic during peak or critical hour	
D	Percent of peak hour traffic in peak direction	

Table 2.3 Measures of Capacity		
Measure	**Parameter**	**Describe/Define Applicability**
Maximum uninterrupted flow rates	Vehicles per hour or equivalent passenger cars per hour per lane	Maximize—values based upon research and experience for different highway types (2,000 to 2,400 pcphpl)
Σ Critical lane volumes (at intersections)	Vehicles per hour per lane	Intersection capacity measure (1,400 to 1,600 vphpl)
Saturation flow rate (at intersections)	Passenger cars per hour per lane	1,800 to 2,000 pcphpl for discharge from stopped position—values based upon research and experience
Intersection approach capacity	Vehicles per lane hour of green	Approach capacity (400 to 900 pcph/g)
Transit capacity	Passengers per hour per lane to 8,000	Based on frequency of services, number of transit routes with common link and seated capacity of transit vehicles. [3,000 pass/hr (suburban) to 8,000 pass/hr (urban)]

Composite Performance Indices

A number of authors have developed and utilized what are referred to as composite indices of operational performance. These are summarized in Table 2.4. Composite indices have the advantage of expressing the combined effects of many operational characteristics in one number. These indices combine measures of quality, demand, and/or cost of transportation into one equation or formula. The resultant value is often non-dimensional, and implicitly takes into account several factors. A disadvantage, however, is that it requires interpretation and explanation to describe the result, and therefore the significance of the result is often missed or not perceived. Indices which measure time and delay, characteristically result in an index whose relative value increases as conditions deteriorate. The Congestion Index, proposed in HRB Special Report 130, is essentially a ratio of actual traveltime to optimal traveltime. Hence as conditions deteriorate, the actual traveltime will increase and the ratio will increase. The result is an inverse index, which is often prone to misinterpretation.

Composite indices are intended to measure system wide or regional changes and therefore are biased toward the dominant characteristic or segment of the population. For example, the Congestion Severity Index relates total delay to million miles traveled. Delay and miles traveled are disproportionately higher on urban routes compared to rural routes. Therefore significant changes on rural routes will not be reflected in this index.

Table 2.4
Summary of Composite Operational Indices

Index	Author/Reference	Definitions	Remarks
Congestion Index	*Measures of the Quality of Traffic Service—HRB Special Report 130.* 1972.	Ratio of actual time of occupancy of vehicles on road to optimum time	
Congestion/ Demand Ratio	*Measures of the Quality of Traffic Service—HRB Special Report 130.* 1972.	Ratio of number of vehicles in queue of less than one car length separation divided by total number of vehicles on the road	Combines "quality of service" with "demand"
Delay Ratio	*Measures of the Quality of Traffic Service—HRB Special Report 130.* 1972.	Delay time per mile divided by travel time per mile	
Sufficiency Ratio	*Measures of the Quality of Traffic Service—HRB Special Report 130.* 1972.	Point rating assigned to each section of road based on its "sufficiency," as compared with a uniform set of standards to carry traffic load safely and efficiently	
Greenshields Number (GN)	*Measures of the Quality of Traffic Service—HRB Special Report 130.* 1972.	$GN = (t/d) \times \Delta_s \times \Delta_o$ Index that indicates the roughness of short segments of a route	t = elapsed time for section d = length of section Δ_s = total change in speed Δ_0 = total change in direction
Composite Index	*The Highway Performance Monitoring System Analytical Process, Volume II.* Technical Manual. U.S. Dept. of Transportation. March 1983.	Sum of three indices: (Condition + Safety + Service)	

Table 2.4
Summary of Composite Operational Indices

Index	Author/Reference	Definitions	Remarks
Energy Concept	*Measures of the Quality of Traffic Service—HRB Special Report 130.* 1972.	KE = density x $(\text{speed})^2$	Optimization depends on finding those values of density and speed that maximize the kinetic energy of the traffic stream
Percent of Vehicle Miles that Exceed LOS C	North Central Texas Council of Governments	Percent of vehicle miles that exceed volume to capacity ratio of LOS C	Combines daily and peak period demand measures with capacity
Cost Effectiveness Index	*The Highway Performance Monitoring System Analytical Process, Volume II.* Technical Manual. U.S. Dept. of Transportation. March 1983.	Composite of improved conditions: composite index, base year composite index, AADT, the economic life of the improvement, section length, and the cost of the improvement	Combines measures of quality of service, demand, and cost
User Satisfaction Index	*Long-range Transportation Plan Re-evaluation.* Technical Supplement. National Capital Region Transportation Planning Board/Metropolitan Washington Council of Governments. December 1982.	A measure of congestion obtained by interviewing people about trip convenience, with a threshold expressed in terms of airline speed as a function of airline distance	
Congestion Severity Index	Lindley, J.A. *Quantification of Urban Freeway Congestion and Analysis of Remedial Measures.* Federal Highway Administration. October 1986.	Ratio of total delay to million vehicle miles of travel	Combines quality of service with total demand measures

Table 2.4
Summary of Composite Operational Indices

Index	Author/Reference	Definitions	Remarks
Corridor Mobility Index (for freeways and arterials)	Texas Transportation Institute.	$\frac{(Travel\ Speed) \times (Peak\ Hour\ person\ volume\ per\ lane)}{v}$	Combines quality of service with demand $v = v_f = 100{,}000$ for freeway $v = f_a = 20{,}000$ for arterial
Roadway Congestion Index	Lomax, Timothy J. and James W. Hanks, Jr. *Roadway Congestion in Urbanized Areas—1982 to 1988.* July 1990.	Areawide Congestion Index $RCI = \frac{[(Freeway\ VMT\ /\ lane\text{-}mile)(Freeway VMT)] + [(Prin.\ Art.\ St.\ VMT\ /\ lane\text{-}mile)(Prin.\ Art.\ St.\ VMT)]}{(13{,}000 \times Freeway\ VMT) + (5{,}000 \times Prin.\ Art.\ St.\ VMT)}$	
Level of Service Index	*Measures of the Quality of Traffic Service—HRB Special Report 130.* 1972.	[Quality of Traffic Flow + (Driver Satisfaction / Driver Effort)] - Driver Annoyance Due to Delay	
Number of Hours at LOS E–F Operation	California Department of Transportation; North Central Expressway Planning Study	Number of hours of level of service E–F operation	Measures the extent of congestion on major urban roadways
Individual Congestion Index (ICI)	*Development of Preliminary Congestion Indices for Urban Freeways in Texas.* Texas Transportation Institute. June 1979.	$\frac{Delay\ Time\ (Minutes)}{10''} + \frac{AADT\ /\ Lane}{20{,}000}$	

Table 2.4
Summary of Composite Operational Indices

Index	Author/Reference	Definitions	Remarks
Commuter-Oriented Individual Congestion Index (CICI)	*Development of Preliminary Congestion Indices for Urban Freeways in Texas.* Texas Transportation Institute. June 1979.	$\frac{\text{Delay Time (Minutes)}}{10''} + \frac{\text{AWT / Lane x P.M. Directional Split}}{10{,}000}$	
Societal Congestion Index (SCI)	*Development of Preliminary Congestion Indices for Urban Freeways in Texas.* Texas Transportation Institute. June 1979.	$ICIx \frac{ADT}{100{,}000}$	
Consumer-Oriented Societal Congestion Index (CSCI)	*Development of Preliminary Congestion Indices for Urban Freeways in Texas.* Texas Transportation Institute. June 1979.	$CICI \times \frac{\text{200th Hourly Vol. x P.M. Dir. Split}}{6{,}000}$	

Perhaps the best known set of composite indices is the Texas Transportation Institutes series of indices listed at the bottom of Table 2.4 (RCI, ICI, CICI, SCI, CSI). These have been used to characterize the overall congestion in an urban area, and to provide comparisons between cities. They have also been used by some planners and researchers to measure the combined impacts of major roadbuilding, demand management, and regional growth over time.

Composite indices may have value to CATS or others who desire broad measures of regional transportation conditions on the SRA system. Their utility is limited, however, in providing corridor or project-specific insights.

The composite indices presented in the literature, typically focus on one or two measures of performance: travel delay or time and traffic volume. A third measures of route performance such as traffic safety, is not included. Performance of safety oriented operational improvements cannot be readily determined from these composite indices. Safety oriented operational improvements such as combining multiple driveways in a signalized common driveway, may increase travel time and decrease throughput volume. The composite index could misleadingly result in an implied worsening condition.

The disadvantages of such an approach are clear: the output number may not be understandable, may not reflect all important sensitivities, and may require an intensive and costly data collection effort.

Extrapolating from the composite indices presented in the literature, several alternative performance measures could be applied. These alternative measures are based on readily understood parameters such as speed, and as such may provide more meaningful results.

"Average Daily Speed" Index

This index expresses a weighted speed for all travel during a 24-hour day. The basis for weighting can be VMT (vehicle miles of travel) or PMT (person miles of travel)

Average Daily Speed = Σ Weighted Speed in Peak Hours, Midday Off-Peak, Off-Peak Periods

For each hour or period i, the average speed over section j can be observed or estimated. The average daily speed is then calculated by:

$$\sum_{i=1}^{n} \frac{(VMT \text{ or } PMT \text{ in } j)\ (Average\ Speed \text{ in } j)}{\sum_{i=1}^{n} (VMT \text{ or } PMT \text{ in } i)}$$

(if hourly, n = 24)

Example calculation: Assume a 2-mile segment of arterial carries traffic volumes at the following speeds during different times of the day

	Peak Period	**Mid-Day Off-Peak**	**Other Off-Peak**
Number of Hours	4	8	8*
Hourly Volume	2,000 vph	1,200 vph	500 vph
Average Speed in Period	15 mph	24 mph	32 mph
Average Auto Occupancy in Period	1.1	1.3	1.3

*For analysis purposes, it is assumed that traffic volume is negligible for 4 hours of the day. The weighted average daily speed is calculated as follows:

By VMT:

$$ADS = \frac{(2 \text{ miles} \times 2{,}000 \times 4)(15 \text{ mph}) + (2)(1{,}200)(8)(24) + (2)(500)(8)(32)}{(2)(2{,}000)(4) + (2)(1{,}200)(8) + (2)(500)(8)} = 22.1$$

The Average Daily Speed index measures a readily understood parameter, speed. This parameter can be related directly to criteria used to characterize arterial operations in the Highway Capacity Manual. As shown in Table 2.5, the average travel speed is related to levels of service for the range of typical arterial conditions. The relationship of arterial classification to functional classification, by design category is presented in Table 2.5.

Of course, an average daily speed index may require some explanation and interpretation, as the resultant values may not be readily understood.

Table 2.5
Arterial Levels of Service

	Arterial Classification		
	I	**II**	**III**
Range of free-flow speeds (mph)	45 to 35	35 to 30	30 to 25
Typical free-flow speeds (mph)	40	33	27
LEVEL OF SERVICE	**AVERAGE TRAVEL SPEED (MPH)**		
A	≥ 35	≥ 30	≥ 25
B	≥ 28	≥ 24	≥ 19
C	≥ 22	≥ 18	≥ 13
D	≥ 17	≥ 14	≥ 9
E	≥ 13	≥ 10	≥ 7
F	< 13	< 10	< 7

Source:* *Highway Capacity Manual, Transportation Research Board, October 1994

Table 2.6 Arterial Classifications According to Their Functional and Design Categories		
	Functional Category	
Design Category	**Principal Arterial**	**Minor Arterial**
Typical Suburban	I	II
Intermediate	II	II or III
Typical Urban	II or III	III

Source: *Highway Capacity Manual.* Transportation Research Board. October 1994.

Congestion Time Index

This index describes the total time during the day when the highway's operation is such that unacceptable delay or speeds occur. It measures delay as a percent of an average day.

$$CTI = \frac{\text{No. Hours of Congestion}}{24} \times 100$$

Example calculation: For the example 2-mile arterial, CTI is calculated as follows:

Assume a minimum acceptable speed of 20 mph has been established. During 4 hours of the day, speeds are lower than the minimum.

$$CTI = \frac{4}{24} \times 100 = 17 \text{ percent}$$

For this example, the arterial operates in a "congested" (i.e., unacceptable) manner 17 percent of the time.

The disadvantage of this index is that it measures unacceptable or undesirable conditions. Interpretation of the results could be misleading, as an increasing percent implies a worsening condition, and the difference between, say, 17 and 22 percent is not perceived in measurable terms. It also provides an indirect measure as it is a number derived relative to an arbitrary minimum benchmark. Finally, this number may have little meaning without adequate comparison.

Speed Index

This index combines elements of the above two indexes. It is defined as the ratio of a given segment's average daily speed to a pre-determined minimum or desirable speed for that section.

$$\text{Speed Index} = \frac{ADS}{\text{Section Speed}} \times 100$$

Example calculation: For the above example 2-mile arterial, the speed index (SI) is calculated as follows:

Assume that a minimum acceptable speed of 20 mph has been established as before. Average Daily Speed (ADS) is 22.15 mph.

$$SI = \frac{22.15\ mph}{20\ mph} \times 100 = 110.8$$

Values for SI greater than 100 imply that, on a daily basis, the arterial meets criteria.

This index is non-dimensional and requires explanation and interpretation. It is route segment based and relies on different index levels for each characteristic segment.

Quality of Service Index

A quality of service index can be derived to express the number of trips (again, expressed as either vehicle trips or person trips) over a given segment that are made at or above a pre-determined minimum acceptable speed.

$$QS = \frac{Number\ of\ Trips\ at\ Speed \geq \text{Min}}{Total\ Number\ of\ Trips} \times 100$$

Example Calculation: For the example 2-mile arterial from above, QS is determined as follows:

Assume that a minimum acceptable speed has been established as 20 mph as before.

For 4 hours of the day, this speed has not been achieved. For the remaining 20 hours, the speed has been achieved.

$$QS = \frac{4\,(2{,}000) + 8\,(1{,}200) + 8\,(500) - 4\,(2{,}000)}{4\,(2{,}000) + 8\,(1{,}200) + 8\,(500)} = 0.63$$

This index could be applied to vehicle trips or person trips.

A QS value of 1.00 implies all trips are made in an acceptable manner, i.e., with no "congestion." This index suffers from the same drawbacks presented with the composite indices, in that it requires explanation and interpretation. It measures performance based on readily understood parameters, but presents the results in dimensionless units.

Each of the indices presented measure only one or two performance parameters. Improvements in performance related to a non-measured parameter are excluded. Results presented are not pertinent to "before and after" studies of arterial improvement projects. Consequently, these performance indices do not satisfy the guideline criteria for SRA operational performance measures.

Summary

The aforementioned indices were shared with the SRA subcommittee. It was agreed that some may have merit for specific, limited application. None of the indices however, met the needs of the various agencies and CATS. These requirements are:

- A need to recognize safety as a significant benefit of SRA improvements.
- A need to be able to measure corridor or project-specific benefits as well as regional or overall benefits.

The following chapter outlines the consultant's recommended approach to addressing those needs.