

Computational Method for Performance-Oriented Statewide Highway Needs Analysis

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ABSTRACT

Existing statewide needs studies, previously used in Arizona and currently used in most states, are driven by a minimum tolerable standard, which, typically, cannot be directly related to the performance of the highway system. A revised process, developed in Arizona, is performance driven. The computational procedures select capacity, physical condition, and safety needs in response to performance standards set by the user and test the selected needs against seven performance measures. The results obtained in Arizona have yielded significant differences in costs and performance among the tested performance alternatives.

The revised process for conducting a statewide needs study in Arizona, developed in 1984, represents a significant advance in the state of the art of statewide needs study methodologies.

Existing statewide needs studies, as previously used in Arizona and as currently used in most states, are driven by a minimum tolerable standard, which, typically, cannot be directly related to the performance of the highway system. In other words, there is not a clear relationship between changes in the minimum tolerable standard and performance. Consequently, there is little capability to predict how much improvement in performance is "purchased" for a given level of improvement.

The revised process is performance driven: To initiate the process, a target performance (measured in terms of capacity, physical condition, and safety) is set. Improvements required to realize the target levels of performance are selected. Finally, each set of selected improvements (or needs) is tested for actual performance against the three target measures used to trigger improvements as well as against four additional economic and environmental measures. The performance targets may be varied, resulting in the selection of different improvements, and relationships between differing levels of needs and performance may be compared.

In the revised needs study, needs are triggered by one or more of the following performance measures:

1. Capacity (measured in terms of level of service),
2. Physical condition (measured in terms of pavement ride quality and distress), and
3. Safety (measured in terms of number of high-accident locations or rail crossing hazard index).

Five program modules compute the needs triggered by the three performance standards:

1. Capacity needs on highway links are computed over a 20-year design horizon. For urban links, the program selects from a sequential menu of transportation system management improvements, spot widenings, and full widenings. Improvements are limited

by available right-of-way. For rural highway links, the program selects from a menu of widening and relocation options.

2. Physical condition needs on highway links are selected on the basis of optimized pavement management strategies developed in the Arizona Department of Transportation pavement management system.

3. Safety needs for highway links and structures are obtained by computing the cost of reducing the number of high-accident locations in the state to target levels.

4. Capacity, physical condition, and safety feature needs for bridge structures are obtained by selecting, on the basis of a decision-tree algorithm, from a sequential menu of structural widenings, rehabilitations, and replacements.

5. Safety needs for railroad crossings are derived by computing the number of improvements needed to reduce the hazard index at railroad at-grade crossings to target levels.

Once selected, each set of needs is further tested against seven performance measures: the three initially used to trigger improvements (capacity, physical condition, and safety) and four additional measures: financial, aggregate volume-to-capacity ratio, vehicle hours of travel, and environmental.

These elements are packaged in a single computer jobstream from which a variety of worksheets and reports is produced.

PERFORMANCE STANDARDS

Capacity Performance Standard

The target capacity performance standard is defined as the peak-hour, peak-direction volume-to-capacity (v/c) ratio above which a need is said to exist. The program will attempt to select improvements to maintain the v/c ratio at a level lower (better) than the capacity performance standard for any highway link that fails to meet the standard. The program will also determine the need for any bridge structure widenings along each highway link for which a capacity improvement is selected. For example, if the target capacity performance standard is set at a peak-hour, peak-direction v/c ratio of 0.85, or level of service (LOS) D, an improvement will be selected for each link (and the structures contained

therein) with a calculated peak v/c ratio of 0.86 or worse.

The capacity performance standard can be set to reflect whatever policy alternative the user desires to test. Capacity standards set for the 1985 Arizona needs study ranged from 0.75 (LOS C), under a performance alternative that called for significant improvement in capacity, to 1.05 (LOS F), under an alternative that allowed capacity performance to decline.

Physical Condition Performance Standard

Physical condition needs for highway links are selected on the basis of two measures: pavement ride quality (or roughness) and pavement cracking (or distress). The standards for both ride quality and cracking are defined as the percentage of pavement area in good condition versus the percentage in adequate and poor condition, and the number of years into the future at which the standards are to be met. "Good" and "poor" are defined as follows:

	<u>Pavement Ride Quality</u>	<u>Pavement Cracking (%)</u>
Good	< 165 in. axle deflection/mile	< 10
Poor	> 255 in. axle deflection/mile	> 30

Note that axle deflection is measured using standard ridemeter techniques.

Three of the physical condition standards used in the 1985 Arizona needs study were set on the basis of the current percentage of pavement in good and poor condition for both ride quality and cracking within each administrative category (state, county, and city): (a) maintaining exactly the current levels of good and poor, (b) a 5 percent decrease in the amount of pavement in poor condition and a 5 percent increase in the amount in good condition under improving performance alternatives, and (c) vice versa under declining performance alternatives. A fourth physical condition standard involved degradation of pavements to the lower limit of public acceptance (80 percent poor). These standards were to be met by the fifth year into the future, after which they were to be maintained in a steady state.

Variable physical condition performance standards are not set for bridge structures. Structural condition needs are selected through a decision-tree algorithm that remains constant under all performance scenarios.

Safety Performance Standard

The performance standard for safety on highway links and structures is set in two parts: the percentage reduction or growth to be achieved or allowed in the total number of high-accident locations (HALs) in the state and the number of years into the future at which the standard is to be met. A HAL is defined as any intersection with a rate of one or more accidents per million vehicles or any road segment or structure with a priority index (a composite measure incorporating accident rates and severities) of 5.0 or greater. This definition is adopted from the Arizona Department of Transportation (ADOT) highway safety improvement program.

The performance standard for safety at railroad at-grade crossings is stated in terms of a permissible hazard index, which is defined as the annual

average number of accidents per rail crossing. The program will attempt to select an improvement for any at-grade crossing at which the calculated hazard index exceeds the standard.

The safety standards set for highway links in the 1985 Arizona needs study ranged from a "do-nothing" level (allowing the number of HALs to increase unchecked) to a 15 percent reduction in HALs across the state by 10 years into the future. Railroad safety standards ranged from a hazard index of 1.00 to a hazard index of 0.05.

COMPUTATION OF NEEDS

Highway Link Capacity Needs

The computation of capacity needs for highway links is performed link-by-link. For each highway link, the needs study computer program conducts the following procedure.

Traffic Forecasts

The needs study program determines the base year average daily traffic (ADT) volume and average annual ADT growth rate for automobiles, medium trucks, and heavy trucks on each link through one of three methods. Where recent traffic counts and future projections from either the ADOT state highway traffic forecasting program or local government planning agencies are available, these are used. If recent traffic counts are known but future projections are unavailable, the program will estimate future traffic growth through the application of projected population growth rates for each jurisdiction. Finally, if there are no traffic data available for the link, the program will fill in the gap by extrapolating ADT and traffic growth rate data from adjacent links.

ADTs by vehicle type for each future year under study are calculated from the base year ADTs and the projected average annual ADT growth rate. The yearly link peak-hour, peak-direction volumes are then determined through the application of peak-hour directional factors derived from historical data for highways within the state of Arizona.

Daily and peak-hour, peak-direction vehicle miles of travel (VMT) by vehicle type are calculated for each year by multiplying the yearly ADTs and peak-hour direction volumes, respectively, with the length of the link.

Each of the various types of calculated traffic data (daily and peak volumes, and daily and peak VMTs, each by three-way vehicle split) are used at various locations throughout the remaining procedures for the link.

Capacity Circulation

The peak-hour, peak-direction capacity of each link, as calculated by the program, is dependent on a number of variables. The equations used are

Rural two-lane undivided highway

$$C = 2000 \cdot W \cdot T \cdot 0.55$$

where

C = one-way hourly capacity,
W = lane width and lateral clearance factor, and
T = truck factor.

Freeways, rural divided highways, and rural multilane undivided highways

$$C = 2000 \cdot W \cdot T \cdot L$$

where

C = one-way hourly capacity,
W = lane width and lateral clearance factor,
T = truck factor, and
L = number of lanes in peak direction.

The capacity calculation methodologies used for these types of highways, along with the various lane width and lateral clearance factors and truck factors, were adopted from those described in the 1965 Highway Capacity Manual (1). The lane widths and lateral clearances for each link are calculated from roadway geometric data stored in the needs study data base. Truck percentages are calculated from the previously determined traffic volumes by vehicle type.

The capacity calculation methodology for urban links other than freeways was developed on the theory that urban link capacity will be controlled by intersection capacities, resulting in the equation:

$$C = B \cdot T \cdot G/100$$

where

C = one-way hourly capacity,
B = base capacity dependent on number of lanes and intersection lane configuration,
T = truck factor, and
G = percentage green time.

The base capacity for the link is derived from the following table:

No. of Peak-Direction Lanes	Base Capacity for One-Way Street	Base Capacity for Two-Way Street With Left-Turn Lanes	Base Capacity for Two-Way Street Without Left-Turn Lanes
1	1,700	1,700	1,190
2	3,400	3,400	2,720
3	5,100	5,100	4,335
4	6,800	6,800	6,035
5	8,500	8,500	7,735
6	10,200		

The truck factors were adopted from the 1965 Highway Capacity Manual (1), and the truck percentages were calculated from the previously determined traffic volumes by vehicle type.

Volume-to-Capacity Ratio

The unimproved peak-hour, peak-direction v/c ratios for the base year and for 5, 10, and 20 years into the future are calculated by dividing the peak capacity into the total peak traffic volumes for each of the years.

Capacity Needs

The link v/c ratio at 20 years from the present is compared with the capacity performance standard. If the ratio is lower than the standard, the program does not select any capacity-driven needs for the link. If, however, the ratio is higher than the standard, the capacity-driven needs selection process is triggered.

The first step in the capacity-driven needs selection process is to determine the first year in

which the link fails to meet the standard, because this will be the year in which any selected improvement will be made and the year in which improvement costs will be assigned as a need. The design year for the improvement is defined as the first year of failure plus 20 years (i.e., a 20-year design horizon). Using the design year peak traffic volumes, the program then calculates the peak capacity that will be required to maintain the capacity standard in the design year.

Selection of the most cost-effective capacity improvement occurs by iteratively searching through a sequential menu of improvements and calculating the peak capacity for each improvement category within the menu until either the required design year capacity is attained or a terminal condition is reached. Terminal conditions include the availability of right-of-way (in urban areas) and the total permissible number of through lanes (in both urban and rural areas) and in some instances may constrain the selected improvement to one that will not attain the desired capacity.

The choice of improvement menu used for urban links depends on the functional class; the presence of left-turn lanes or medians, or both; and the surface type (paved versus unpaved). The choice of menu used for rural links depends on the functional class, the vertical and horizontal alignment adequacies, the surface type (paved versus unpaved), and whether the link is divided or undivided. Urban improvement menus may include transportation system management (TSM) actions, continuous left-turn lanes, spot widenings, and full widenings; rural menus include a combination of widening and relocation options. Table 1 gives a sample improvement menu developed for the Arizona needs study.

As the sample improvement menu indicates, improvements may be selected that have two or more stages spaced over the 20-year design horizon. In these situations, the program will determine the appropriate year for each improvement stage by comparing the improved capacity of each stage with the traffic volumes and the capacity required to maintain the performance standard over time. This process is graphically shown in Figure 1.

When the improvement has been selected, the cost is calculated by multiplying the link length with various per mile unit costs appropriate to the improvement type. These costs may include the cost of additional right-of-way, additional pavement, roadway striping, engineering and design, TSM actions, and so forth. The unit costs are based on the Arizona construction cost index, which is developed from recent construction project costs throughout the state. All improvements are designed to meet ADOT lane width, shoulder width, and median width design standards.

The program then stores the cost, year, action type, and improved peak capacity for each improvement stage selected for the link for purposes of performance calculation and reporting.

The capability to override the entire capacity-driven needs selection process for any particular link is provided within the program. This feature enables the user both to stipulate known future improvements to existing links and to suppress the selection of improvements where none are desired for reasons external to the program. In a similar manner, known future new highway facilities can be input into the process as "survey routes."

Physical Condition Needs

Physical condition needs for all highway links, with the exception of unpaved and portland cement con-

TABLE 1 Sample Capacity Improvement Menu (urban minor arterial, paved, no left-turn lanes or raised medians)

Improve- ment Category	No. of Stages Within Category	Capacity Improvement	Consumed Right- of-Way (ft)	Additional Pavement Width (ft)	Additional Through Lanes	Left- Turn Lane Status
1	1	Transportation system management (TSM)	0	0	0	No
2	2	TSM actions	0	0	0	No
		Add continuous left-turn lane	11	Existing deficiency plus 11	0	Yes
3	2	TSM actions	0	0	0	No
		Spot widen by two lanes at intersections	12	Existing deficiency plus 24 ^a	2 ^b	No
4	3	TSM actions	0	0	0	No
		Spot widen by two lanes at intersections	12	Existing deficiency plus 24 ^a	2 ^b	No
		Add continuous left-turn lane	11	11	0	Yes
5	3	TSM actions	0	0	0	No
		Spot widen by two lanes at intersections	12	Existing deficiency plus 24 ^a	2 ^b	No
		Widen by two lanes and add continuous left-turn lane	35	35	2	Yes
6	3	TSM actions	0	0	0	No
		Widen by two lanes and add continuous left-turn lane	35	Existing deficiency plus 35	2	Yes
		Widen by four lanes	48	48	4	Yes

^aPlus 24 ft at intersections, plus 0 ft between intersections.^bAt intersections.

crete (PCC) links, are selected through the application of the ADOT pavement management system (PMS).

The PMS is a network optimization system, developed and implemented by the ADOT Materials Section, that optimizes the design, maintenance, and preservation of pavements. Using a probabilistic model of deterioration, PMS predicts the future ride and cracking condition for asphaltic concrete pavements, depending on their initial condition. PMS determines the most cost-effective rehabilitation actions over time to achieve and maintain desired performance standards for different roadways in the state and calculates the yearly pavement maintenance and construction costs associated with these actions. Actions are selected from a menu that includes a variety of overlays and seal coats.

The PMS system divides all highways within the

state into 36 possible problem groups, each of which has different characteristics in regard to pavement condition needs. The PMS problem groups are stratified as

- Four administrative systems (Interstate, state, county, and city);
- Three ADT groups (<2,000, 2,001 to 10,000, and > 10,000; and
- Three regional types (desert, transitional, and mountainous).

The PMS network optimizing program is run for each PMS problem group of interest (some of the groups have little or no mileage within them and thus are not run) with the physical condition performance standards as inputs. Each PMS run yields the total optimized pavement maintenance and construction costs in each of the next 10 years for all highways within that problem group.

The needs study program takes the results from each of the PMS runs as inputs. As the link-by-link analysis is being performed, the program determines which of the PMS groups the link belongs in and apportions the yearly pavement maintenance and construction costs to the link based on that link's share of the total square yards of pavement in the entire PMS group. A factor representing engineering and design overhead costs is then applied to the link pavement construction costs.

Physical condition needs for unpaved and PCC links are handled separately because they are not presently included within the PMS program. Unpaved maintenance needs are calculated by applying an annual unit cost of grading and spraying to the surface area of the link. PCC needs are calculated by multiplying annual unit costs for PCC pavement maintenance and construction with the link pavement area. Both unpaved and PCC unit costs are stratified by region type and were developed from recent ADOT project costs.

Highway Link Safety Needs

The needs study program projects the future number of HALs in the state by assuming that the number will grow in direct proportion to the increase in daily VMT on substandard roads statewide (a substandard road for this purpose is one with either poor horizontal or vertical alignments, or lane widths or

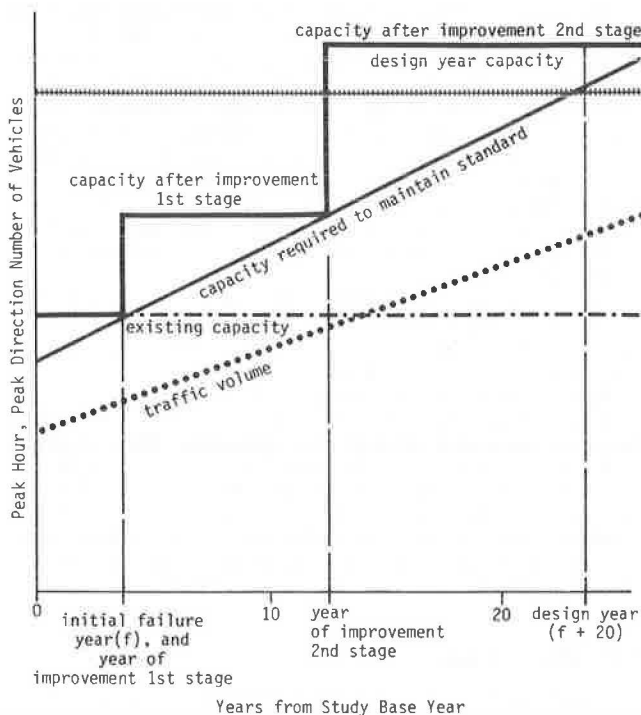


FIGURE 1 Determination of capacity improvement years.

lateral clearances that are below design standards). The target number of HALs required each year to meet the highway safety performance standard by the target year is determined with the difference between the target and projected numbers representing the amount to be improved. A portion of the number of HALs to be improved, related to the proportion of substandard road VMT for which highway capacity improvements were selected, is presumed to have been improved as a consequence of capacity improvement (capacity improvements by definition are designed to meet design standards).

The remaining HALs to be improved are divided into two groups based on proportions provided by the ADOT highway safety improvement program: those requiring major reconstruction and those requiring a minor improvement. An average improvement cost for each type, based on recent experience within Arizona, is applied to the two groups to determine total yearly highway safety needs.

Bridge Structure Capacity, Condition, and Safety Feature Needs

Bridge structure needs for each structure on a particular highway link are calculated after the needs selection process for the link itself has been completed. The methodology employed depends on whether the structure carries or passes over the link. Data for the structures methodology were obtained from the structures inventory data base maintained by the ADOT Structures Division based on FHWA National Bridge Inventory Project procedures (2).

The need for physical condition or safety improvements to structures carrying links is determined through a series of checks on present structural and deck conditions, safe load, inventory rating, and status of traffic safety features (including railings, approach guardrails, and transitions). If a capacity improvement has been selected for the link, the structure is also checked to determine whether the present structure is wide enough to accommodate the link improvement (Table 2). Depending on the result of these checks, the program will select an action ranging from no improvement to structural replacement with a wider cross section. These checks and resulting improvements are calculated from unit costs provided by the ADOT Structures Division.

The vertical underclearance provided by any structure that passes over a link is compared with a standard of 16 ft to determine if it is adequate. If a capacity improvement has been selected for the

link under the structure, the structure is also checked to determine whether the present lateral underclearance is sufficient to allow the link improvement. If either or both of these tests are failed, the program flags the structure for a later manual analysis because the necessary improvements and costs required to correct these types of deficiencies are highly dependent on the particular location and cannot be calculated by a generalized program.

Railroad At-Grade Crossing Safety Needs

The methodology employed by the program to estimate safety needs at railroad at-grade crossings is based on the rail crossing hazard index and uses rail crossing data obtained from a data base maintained by the ADOT safety program. The hazard index is a measure composed of the daily train volume, a traffic coefficient dependent on ADT, and a device coefficient dependent on the type of protective device (crossbucks, flashers, or gates) and is calculated using a modification of the New Hampshire method.

The program determines the hazard index for each year and compares it with the hazard index standard previously set by the user. If the standard is met, no improvement is selected and the program proceeds to the next year. If the standard is not met, however, the program selects an improvement based on the existing device type:

<u>Existing Device Type</u>	<u>Selected Improvements</u>
Gates	None
Flashers	Gates
Crossbucks	Flashers or gates

When there is a choice of flashers or gates, the most cost-effective improvement, determined by comparing the estimated hazard index decrease for each improvement divided by the improvement cost, is selected. Unit costs for installation of flashers and gates are obtained from the Arizona Construction Cost Index, and are assigned to the improvement (if selected) for the year in which the standard was not met.

Needs Summaries

The improvement costs calculated during needs selection are aggregated by the program and summarized in three reports. The first reports the needs for each local jurisdiction, stratified by need type (capac-

TABLE 2 Bridge Structure Improvement Selection Decision-Tree

Safe Load	Inventory Rating	Structural Condition	Deck Condition	Traffic Safety Features	Selected Improvement Action	Selected Improvement Action if Link on Bridge to be Widened
Pass		Pass	Pass	Pass	No improvements	Widen bridge
Pass		Pass	Pass	Fail	Safety improvements	Widen bridge
Pass		Pass	Fail (R)		Rebuild deck	Rebuild deck wider
Pass		Pass	Fail (N)		Replace deck ^a	Replace deck wider ^a
Pass		Pass	Fail (N)		Replace bridge ^b	Replace bridge wider ^b
Pass		Fail (R)	Pass		Repair bridge	Replace bridge wider
Pass		Fail (R)	Fail		Replace bridge	Replace bridge wider
Pass		Fail (N)			Replace bridge	Replace bridge wider
Fail (R)	Pass	Pass	Pass		Strengthen bridge	Replace bridge wider
Fail (R)	Pass	Pass	Fail		Replace bridge	Replace bridge wider
Fail (R)	Pass	Fail			Replace bridge	Replace bridge wider
Fail (R)	Fail				Replace bridge	Replace bridge wider
Fail (N)					Replace bridge	Replace bridge wider

Notes: R = repairable failure and N = nonrepairable failure.

^aStructure design allows replacement of deck.

^bStructure design does not allow replacement of deck.

ity, physical condition, structure, and rail crossing) and administrative system (state, county, and city). The second summarizes the statewide needs by need type, administrative system, and functional class; and the third reports the safety needs for the entire highway system. Each report is produced for 5-, 10-, and 20-year cumulative needs.

PERFORMANCE MEASURES

After the needs selection process has determined highway, structural, and rail crossing needs in reaction to the performance standards, the following measures are calculated to test the resulting performance. Each of the performance measures, with the exception of the 20-year earnings-to-cost ratio (which is calculated for the 20-year period only), is calculated for the base year and for 5 and 10 years into the future.

Capacity Performance Measure

The improved capacities resulting from the capacity improvement selection process for the link are divided into the link traffic volumes to determine the improved peak-hour, peak-direction v/c ratios for each year.

The program reports the number of miles in each capacity LOS category stratified by administrative system and functional class, where the LOS categories are defined as follows:

LOS	v/c Ratio Range
A/B	< 0.70
C	0.71-0.80
D	0.81-0.90
E	0.91-1.00
F	1.01-1.20
FF	> 1.20

Physical Condition Performance Measure

As a result of the use of optimization in the PMS for the determination of highway physical condition needs, the percentage of highway pavement area in good condition versus the percentage in poor condition for both pavement ride quality and pavement distress or cracking resulting from the selected physical condition needs equates precisely to the standards that were set and therefore does not require any further calculation by the program.

Safety Performance Measure

The safety performance measure for highway links and structures is defined as the total number of improved HALs on the entire highway system. The rail safety performance measure is reported as the number of selected rail crossing improvement projects of each type (flashers or gates) stratified by administrative system and functional class.

Financial Performance Measure

Two measures are included in the financial performance measure. The capacity benefit-to-cost ratio is designed to compare the relative cost-effectiveness of the capacity improvements selected for individual links and is defined as the net decrease in link v/c ratio (weighted by the link length) in the year of interest divided by the link capacity improvement

costs up to that year. The program produces a listing of all selected capacity improvement project locations and costs, ranked in descending order by benefit-to-cost ratio.

The 20-year earnings-to-cost ratio measures the ability of a roadway to generate user revenue in excess of its improvement costs. The yearly earnings generated by each link are calculated through the application of annual commercial and noncommercial earnings factors to the link daily VMTs and are summed over the next 20 years. The link earnings are then divided by the link total calculated costs over 20 years, including the costs of structural and rail crossing improvements on the link, to yield the 20-year earnings-to-cost ratio. The earnings factors used were derived from highway revenue projections provided by the ADOT Administrative Services Division. The program reports 20-year aggregate earnings-to-cost ratios by administrative system and functional class for each jurisdiction.

Peak-Hour Aggregate Volume-to-Capacity Ratio Performance Measure

The peak-hour, peak-direction aggregate v/c ratio is a measure designed to reflect the aggregate level of congestion within a given jurisdiction or administrative system. It is calculated by summing the product of the peak-hour v/c ratio and VMT for each link and dividing this sum by the summed link VMTs (thus weighting the measure by peak-hour VMT).

The program reports the weighted aggregate peak-hour v/c ratio, stratified by administrative system and functional class, for each jurisdiction.

Peak-Hour Vehicle Hours of Travel Performance Measure

The program calculates the link peak-hour, peak-direction average travel speed from the improved v/c ratio using the appropriate relationship (rural or urban) shown in Figure 2. The peak-hour, peak-direction vehicle hours traveled (VHT) is calculated by dividing the link average speed into the peak VMT.

The program reports VHTs summed by administrative system and functional class. Comparison of the differing levels of VHT under varying performance alternatives yields the relative amount of vehicular delay experienced with different calculated needs.

Environmental Performance Measure

Peak-hour vehicle emissions and fuel consumption on urban links are calculated using equations and factors adopted from the FHWA report "A Method for Estimating Fuel Consumption and Vehicle Emissions on Urban Arterials and Networks" (3). Emissions are determined by multiplying link peak VMTs with an emission factor dependent on ambient temperature, altitude, and link average speed. Fuel consumption is calculated separately for automobiles, medium trucks, and heavy trucks, using equations dependent on the average speed and VMT, and is summed to yield the link total.

The program reports urban peak-hour fuel consumption and HC, CO, and NOX vehicle emissions, stratified by administrative system and functional class, summed over all links.

It should be noted that the calculation of estimated vehicle emissions by the needs study program is not intended to be an overall analysis of air quality impacts, which would require extensive analysis of local meteorology, climate, and other fac-

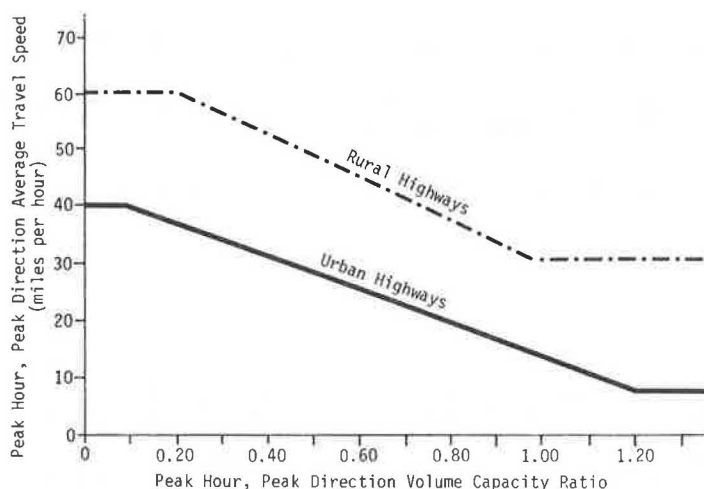


FIGURE 2 Relationship of peak-hour travel speed and v/c ratio.

tors, but rather is meant to provide some insight into the comparative effects of varying performance alternatives on air quality.

CONCLUSIONS

The computational procedures described for the revised highway needs study process select capacity, physical condition, and safety needs in response to performance standards set by the user and test the selected needs against seven performance measures. The process gives the user the capability to test any desired number of different performance alternatives rapidly and efficiently, covering a range of scenarios from "minimum tolerable" to "free-flow, like-new." In this way, the performance of the highway system resulting from different needs levels can be analyzed and compared.

The results obtained in Arizona from the revised process have yielded significant differences in costs and performance among the tested performance alternatives.

Devising performance alternatives is simple because all that is required to specify an alternative are the standards for the three "trigger" performance measures: capacity, physical condition, and

safety. Less than one-half of a man-day is required to input new standards and run the needs program for a new alternative, and experience in Arizona indicates that as many as five different alternatives can be batched and run in a single day. The revised needs study process is flexible, efficient, and easy to use.

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