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Estimating the Impacts of Changing Highway Conditions

JAMES GRUVER AND WILLIAM REULEIN

A discussion of the Highway Performance Monitoring System (HPMS) is presented. The analytical package is a series of computer models designed to use the annually updated HPMS sample inventory data to estimate needs, determine the relationship between highway investments and highway performance, and assess the benefits and costs associated with various investments. The models express highway performance in terms of sufficiency indexe vehicle operating costs, fuel consumption, and overall running speed. This ., stem-level planning tool is described and examples of the data output are given. Investment performance curves are presented to illustrate the consequences of different investment levels. Although it is concluded that the current analytical package is useful for assessing the effects of future investments on future system performance, there is a need to bring this package together with economic analyses and econometric forecasting tools to permit economic impact analyses of various sectors of the economy, including highway users and industries. As the predictive ability of the models improves, the ability to estimate the costs and benefits of alternatives will improve.

During the past 8 years, as a part of the Highway Performance Monitoring System (HPMS), FHWA has been developing an analytical package (series of computer models) designed to estimate future highway needs; test the sensitivity of highway needs to repaving and reconstruction policies, the makeup of the vehicle fleet, future travel, and future investment levels; determine the relationship between future highway investment and future highway performance; and assess the benefits and costs associated with various future investments in the functional system. The output from these models is used by the U.S. Department of Transportation and the U.S. Congress in the development of highway programs and policy. Although the models were developed to provide information at the national level, the states have program concerns similar to those of FHWA. For this reason, the models have been modified to provide state highway agencies with the same capability to test their own state highway program options. The purpose of this paper is to describe the operation of these simulation models and to illustrate how they are used to measure the changes in highway conditions and performance resulting from future highway investments.

INPUT

Basic input to the analytical package is inventory data consisting of a limited number of data elements for each section in a statistically designed, small sample of highway sections. These samples (3 percent of statewide mileage) are expanded to represent the arterial and collector highway systems in rural, small urban, and urbanized areas of each state. Specific physical, condition, operational, accident, and capital improvement data for the highway sections sampled are reported annually by the states as a part of the HPMS (1). A list of the data reported annually by the states for the sample sections used by the models is as follows (items followed by an asterisk are rural data; those followed by two asterisks are urban data):

1. Identification
   a. State code
   b. County code
   c. Rural or urban designation
   d. Urbanized area code **
   e. Expansion factor
2. System or jurisdiction: functional class
3. Operation or travel
   a. Type of facility
   b. Section or group length
   c. Current and future average annual daily traffic (AADT)
   d. Number of through lanes
   e. Speed limit
   f. Average highway speed *
   g. K-factor
   h. Directional factor
   i. Capacity
   j. Signal type and timing **
   k. Parking
   l. Percentage of trucks (peak and off-peak)
4. Pavement
   a. Surface or pavement type
   b. Pavement section
   c. Skid number or slab thickness
   d. Pavement condition
5. Geometrics or configuration
   a. Access control
   b. Lane idth
   c. Approach width **
   d. Shoulder type and width
   e. Median type and width
   f. Horizontal and vertical alignment
   g. Percentage of sight distance *
6. Supplemental
   a. Drainage adequacy
   b. Type of terrain *
   c. Type of development
   d. Urban location **
   e. Number of intersections

METHODOLOGY

The analytical package is a series of interdependent computer models that use the HPMS sample data as primary input. There are four major models in the analytical process:

1. Needs,
2. Composite index (sufficiency),
3. Investment performance, and
4. Impact assessment.

These models are not designed for independent use. Several options are available to perform specific analyses and to provide output for different times. The needs and investment-performance models are always used in the analysis of future scenarios, whereas the remaining two models may be optionally called for an analysis of the current highway systems or as a part of the analysis of future scenarios or both. Figure 1 illustrates the analytical process and its outputs.

Needs Model

The needs model simulates the improvements necessary to keep the physical and operational conditions of a highway system from falling below prescribed minimum criteria during the analysis period. Basically the model identifies individual highway section deficiencies that occur during the analysis period, determines logical improvement types to correct these deficiencies, estimates the costs of the improvements, and modifies the section record to reflect performance in the analysis year with and without improvement. The analysis period for this process may be a single time period of up to 20 years (investment-level analysis) or it may be one of up to four separate funding periods (funding-period analysis) within the overall analysis period. In the latter case, each period is analyzed separately.

Deficiency Determination

Each highway section is analyzed independently for each analysis cycle (cycles may be one or more years) starting with the year for which data are reported and continuing until a deficiency has been identified or the last year in the analysis period has been reached. Section deficiencies are identified through comparison of existing or projected conditions with the minimum tolerable conditions (MTCs) established for physical conditions, geometrics, and operational characteristics. These minimum conditions vary by functional class (and rural terrain type and AADT group) and are selected to reflect a general consensus on the lowest level of performance the public would or should tolerate. MTCs represent an adequate or acceptable level of performance for existing or projected traffic, although it is recognized that it is not realistic to identify a section as being deficient if the facility is providing reasonably good service. Table 1 contains one possible set of MTCs. A set of reduced MTCs is also provided for later demonstration of the consequences of such reduction. Design standards

Figure 1. HPMS analytical package, 1982.

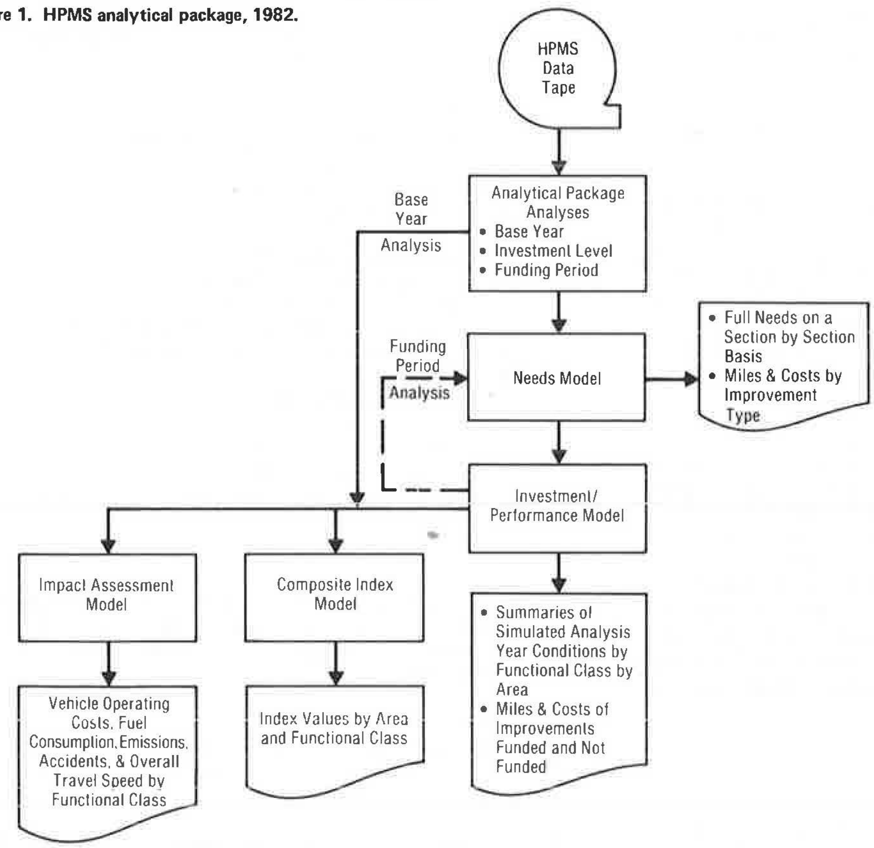


Table 1. MTCs for rural other principal arterials.

Item	High MTCs by Terrain[a]			Reduced MTCs by Terrain[a]		
	F	R	M	F	R	M
Lane width (ft)	11	11	11	10	10	10
Right shoulder width (ft)	8	8	6	6	6	4
Shoulder type[b]	S	S	S	S	S	S
Pavement condition	2.6	2.6	2.6	2.1	2.1	2.1
Operating speed (peak hour) (mph)	55	50	45	20	20	15
Volume-to-capacity ratio	0.70	0.70	0.70	0.99	0.99	0.99
Surface type[c]	High	High	High	High	High	High
Horizontal alignment adequacy[d]	2	2	2	4	4	4
Vertical alignment adequacy[d]	2	2	2	4	4	4

[a] F = flat; R = rolling; M = mountainous.
[b] S = stabilized.
[c] High = high rigid and flexible pavements, pavement-surface codes 60, 70, and 80 as defined in HPMS field manual.
[d] Rating of alignment adequacy of 1 (good) to 4 (poor) as defined in HPMS field manual.

for the rural other principal arterials are as follows (F = flat; R = rolling; M = mountainous):

Item	Terrain F	Terrain R	Terrain M
Lane width (ft)	12	12	12
Right shoulder width (ft)	12	10	8
Surface type	High	High	High
Median width (ft)	64	64	16
Avg highway speed (weighted design speed) (mph)	70	70	55

The data elements representing the section's conditions and operating characteristics in the first year of the analysis period are compared with the MTCs to determine whether a deficiency already exists. If a section is tolerable in the initial or base year, it is examined for future deficiencies. Future conditions [forecast AADT, deteriorated pavement condition, and operating speed or volume-to-capacity (V/C) ratio or both] are simulated for each analysis cycle and compared with the MTCs. Sections are deficient if any of the following items do not meet the MTCs:

1. Peak-hour operating speed or V/C ratio,
2. Lane width,
3. Pavement condition, or
4. Rural horizontal or vertical alignment adequacy (rural only).

Table 2. Typical rural deficiencies and improvement types.

Deficiency Type and Combination	Resulting Improvement Type
Access control and operating speed[a] (Interstate and high-volume principal arterials only)	Reconstruct to freeway
Operating speed[a]	Major widening
Widening not feasible	No improvement
Operating speed,[a] pavement condition <R,[b] or alignment	Reconstruct with more lanes
Widening not feasible	Reconstruct as is
Lane width	Minor widening
Widening not feasible	No improvement
Lane width, alignment, or pavement condition <R[b]	Reconstruct with wider lanes
Widening not feasible	Reconstruct as is
Pavement condition <R[b]	Pavement reconstruction
Alignment	Isolated reconstruction
Pavement condition <MTC and >R[b] and shoulder type or width	Resurfacing and shoulder improvement
Pavement condition <MTC and >R[b]	Resurfacing

[a] Peak-hour operating speed or V/C ratio.
[b] Present serviceability rating (PSR) below which reconstruction is needed.

Improvement Analysis

The improvement type selected by the needs model depends on the combination of deficiencies identified on the section under analysis. Table 2 gives typical rural deficiencies and the resultant improvement types simulated by this analysis. This table does not contain the complete improvement selection logic.

Improvements sufficient to carry 20-year traffic are made to design standards but may be constrained because of reported widening restrictions. If widening is not feasible, improvements are restricted to maintaining the existing pavement and roadway structure and traffic engineering improvements. Once the improvement types have been selected, the capital improvement (right-of-way plus construction) costs are calculated by using unit improvement-type costs, which vary by functional class, number of lanes after improvement, and terrain in rural regions and by design type, number of lanes after improvement, and type of development in urban regions. Table 3 gives the major output of the needs model, miles and cost by improvement type, for both high and reduced MTCs. By reducing the MTCs, the miles of improvements by type of improvement are greatly changed as are the costs (a 71 percent reduction for the latter). The number of miles improved has been reduced by only 13 percent. The needs model projects the analysis-year conditions with and without improvements and places this information on the section record. This information is the primary input to the investment-performance model in which decisions are made as to what improvements will be made under different investment levels.

Composite-Index (Sufficiency) Model

The composite-index model evaluates highway condition, safety (geometrics), and service (use and operating characteristics) on a section-by-section basis and aggregates these section evaluations by functional system. These evaluations are in the form of composite and component indexes. Section indexes are similar to sufficiency ratings. A rating between 0.0 and 1.00 is given to each data item evaluated and is applied to the total points assigned to the data item. For example, a pavement condition of 2.5 may warrant a factor of 0.4, which, multiplied by 15, yields 6 points out of a possible

Table 3. Rural other principal arterials: miles and cost by improvement type.

Improvement Type	High MTCs Miles	High MTCs Cost ($000,000s)	Reduced MTCs Miles	Reduced MTCs Cost ($000,000s)
Reconstruct to freeway	8,546	18,845	447	1,263
Reconstruct with more lanes	1,221	2,568	24	56
Reconstruct with wider lanes	2,334	2,964	68	77
Reconstruct as is	138	95	0	0
Isolated reconstruction	5,349	2,940	0	0
Major widening	3,953	5,228	57	91
Minor widening	5,437	2,928	881	483
Resurfacing with shoulder improvement	15,009	3,066	20,715	4,131
Resurfacing	19,074	3,447	31,041	4,584
Pavement reconstruction	2,661	2,467	2,146	2,052
Total	63,722	44,548	55,379	12,737

Note: Data are based on 1978 HPMS data for 40 states.

Table 4. Components of composite-index model and point values.

Component	Subcomponent	Point Value	
Condition		30	
	Pavement type		10
	Pavement condition		15
	Drainage adequacy		5
Safety		30	
	Lane width		10
	Shoulder width		5
	Median width		5
	Alignment adequacy		10
Service		40	
	Operating speed		20
	V/C ratio		10
	Access control		10

Table 5. Physical features and operating conditions for rural other principal arterials: 1995 conditions with full needs investment.

	Percentage of Mileage[a]		
Item	High MTCs	Reduced MTCs	No Improvement
Surface type high	100	100	90
Pavement condition (PSR)			
<2.0	7	0	82
≥2.0	93	100	18
Lane width, 11 ft	99	93	92
Cross section undivided	61	81	81
V/C ratio			
<0.41	87	74	72
≥0.41	13	26	28
Operating speed (mph)			
<40	4	12	13
≥40	96	88	87

[a]Weighted by mileage.

15 points. The points assigned to each of the three components may vary by functional class. For example, for rural principal arterials, weighting points of 30 for condition, 30 for safety, and 40 for service may be assigned. A composite index of 100 represents a section with no defects and a lesser total represents the degree of deficiency. Each component and its subcomponents and their assigned point values are listed in Table 4. Weighted component and composite indexes by functional system and mileage and travel distributions by component and composite are provided if desired.

Investment-Performance Model

The investment-performance analysis provides the means for relating investment to future highway performance in terms of composite-index values and as summaries of certain physical features and operating conditions--the first significant output of the analytical package. This analysis first determines priority rankings for all proposed improvements by functional system and area (rural, small urban, and urbanized) based on user-specified ranking factors. Potential improvements can be ranked by using one of several methods. The most commonly used method is the cost-effectiveness index calculated by the model as follows:

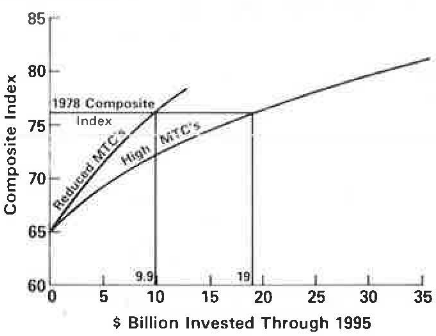
Cost-effectiveness index = [0.5 (100 + target-year composite index) - (smaller of base-year composite indexes or 70)] x 0.5 (target-year AADT + improvement-year AADT) x economic life of improvement type x section length/cost of improvement.

On completion of the ranking process, the improvements are selected and improved analysis-year conditions for the simulated improvement are summarized from the top of the priority list downward until the funds for the given investment level are exhausted. At that point the summarization process is continued by using analysis-year unimproved conditions for the remaining sections because funds are no longer available to support the potential improvements. This process is applied separately for each functional system by area (rural, small urban, and urbanized). The output from this analysis consists of a series of summary tabulations, which are produced for each investment level or funding period. Summaries are provided of composite-index values, pavement types and conditions, lane widths and cross sections, V/C ratios, and peak-hour operating speeds. Also given are the mileage and cost of investment (both funded and unfunded) by functional type and improvement type. Tables 5 and 6

Table 6. Composite-index values for rural other principal arterials: 1995 conditions with full needs investment.

Functional System	High MTCs	Reduced MTCs	No Improvement
Condition	26.4	27.4	15.7
Safety	27.9	26.0	24.9
Service	29.3	24.9	24.3
Total	83.7	78.3	64.9

Figure 2. Rural other principal arterials: 1995 composite index versus dollars invested.



show the output of this analysis in terms of 1995 conditions for investments equal to full needs for the high and reduced MTCs. (Reduced MTCs concentrate investments on pavement problems, thus producing much higher system pavement conditions for much less money at the expense of increased congestion.) The 1995 conditions with no improvement are also shown. Figure 2 shows one method for presenting investment-performance information--the investment curve. By plotting the systemwide composite index versus various investment levels, a curve is produced that enables one to assess the investment necessary to achieve certain conditions (e.g., to maintain the 1978 composite index in 1995, $9.9 billion will be necessary under reduced MTCs and $19 billion with high MTCs).

Impact-Assessment Model

The purpose of this section of the modeling process is to convert existing and future highway physical and operating conditions into user cost factors. Because a primary reason for highway investment is to reduce user costs, this impact-assessment methodology was developed to supply the benefit portion of the cost/benefit ratio.

The calculated user cost factors are expressed in terms of rates. The factors include fuel consumption, vehicle emissions (carbon monoxide, hydrocarbons, and nitrogen oxide), vehicle operating costs, average overall travel speeds, and three types of accidents--property damage only, nonfatal injury, and fatal. With these factors comparisons can be made between today's highway performance and future performance levels achieved with various investment levels and investment strategies. The comparisons can then be used to determine the relationships that exist among investment, travel, user costs, and improvement types.

Input

The primary input to the impact-assessment model is sample inventory data. Analyses of base- or inventory-year physical and operating conditions use these data as reported. Analyses of future target- or analysis-year user cost factors use the inventory data modified by the needs and investment-performance analysis models described earlier to reflect analysis-year conditions. Individual sections will have analysis-year conditions reflecting improvements simulated, if any, as a result of investments made.

Analysis Process

The impact-assessment model analyzes physical and operational conditions in the inventory year or a future analysis year and produces user cost factors indicative of either the conditions that exist in the inventory year or the conditions that are expected to exist in the analysis year as a result of the assumptions made in the needs and investment-performance analyses. Each sample, expanded to represent its portion of the universe, is individually analyzed, and individual section user cost factors are weighted together to produce functional system user cost factors or performance measures.

The logic of the analytical process is built around a series of tables, curves, and equations developed by FHWA through in-house or contract research efforts. These components of the process can be changed when updated or improved data or relationships are available. The major components are as follows:

1. Daily distributions of traffic by functional class and design type (2);
2. Speed-estimating relationships by design type and congestion level (2);
3. Adjustment relationships for pavement condition and alignment speed (3);
4. Estimating relationships for speed-change cycle, stop cycle, and speed-change magnitude by vehicle type (2);
5. Idling-time relationships (2);
6. Tables for fuel consumption, travel time, and vehicle operating cost by vehicle type for pavements in good condition (PSR = 4.5) (2,3);
7. Pavement condition adjustment factors for vehicle operating costs and fuel consumption (2);
8. Vehicle classification data by area and functional class (3,4);
9. Emission rates for carbon monoxide, hydrocarbons, and nitrogen oxide by vehicle type and calendar year (5); and
10. Total, fatal, and injury accident rates by design type and AADT carried (2).

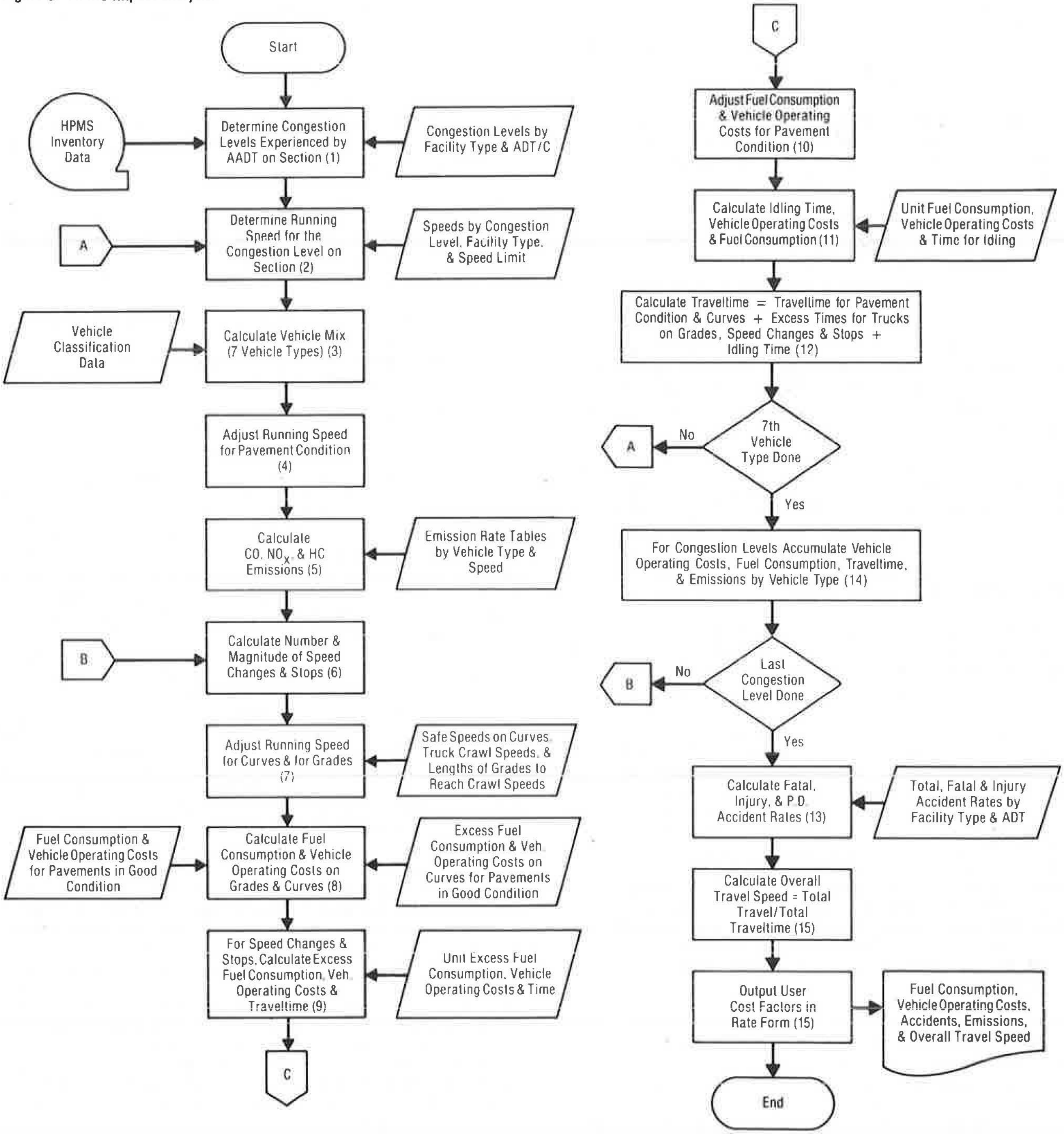
Specifically each section is analyzed as follows (see Figure 3 for flowchart of analytical process; numbers on flowchart refer to steps in process):

1. The AADT is stratified into 3 to 12 daily increments of relatively uniform congestion to more accurately represent daily vehicle operations and the required user cost factors. Each congestion period is analyzed independently and the resulting user cost factors are weighted together to develop factors for each vehicle type representative of the overall average day.
2. For each congestion period an initial unadjusted running speed free from the effects of pavement condition, speed changes, curves and grades, and idling time for specific design types is established.
3. Within a congestion level the AADT is stratified into seven vehicle types, as follows:
   a. Small automobiles (<3,000 lb);
   b. Large automobiles (>3,000 lb);
   c. Pickups and vans;
   d. Two-axle, six-tire, single-unit trucks;
   e. Single-unit trucks with three or more axles;
   f. Multiunit trucks with three or four axles; and
   g. Multiunit trucks with five or more axles.

The number of each type of vehicle on the average day is determined as a function of the reported percentage of trucks and vehicle classification data for each rural and urban functional class. Each vehicle type is independently processed for a given congestion period.

4. The initial running speed for a given congestion period is adjusted to reflect the pavement condition of the section being analyzed.
5. The emission measures (CO, HC, and NO_x) are calculated as a function of the year being analyzed, vehicle type, and the running speed adjusted for pavement condition.
6. The running speed adjusted for pavement condition is then used to calculate the number and magnitude of speed-change cycles for automobiles, single-unit trucks, and multiunit trucks. Likewise, the number of stop cycles is calculated.
7. The running speed, which has already been adjusted for pavement condition, is then adjusted for curvature by using the safe speed for each curve class. If the running speed exceeds the safe speed of a curve, the safe speed becomes the running speed for that part of the section. The calculated running speed is used as the entry speed in the table for vehicle operating cost and fuel consumption for automobiles, panel trucks, and pickups. This same running speed is then used to determine the table entry speeds for trucks for the reported grades as a function of the running speed, the length of grade, and the crawl speed.
8. By using the table entry speeds calculated for each grade class, the unit vehicle operating cost and fuel consumption rates are interpolated from the appropriate grade tables and used to calculate the fuel consumption and vehicle operating costs for grades for the section. A similar procedure is used to determine the excess fuel consumption and vehicle operating costs for curves by using table entry speeds adjusted for curvature. The excess operating costs and fuel consumption rates for curves are added to values for grades to get the vehicle operating costs for curves and grades.
9. By using the running speed adjusted for pavement condition as an initial table entry speed and the magnitude of the speed-change cycle, the excess vehicle operating costs, fuel consumption rates, and travel times for a speed-change cycle and

Figure 3. HPMS impact analysis.



stop are determined by interpolating from the appropriate tables. By multiplying the appropriate unit values by the numbers of speed-change cycles and stops, the excess operating costs, fuel consumption, and travel times associated with speed-change cycles and stop cycles for the section and congestion level are determined. The excess costs and fuel consumption are added to the like values for curves and grades.

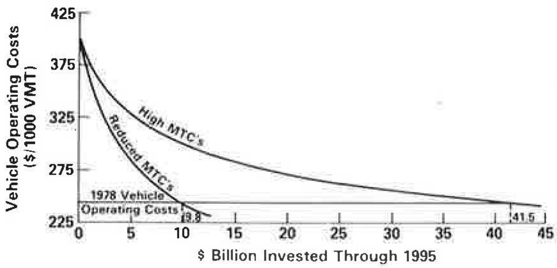
10. The vehicle operating costs and fuel consumption rates for curves, grades, speed-change cycles, and stops are modified to reflect pavement conditions other than 4.5.

11. The amount of time spent idling is calculated. Then the vehicle operating cost and fuel consumption associated with idle time are calculated and added to similar values for curves, grades, speed-change cycles, and stops to get the section totals for these items.

12. The total travel time is based on the initial running speed adjusted for pavement condition, curves, grades (trucks), speed-change cycles, and stops plus the idling time. The overall travel speed is calculated as the vehicle miles of travel (VMT) divided by the travel time.

13. The accident measures (fatal accidents, in-

Figure 4. Rural other principal arterials: 1995 vehicle operating costs versus dollars invested (all vehicles).



jury accidents, and property-damage accidents) are calculated as a function of traffic volume, design type, and VMT on the section.

14. This process is repeated until all vehicle types and congestion period traffic volumes are complete. Vehicle type values are accumulated for all congestion levels.

15. Final user cost factors are calculated and output.

Output

An example of the all-vehicle output (vehicle operating costs) for the rural other principal arterial system is illustrated as an investment performance curve in Figure 4. This figure shows that user cost factors may be used as a tool for assessing the consequences of different investment levels under different assumptions.

CONCLUSION

The analytical process described here has been developed to provide a tool for predicting the economic and environmental effects of current and future highway investment options. It is essential that decision makers be aware of the interactions among several dynamic factors, including highway user costs, changing highway performance, capital investment in highways, and highway travel demand.

Investments for capital improvements on U.S. highways have been at the $15 billion level in recent years. Investments of this magnitude, approaching 1 percent of the gross national product, have a substantial impact on the labor force and many industries and have a ripple effect throughout the economy. The effect of investments of this magnitude and the resulting changes in system performance must be understood and should be analyzed. The HPMS analytical process has been in use only a short time. Over the next few years the process will be fine tuned, providing the U.S. highway system with a better current and projected condition inventory than most, if not all, public-owned property in the United States.

Bringing these products together with currently available economic analysis and econometric forecasting tools will permit economic impact analyses on various sectors of the economy, including highway users, the construction industry, and related industries. Cost-benefit analyses of alternatives will improve as the predictive ability improves.

ACKNOWLEDGMENT

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Long-Term Projection of Highway System Condition

DAVID T. HARTGEN

A computer model is described that has been developed by the New York State Department of Transportation (NYSDOT) to predict long-term deterioration and investment impacts on the New York State highway system. The model, the Highway Condition Projection Model, is being used by NYSDOT management to assist in identifying pavement rehabilitation strategies. In the model each section of highway on the New York State system is treated as a separate entity. With a rehabilitation strategy provided by the analyst, the condition and financial requirement are projected for each section of highway for each year for up to 50 years into the future. Deterioration rates determined from empirical data from the New York State highway system and typical costs based on recent construction experiences are applied. The model output is summarized by system, region, and condition. A description is given of how this model may be used to identify sections in need of repair, test alternative rehabilitation strategies, and evaluate the implications of these strategies on long-term condition and funding requirements. The model is operational and is currently undergoing testing and refinement. Applications of the model to NYSDOT's analysis of Interstate funding proposals for highway repair and rehabilitation are described.

U.S. roads are deteriorating as high inflation and interest rates push construction costs up; at the national level, estimates of the repair bill for highways and bridges run as high as $100 billion (1). Evidence from the Highway Performance Monitoring Study (HPMS) (2, pp. 158-159) suggests that the condition of state and local roads is poorest, but these government units are now being called to bear the brunt of federal cutbacks in many programs. Significant attention must be paid to this problem soon, or the United States risks losing its vast investment in highway infrastructure. The recently passed Surface Transportation Assistance Act of 1982 provides additional funds for highway repair and rehabilitation.

To ensure that funds are spent wisely, state and local governments must be able to identify current problems and estimate repair needs, yet the tools available to undertake this task are weak or unavailable. Numerous procedures have been developed to evaluate alternative highway rehabilitation strategies, but their context has been limited to the study of a handful of sections (3) and they do not handle system-level analysis. Other simple optimization procedures exist for network problems (4). Detailed analysis methods of rehabilitation strategies for individual sections are well advanced, but only recently has the magnitude of the overall network problem begun to emerge. Even the federal HPMS (5) does not review all road categories; locally owned roads are not required for inclusion. The use of different highway rating procedures in different states has exacerbated the situation and clouded comparisons between system. Clearly the states and local governments need the capability to assess network highway conditions, and soon. The recently released HPMS Analytical Process helps in this regard (6).

Recognizing these issues, the New York State Department of Transportation (NYSDOT) has recently undertaken a strengthening of its pavement management activities. NYSDOT's Pavement Management Task Force has been formed to review current procedures and recommend improvements in pavement management. Methods for determining highway condition and reporting it in timely fashion are being improved and streamlined. Studies of deterioration have also been initiated. This work is expected to yield a better capability to manage pavement needs as funds are restricted. In this paper a model to project the long-term impact of alternative general rehabilitation strategies on network condition is summarized, and recent work by NYSDOT (7-9) on highway condition assessment is reviewed. A parallel paper (10) contains a summary of the data-collection methods used to obtain current condition data.

METHOD

The method described here is known as the Highway Condition Projection Model (HCPM) (8). This is a computerized procedure that projects the condition of each section of the New York State highway system, applies repairs as directed by the analyst, and keeps track of costs by location, federal-aid class, and so on. This is not an optimization model but rather a what-if tool that describes the implications of policies proposed by the analyst. Except for this feature, the model is similar to the Washington State model (4). Because the HCPM operates substantially on each section of highway and then sums up the entire system, its output can be summarized in a variety of ways not available in higher-level sample-based models [e.g., the federal HPMS model (11,12)]. In addition the model can be focused on section-level or route and county analysis, a capability not possible with sample-based techniques. The general operation of the model is shown in Figure 1, which is discussed in more detail in the following.

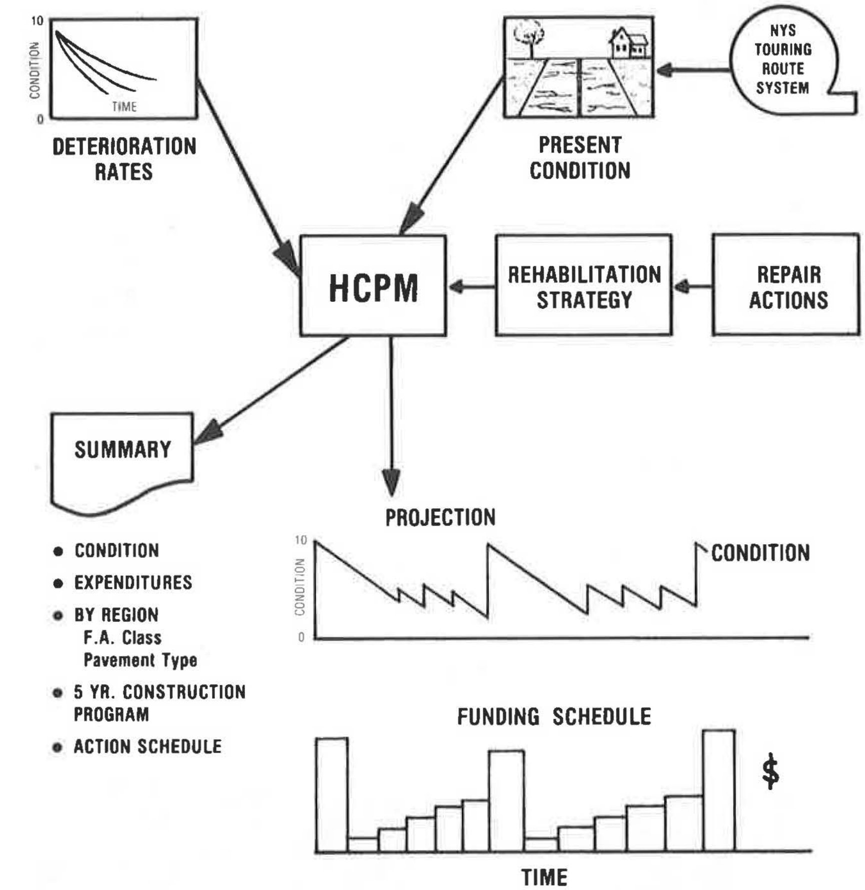
Highway Section Data

The HCPM uses the NYSDOT sufficiency file (13), which contains detailed characteristics, conditions, and traffic data for each section of the state touring route system. The 1982 file contains 19,803 records totaling 15,687 miles. Data items for each record include the following:

1. Characteristics
    a. Location and identity
    b. Length
    c. Number of lanes
    d. Direction: two-way or one-way
    e. Pavement width
    f. Surface, base, and subbase types
    g. Functional class
    h. Federal-aid class
2. Traffic
    a. Count year
    b. Annual average daily traffic
    c. Design-hour volume
    d. Capacity (level D)
    e. Volume/capacity (V/C) ratio
    f. Percentage of trucks
3. Condition
    a. Surface rating
    b. Base rating
    c. Maintenance index
    d. Structural rating
    e. Sufficiency rating
    f. Year of last repair

This detail permits extensive analysis of pavements by location and evaluation of unit costs, traffic loads, and so forth.

Figure 1. Highway condition projection model.



Condition

The condition of New York's highways is measured in several ways:

1. Surface score: A scale of 1 to 10 indicates the quality and condition of the roadway surface.
2. Base (rupture and displacement) score: A scale of 1 to 10 represents the condition of the base material underlying the surface.
3. Maintenance index: A scale of 1 to 10 indicates whether maintenance on that particular segment has been greater than normal, average, or less than normal.
4. V/C ratio: This ratio indicates the density of traffic and the degree of congestion.
5. Structural score: A weighted combination of the first three items on a scale of 0 to 100 is computed as follows: 3 times the surface score plus 4 times the base score plus 3 times the maintenance score.

Measurement of the first two items (surface and base) is easily related to visual characteristics. NYSDOT has recently developed visual scales showing pavements in various stages of condition. Two such scales have been prepared (7) for surface and base (rupture and displacement) and are shown in Figure 2. The visual scales provide a means that is straightforward, easily understood, and rapidly carried out of assessing highway condition in the field while also relating that assessment to perceptions of highway condition by public officials and citizens. Although the method of developing such scales need not be discussed in detail here, it should be noted that it was based on standard procedures involving the sorting and arranging of photographs by U.S. Department of Transportation experts. Once developed, the scales were retested to ensure validity.

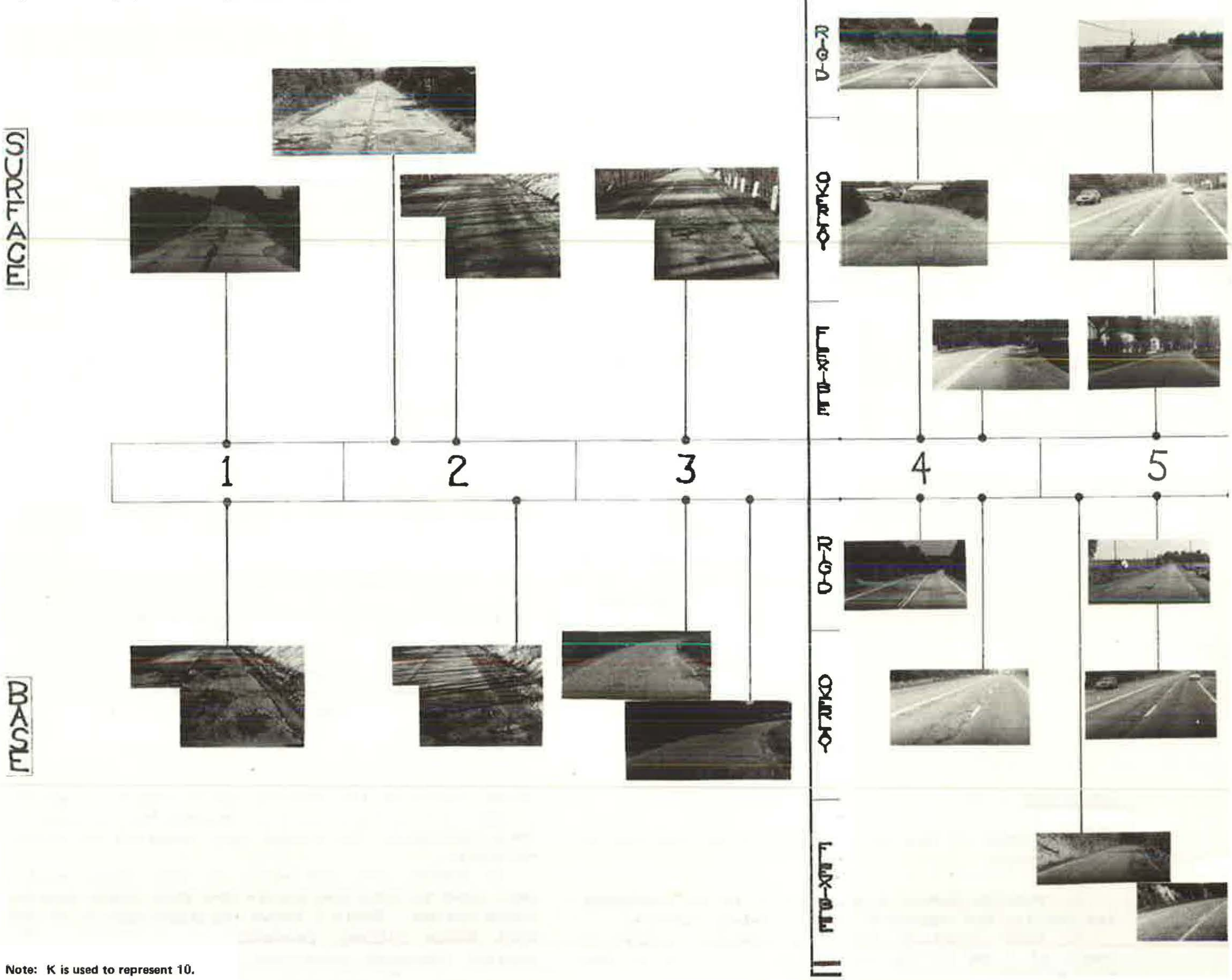
In summer 1981 and again in 1982 these scales were used to rate the entire New York State touring route system. Table 1 shows the distribution of New York State highway pavements by condition. The overall pavement condition of the state touring route system is generally quite good, and road surfaces are in better condition than road bases. Approximately 86 percent of road surfaces were in fair or better condition in 1982 compared with about 80 percent of road bases. About 14 percent of road surfaces and 20 percent of road bases were in poor condition.

The relationship between the NYSDOT condition scale and the present serviceability rating (PSR) used by AASHTO (14) and FHWA for evaluating HPMS sections (11) has been established. The PSR is a scale of 0 to 5 that considers surface, rideability, and structural condition. With data on 100 pavement sections scored by both methods, NYSDOT found that a simple average of its surface and base scores adequately represented the relationship. In other words, the PSR is about one-half the average of surface and base scores. This relationship has proved valuable in developing user cost routines, because most national data express the relationship between user costs and highway condition in terms of PSR and operating speed (15).

Deterioration Rates

Five basic factors influencing the deterioration of pavements are initial construction, traffic load,

Figure 2. Photographic scales of pavement condition.



Note: K is used to represent 10.

Table 1. Pavement condition, 1982, New York State touring route system.

		Surface		Base	
Condition	Level	Lane Miles	Percent	Lane Miles	Percent
Excellent	10	1,021	9.9	1,044	9.5
	9	2,904		2,747	
Good to fair	8	7,656		6,461	
	7	11,858	76.1	11,039	70.4
	6	10,745		10,439	
Poor	5	4,249		5,763	
	4	1,041		1,763	
	3	234	14.0	403	20.1
	2	19		77	
	1	2		3	
Total		39,729		39,739	
Avg			6.82		6.64

maintenance, environment (primarily climate and weather), and time. In spite of much research to sort out these factors, the understanding of highway deterioration is weak at best. In a recent review (3), two analysts summed it up:

> The first point worthy of emphasis is the lack of published information on deterioration of road pavements. The available (separate) sources can vary nearly be counted on one hand. This lack of information is even more surprising when one considers the wide variations that exist between deterioration relations developed from available data.

To determine approximate deterioration rates for New York State pavements, two approaches were used:

1. The data for the entire 1978 state highway system were arrayed by condition versus number of years since last contract work and initial-year deterioration rates were computed for different pavement types, and
2. Pavement conditions from NYSDOT's 59 continuous-counter locations were analyzed to determine average deterioration rates for pavement types.

Table 2 gives the results from this comparison. The rates are comparable for flexible and rigid pave-

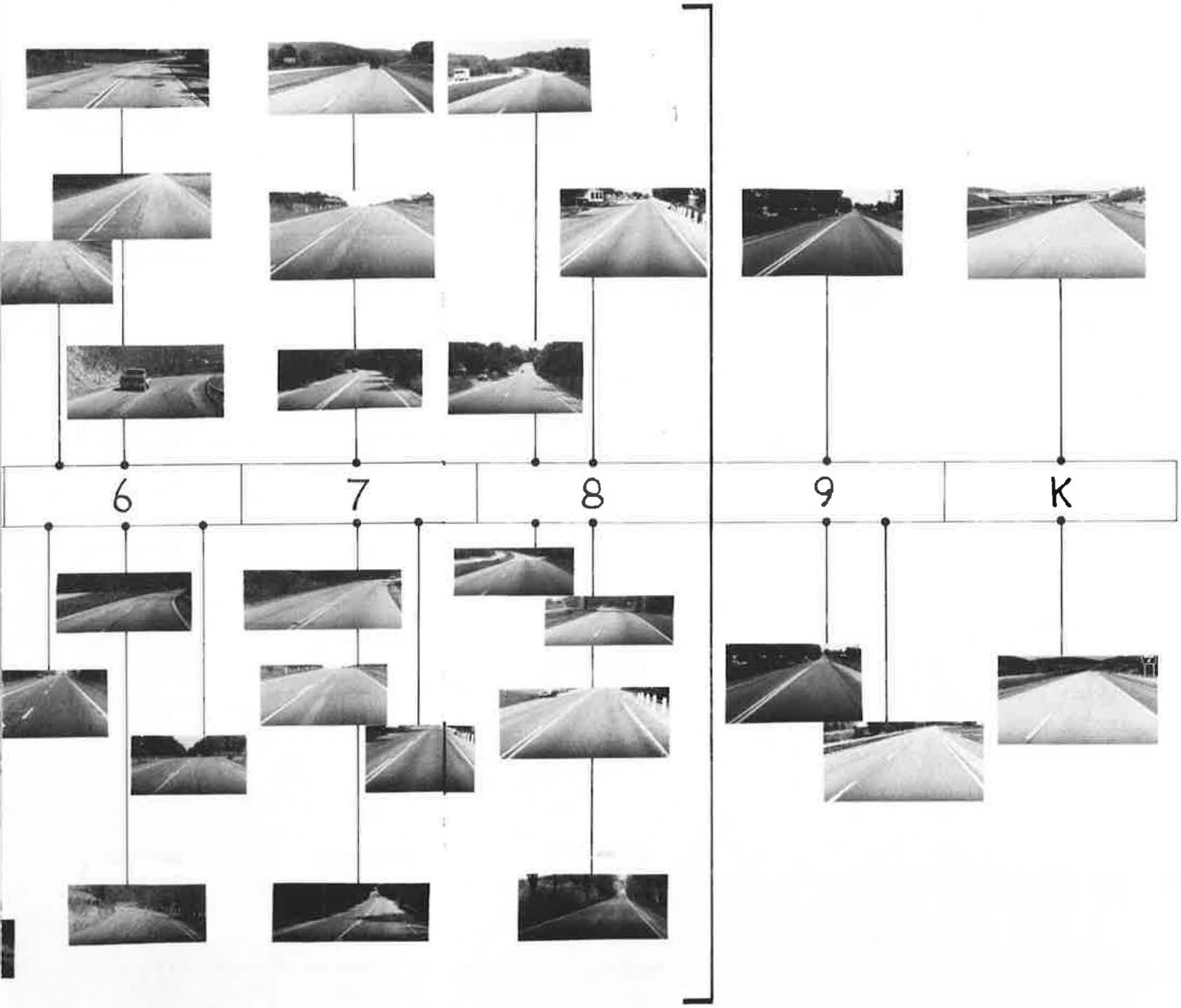


Table 2. Average deterioration rates.

	Avg Deterioration Rate (points/yr)[a]			
	1978 New York State Highway System		Continuous-Counter Sites	
Pavement Type	Surface	Base	Surface	Base
Flexible	-0.33	-0.36	-0.32	-0.32
Rigid	-0.18	-0.19	-0.21	-0.21
Overlaid	-0.45	-0.53	-0.40	-0.35

[a]On the 10-point scale shown in Figure 2.

ments; for overlays, system-based rates are a bit higher.

Repair Actions

Literally hundreds of different treatments and actions are used in rehabilitating and repairing roads, and it is not possible to review them here. The HCPM permits the analyst to identify up to 50 such actions; not all, of course, might be tested in a given analysis. Recent tests of the HCPM have been made with the generic-type repair actions shown in Figure 3. These actions cover the range of work typically undertaken to repair pavements.

Costs of rehabilitation actions were estimated by reviewing current contract prices and discussing with department experts the steps involved in various jobs. The column Percent of Cost Capitalized refers to the proportion of such work that would normally be let out for contract as opposed to that undertaken by NYSDOT. The columns Improvement in Surface and Improvement in Base refer to the incremental improvements in pavement condition (on the scale of 1 to 10 in Figure 2) resulting from the action. As an example, if a multilayered overlay (action 5) were placed on a pavement surface at condition level 5 (Figure 2), the resulting surface condition level would be 9.5 (5 + 4.5). These values were obtained by reviewing construction jobs and determining the improvement they made on pavement condition.

Figure 3. HCPM sample input.

HIGHWAY CONDITION PROJECTION MODEL

NYS DEPARTMENT OF TRANSPORTATION
TRANSPORTATION STATISTICS AND ANALYSIS SECTION

TEST DESCRIPTION: 1982 S-1; INTER-RIGID; 60-72 HIGH TK-VOL; FAULTING/SPALLING; VOL = 0

PARAMETER INPUT DESCRIPTION

NUMBER OF YEARS PROJECTED	25			
REPORT TYPE REQUESTED	SYSTEM SUMMARY ONLY			
CURRENT YEAR INPUT	1982			
INFLATION RATES	10.9%	8.7%	7.6%	7.4%
INTEREST RATES	12.9%	14.9%	13.7%	12.0%

DETERIORATION RATES

RIGID		OVERLAY		BITUMINOUS	
SURFACE	BASE	SURFACE	BASE	SURFACE	BASE
.30	.30	.45	.25	.32	.32

DESCRIPTION OF REPAIR ACTIONS ******************

ACTION NUMBER	DESCRIPTION	IMPROVEMENT IN: SURFACE	IMPROVEMENT IN: BASE	COST TO REPAIR MIL $/2LA MILE	PERCENT OF COST CAPITALIZED	ECONOMIC SERVICE LIFE	ENDING PVMT TYPE
3	MED. RECONST-PCC	7.0	7.0	1.000	100	25	RIGID
4	RECON RESURF PCC-OV	6.0	6.0	.500	80	20	OVERLAY
5	ML OVERLAY PCC -> OV	4.5	4.5	.200	80	15	OVERLAY
6	CM RESURFACE PCC-OV-OV	3.0	3.0	.120	80	07	OVERLAY
7	GRIND DR. LA/RESEAL PCC	0.4	2.5	.070	80	05	RIGID
8	PATCH SPL/RESEAL-PCC	0.5	1.0	.016	80	05	RIGID
13	MED. RECONST-BITUM	7.0	7.0	1.000	100	25	BITUM
15	ML OVERLAY PCC-OV POST 72	4.5	3.0	.200	80	12	OVERLAY
16	CM RESURF-AC-AC-AC	2.0	2.0	.120	80	07	BITUM
17	GRIND DR. LA/PATCH SPL/RESEAL	0.8	2.5	.100	80	07	RIGID
25	ML OVERLAY AC-AC	4.5	3.5	200	80	10	BITUM

STRATEGY MATRIX (ACTION X AT CONDITION X,X) ******************

SURFACE CONDITION

BASE CONDITION	1	2	3	4	5	6	7	8	9	10
1	3	3	3			3				
2	3	3	3			3				
3	3	3	3			3				
4				5	5	5				
5				5	5	5	7	7		
6	5	5	5	5	5		7	7		
7										
8						6				
9					6					
10										

ACTIONS ARE APPLIED IF: SURFACE <= 3.50 AND BASE <= 3.50 O R LANEVOLUME > 0

Repair Strategy

The HCPM uses a repair-strategy matrix that directs the model to undertake road repair at specified condition levels. Essentially, the matrix tells the model when (at what pavement condition level) to undertake repairs to a particular section and what work to do. Figure 3 shows an example of the strategy matrix for one group of sections (rigid Interstate highways built between 1960 and 1972 that have high truck volumes). Numbers in this matrix refer to the repair actions above the matrix; for example, the matrix directs the model to apply action 5, a multilayered overlay, to a road section on which the surface and base are at condition level 5. Two additional important features are the lane-volume cutoff, which directs the model to take the specified action only if the traffic volume is greater than the cutoff, and the condition cutoff, which directs that action be taken regardless of volume if the condition is below the specified levels. These features together with the range of actions permit examination of a wide variety of policies and strategies.

Operation and Output

The model reads the input data shown in Figure 3, specified by the analyst, including detailed data on the repair actions, the strategy matrix, the volume cutoff and condition cutoff (minimum levels), and the deterioration rates. The model then begins by reading the data on a highway section from the Highway Sufficiency File. Beginning with the current year, the model checks to see whether the condition of the section is in a cell of the strategy matrix that identifies repair. If not, the model causes the condition of the highway section to deteriorate to the next year's condition by applying the deterioration rates specified by the user. This continues until work is required according to the strategy matrix. The model then checks to see whether the section has enough traffic (whether the section is above the volume cutoff) and whether the condition is below the condition cutoff. If either of those cases applies, the model applies the prescriptive action from the strategy matrix to the section of the highway. It adds the increment in condition (improvement in surface and improvement in base) to the condition scores to determine the resulting condition scores for surface and base, calculates the cost of the work by multiplying the length of the section times cost per mile, and adds these data to all of its summary counters. The model then goes on to the next year and continues the cycle until the ending-year horizon is reached for this particular section. It then goes back to the beginning of the program, reads data for another section, and begins the process again.

On completion of the analysis for the entire system, the model summarizes the results, showing average condition and cost of rehabilitation for each year for the state highway system and various subsystems. Figures 4-6 show typical system output. The model is currently programmed to output a summary of data by region and federal-aid class, a 5-year construction program, and an action schedule. Other options are also possible. One of the most useful current outputs is the 5-year construction

Figure 4. HCPM system summary.

H I G H W A Y C O N D I T I O N P R O J E C T I O N M O D E L

NYS DEPARTMENT OF TRANSPORTATION
TRANSPORTATION STATISTICS AND ANALYSIS SECTION

TEST DESCRIPTION: 1982 S-1: INTER-RIGID: 60-72 HIGH TK-VOL: FAULTING/SPALLING: VOL = 0

SYSTEM SUMMARY TOTAL SYSTEM MILEAGE = 231.37

YEAR	SURF MEAN	COND %<6	BASE MEAN	COND %<6	COST TO REPAIR ($M) CAP-I	MAINT	TOT-COSTS	R O A D U S E R C O S T S FUEL	ACCDT	OP-EX	TIME
1982	6.86	6	6.80	11	13.5	3.3	16.8				
1983	7.13	24	7.23	19							
1984	6.81	24	6.94	19	24.6	6.1	30.7				
1985	7.57		7.79								
1986	7.22	30	7.51	25							
1987	6.86	30	7.22	25							
1988	6.51	38	6.94	25	28.4	7.1	35.5				
1989	7.52	28	7.97	23	1.2	.3	1.5				
1990	7.19	28	7.74	23	11.4	2.8	14.2				
1991	7.40	22	7.89	21	20.4	5.1	25.5				
1992	7.94	7	8.58	1	14.4	3.6	18.0				
1993	8.36	7	8.83	2	1.3	.3	1.6				
1994	7.98	6	8.63		5.4	1.3	6.8				
1995	7.80		8.59								
1996	7.35		8.34		17.0	4.2	21.2				
1997	7.92		8.68		1.2	.3	1.5				
1998	7.54		8.47		9.0	2.2	11.3				
1999	7.63		8.53		12.5	3.1	15.7				
2000	7.93		8.72		13.8	3.4	17.2				
2001	8.31		8.95		.7	.1	.9				
2002	7.90		8.72		3.3	.8	4.1				
2003	7.65		8.59								
2004	7.20		8.34		18.2	4.5	22.8				
2005	7.84		8.72								
2006	7.40		8.47		9.0	2.2	11.2				

P E R C E N T D I S T R I B U T I O N

SURFACE SCORE

	1	2	3	4	5	6	7	8	9	10
CURRENT YEAR: 1982				.56	5.30	30.16	35.70	27.87	.36	.02
HORIZON YEAR: 2006						21.80	25.24	35.20	17.75	

BASE SCORE

	1	2	3	4	5	6	7	8	9	10
CURRENT YEAR: 1982				.73	10.41	25.32	35.14	27.98	.37	.02
HORIZON YEAR: 2006								47.04	37.32	15.63

Figure 5. Action schedule.

M I L E A G E A N D C O S T F O R R E P A I R S D I S T R I B U T E D B Y A C T I O N

STATEWIDE SYSTEM SUMMARY

	ACTION 3 MILES	COSTS	ACTION 5 MILES	COSTS	ACTION 6 MILES	COSTS	ACTION 7 MILES	COSTS
1982			20.25	12.16	4.25	1.53	18.95	3.19
1983								
1984			51.84	28.53	.02		16.27	2.22
1985								
1986								
1987								
1988			68.10	35.56				
1989					4.25	1.53		
1990			14.88	7.50	18.77	6.76		
1991			50.55	25.54				
1992			1.48	.88	51.86	17.13		
1993			4.07	1.62				
1994			17.33	6.80				
1995								
1996					67.84	21.27		
1997					4.25	1.53		
1998			.08	.03	33.65	11.27		
1999					51.68	15.73		
2000					52.21	17.25		
2001					4.07	.97		
2002			.26	.10	17.33	4.08		
2003								
2004					72.09	22.80		
2005					.26	.06		
2006					33.73	11.29		

Figure 6. HCPM 5-year construction program.

Section Identification: RC ET GY	RTE	CO TRC YDS	BEGIN M-PT	END M-PT	MILES	LANES	AADT HUND	1982 COND S	1982 COND B	1982 ACT NUM	1982 COST	1982 COND S	1982 COND B	1983 ACT NUM	1983 COST	1983 COND S	1983 COND B	1984 ACT NUM	1984 COST	1984 COND S	1984 COND B	1985 ACT NUM	1985 COST	1985 COND S	1985 COND B	1986 ACT NUM	1986 COST	1986 COND S	1986 COND B
83	84I	014	00.73	00.88	00.15	4	265	8	8			8	8			7	7			7	7			7	7			7	7
82	84I	022	00.32	03.47	03.15	4	287	8	8			8	8			7	7			7	7			7	7			7	7
82	84I	022	03.47	03.71	00.24	4	266	8	8			8	8			7	7			7	7			7	7			7	7
82	84I	022	03.71	04.95	01.24	4	266	8	8			8	8			7	7			7	7			7	7			7	7
82	84I	022	11.51	11.71	00.20	4	238	8	7			8	7			7	6	7	.028	8	9			8	9			7	8
82	84I	022	11.71	13.64	01.93	4	238	8	7			8	7			7	6	7	.270	8	9			8	9			7	8
82	84I	022	13.64	13.70	00.06	4	238	10	10			10	10			9	9			9	9			9	9			9	9
82	84I	022	13.70	17.35	03.65	4	238	8	7			8	7			7	6	7	.511	8	9			8	9			7	8
84	84I	031	00.00	00.33	00.33	4	238	8	8			8	8			7	7			7	7			7	7			7	7
84	84I	031	00.37	00.61	00.24	4	238	8	8			8	8			7	7			7	7			7	7			7	7
84	84I	031	00.61	01.41	00.80	4	238	8	8			8	8			7	7			7	7			7	7			7	7
84	84I	031	01.41	03.37	01.96	4	238	8	8			8	8			7	7			7	7			7	7			7	7
84	84I	031	03.39	03.56	00.17	4	254	8	8			8	8			7	7			7	7			7	7			7	7
84	84I	031	03.56	03.98	00.42	4	254	8	7			8	7			7	6	7	.059	8	9			8	9			7	8
84	84I	031	03.98	04.00	00.02	6	254	6	8	6	.007	9	10			9	9			8	9			8	9			7	9
84	84I	031	04.00	05.00	01.00	4	254	8	8			8	8			7	7			7	7			7	7			7	7
84	84I	031	05.00	05.02	00.02	6	254	9	9			9	9			8	8			8	8			8	8			8	8
84	84I	031	05.02	06.94	01.92	4	254	8	8			8	8			7	7			7	7			7	7			7	7
84	84I	031	06.94	07.35	00.41	4	270	8	8			8	8			7	7			7	7			7	7			7	7
84	84I	031	07.40	07.90	00.50	4	270	8	8			8	8			7	7			7	7			7	7			7	7
84	84I	031	07.90	07.93	00.03	6	270	9	9			9	9			8	8			8	8			8	8			8	8
84	84I	031	07.93	08.12	00.19	4	270	7	7			7	7			6	6			6	6			6	6			6	6
84	84I	031	08.12	08.14	00.02	6	270	7	9			7	9			6	8	6	.007	9	10			9	9			9	9
84	84I	031	08.14	09.10	00.96	4	270	8	8			8	8			7	7			7	7			7	7			7	7
84	84I	031	09.10	09.33	00.23	4	270	5	8			5	8			4	7			4	7			4	7			4	7
84	84I	031	09.79	10.75	00.96	4	340	7	8			7	8			6	7			6	7			6	7			6	7
84	84I	031	10.75	10.78	00.03	4	340	5	8			5	8			4	7			4	7			4	7			4	7
84	84I	031	10.78	10.79	00.01	4	401	6	7*			6	7			5	6	5	.004	10	10			9	9			9	9
84	84I	031	10.79	13.01	02.22	4	401	7	8			7	8			6	7			6	7			6	7			6	7
15	87I	081	05.63	12.79	07.16	6	273	6	6			6	6			5	5	5	4.296	10	10			9	9			9	9
15	87I	081	12.79	13.03	00.24	6	172	6	6			6	6			5	5	5	.144	10	10			9	9			9	9
15	87I	081	13.03	16.47	03.44	6	172	6	6			6	6			5	5	5	2.064	10	10			9	9			9	9
15	87I	081	16.47	18.15	01.68	6	244	7	7			7	7			6	6			6	6			6	6			6	6

program (Figure 6), which shows the condition of each section and the funds required to sustain it for each year of the 5-year period.

Some other features are being added to the model at this time. These include the following:

1. A routine that calculates user costs for each section, including travel-time cost, operating cost, fuel cost, and accident cost, the availability of which will permit the analyses of benefits and costs of rehabilitation alternatives;
2. Amortization and interest routines; and
3. An option so the user may focus the analyses on one specific route or county combination or on a particular section of highway.

AN EXAMPLE: INTERSTATE REPAIR AND REHABILITATION NEEDS

The following example illustrates the operation of the HCPM. The tests involve an assessment of recommended repair strategies and actions for New York's Interstate system.

The New York State Interstate system was constructed over a fairly long period of time and consequently exhibits different distress symptoms. In particular, rigid Interstates built between 1960 and 1972 that have a high truck volume (Table 3, second group) are beginning to show joint failure and severe faulting problems. Rehabilitation strategies for these sections are more complex than strategies for older sections or flexible pavement sections.

Suggested repair strategies for each group of Interstates shown in Table 3 were developed by the NYSDOT Pavement Management Task Force. These strategies consisted of actions necessary to correct identified problems and to repair and maintain the pavement for as long as possible. Examples of such repair actions are shown in Figure 3. The HCPM was then used to determine the overall cost of these strategies and the resulting system condition and to prepare a possible 5-year construction program. Examples of these documents, again for the second group in Table 3, are shown in Figures 4-6.

The analysis shows that repair needs for this

Table 3. Interstate pavement groups.

Pavement Group	Typical Problem	Miles[a]
Rigid, before 1960	Spalling and rutting, cracking, roughness	24.63
Rigid, 1960-1972, high truck volume (>3,000)	Faulting >0.25 in., spalling, cracking	231.37
Rigid, 1960-1972, low truck volume (<3,000)	Faulting (less), slight spalling	104.95
Rigid, after 1972	Slight spalling, surface and joints	209.12
Flexible	Cracking and rutting, some potholes	196.46
Overlaid		95.13
Total		861.66

[a]Excludes mileage on the N.Y. State Thruway.

group of sections (231.37 miles total) would total $16.8 million in the first year, $47.5 million over 5 years, and $142.2 million over 10 years (Figure 4); however, after this initial period, repair costs will be less. The average condition of this group of pavements will be substantially better in 1992 than at present (1992 surface condition, 7.94; 1992 base condition, 8.58) if these strategies are followed; this good condition can then be maintained for the next 15 years for about $132.3 million, or $8.8 million per year. The action summary (Figure 5) shows that the initial focus needs to be on joint repair and base protection actions, followed later by 2.5-in. overlays, then still later by cold milling and resurfacing of these overlays. Figure 6 shows a page from the 5-year construction program for this group of sections; it lists each section by location and shows the work required in each year.

The results of the Interstate highway repair and rehabilitation analysis for all six pavement groups are shown in Table 4. Overall, such repair needs total $55.6 million in the first year and $31.7 million over 10 years. The system would be substantially better at that time if these repair strategies were followed.

These data are being used by NYSDOT in a variety of ways:

Table 4. Effect of pavement improvements on condition: New York State Interstate system.

Pavement Group	Miles	1982 Condition Level		1983 Condition Level		1992 Condition Level		Repair Costs ($000,000s)	
		Surface	Base	Surface	Base	Surface	Base	1983	1992
Rigid, before 1960	24.63	6.1	6.2	7.9[a]	8.0[a]	7.3[a]	7.3[a]	5.1	1.1
Rigid, 1960-1972, high truck volume (>3,000)	231.37	6.9	6.8	7.1[a]	7.2[a]	7.4[a]	7.9[a]	16.8	12.4
Rigid, 1960-1972, low truck volume (<3,000)	104.95	7.0	6.4	7.4[a]	7.3[a]	7.6[a]	7.9[a]	9.1	3.4
Rigid, after 1972	209.12	8.6	8.4	8.5	8.3	7.8	7.9	2.1	1.4
Flexible	196.46	7.7	7.8	7.9[a]	8.1[a]	9.0[a]	9.0[a]	12.4	9.5
Overlaid	95.13	7.4	7.3	7.8[a]	7.8[a]	7.4	7.7[a]	10.1	3.9
Total	861.66	7.5	7.4	7.8[a]	7.9[a]	7.9[a]	8.1[a]	55.6	31.7

[a]Improved condition.

1. Overall system repair needs: The tests permit assessment of total system needs and resulting condition over the long term.
2. Repair strategies: The procedure permits analysts to determine the wisdom of various repair strategies.
3. Allocations: The data can be used to assist in allocation of funds to regions of the state; for the 1983 construction program, for instance, funds were allocated by lane miles, vehicle miles of travel, and repair needs.
4. Early alert: The model identifies sections in need of attention or likely to need attention in the future.
5. Suggested repairs: The model suggests, but does not prescribe, repair actions for each section of road. The department's decision making on specific actions is decentralized to its regional offices; the model can be used to assist in these decisions, but the recommendation of the regional director on specific actions is usually followed.

CONCLUSIONS

A new tool, the HCPM is one of several procedural improvements under development by NYSDOT to predict and evaluate the long-term implications of alternative rehabilitation strategies on the condition and the repair costs of the New York highway system. The model operates sequentially on data for each section of state highway and summarizes repair costs and condition by region and federal-aid class. Preliminary tests of the model suggest that it is beneficial in quantifying the implications of different repair strategies.

ACKNOWLEDGMENT

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Organizational Analysis of a State Department of Transportation Program Development Process

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Many state departments of transportation (DOTs) are facing serious problems in developing a transportation improvement program that reflects cutbacks in funding and yet meets the demands of constituent groups. The program development process for one state DOT is examined and organizational and process changes are recommended that will improve the ability of the DOT to produce a realistic and credible program. Although this analysis involves only one DOT, the results are relevant to other DOTs as well. An examination of the current problems of the DOT, the development of a normative model for program development, and the use of this model to recommend process improvements are included. The development of a multiyear program, the formulation of a communications plan that describes to constituent groups the rationale and process for establishing priorities, and the use of a management information system are recommended.

Many state departments of transportation (DOTs) are currently facing serious problems in developing and carrying out a transportation capital improvement program. Perhaps most important, cutbacks in government funding have forced many agencies to examine their implementation priorities carefully. These pressures of fiscal austerity, combined with the need to incorporate a broader range of socioeconomic and environmental concerns into the project planning process, have often lengthened and made more complex the planning, developing, and designing of transportation facilities. In addition, because of major changes in the environment of transportation planning, many projects long under development may be less appropriate than they once seemed.

The purpose of this paper is to analyze the project development and programming process of the New Jersey Department of Transportation (NJDOT) and to recommend changes in process and organization that better reflect the current fiscal and political environment (1). Instead of focusing on the development of techniques that could be used to establish project priorities, this study examines the programming process from the perspective of its role as an organizational activity. This perspective required extensive interviews with NJDOT officials at all levels of the organization. Although the results of this study are based only on the experiences from NJDOT, the problems faced by this agency appear common to state DOTs across the United States (2). Thus in subsequent sections many of the concepts discussed for improving program development are related to any DOT facing similar problems as those of NJDOT.

TRANSPORTATION PROGRAM DEVELOPMENT AS AN ORGANIZATIONAL PROCESS

Much of the research that has been undertaken on program development has focused on the techniques that can be used to rank projects by priority (3,4). Until recently little systematic effort was made to examine the process of program development and the organizational characteristics of this process that affect the effectiveness of the program once formulated. A recent report, however, examined the highway programming process in seven states and highlighted the dimensions of such a process that were crucial to its eventual success (5). These dimensions included

1. Laws, agency objectives, and government regulations;
2. Roles adopted by agency management and other agency personnel with regard to programming;
3. Groups potentially involved in the programming process, including highway users, contractors, legislators, local officials, and so on;
4. Stages of the process by which a program is developed (e.g., project initiation and analysis, program draft, program adoption, scheduling, and monitoring); and
5. Program categories in which projects are classified for funding or other purposes.

These five dimensions in essence imply that the process of developing a capital improvement program is an organizational activity subject to the fiscal and political pressures of an agency's external environment and sensitive to structural and behavioral factors internal to an agency.

This perspective on program development presented a challenge in formulating a methodology that was sensitive to these organizational factors. The methodology used in this study consisted of two major steps: (a) a descriptive analysis of the existing process of program development and (b) formulation of a normative model of such a process that addresses the problems found in the first step. Because the program development process was viewed from the organizational perspective, the first step included the identification of organizational units involved with project development, the flow of information among these units, the perceptions of state DOT personnel toward programming, and the influence of interests outside the DOT.

This descriptive analysis identified the following factors that appeared to lead to problems in the program development process:

1. Timetables established for completing projects were often not met, for reasons outlined in the following.
2. Some categories of federal-aid funding available to the state were not always used in a timely manner, which meant that the lag in highway expenditures represented a financial loss to the state in at least two ways. First the beneficial impact on the local economy generated by the influx of federal money was delayed, and second inflation caused a loss in buying power when the projects were ready for implementation.
3. The first two factors led to a credibility problem for NJDOT, making it difficult to receive support from outside constituencies for securing stable funding and increased staffing levels.
4. There were inadequate financial and personnel resources to achieve the expectations of many individuals both within and outside of the DOT. The process of planning and developing construction projects had become more complicated and expensive at the same time that funding cutbacks had restricted the level of resources to carry out the projects.
5. Because of external pressures to carry out many projects, design and implementation priorities

often changed at many different points during the course of the project. It was thus difficult to communicate clearly to all concerned parties what the top-priority projects were beyond a limited number of highly visible and politically sensitive ones. The result was a tendency for DOT personnel to become frustrated with the process and for projects to sometimes be lost.

6. Because of the complexity of the overall program development process and because so many factors had to be considered, there was often some uncertainty concerning organizational responsibilities within the department. This was especially true at the beginning of the process when many new projects were identified and when an initial sorting out of priorities did not occur. This problem was exacerbated by the many points in the development process at which projects had traditionally started.

7. Significant staff resources were expended on projects for which there had been a previous commitment but that could not possibly be built because of environmental problems, community disruption, or cost escalation. Paradoxically the same outside groups that were no longer confident in the DOT refused to accept the professional opinion of DOT officials that some projects might be infeasible.

8. A committee of NJDOT officials that had been created to establish priorities and monitor project development provided a valuable function. However, many individuals in the DOT were uncertain exactly what roles and responsibilities were held by this committee.

9. There was a sense among several high-level NJDOT officials that a realistic, multiyear program of transportation improvements did not exist. Although plans and programs were available, funding uncertainty and possible intervention in project programming from outside sources made a multiyear program a difficult document to produce.

10. Although there was a large amount of data available on projects in progress, there were often conflicting definitions of terms and no common data base.

These problems served as the point of departure for the identification of possible solutions and for final recommendations. Again, although these problems were related specifically to one organizational context, it appears likely that many, if not most, of them are experienced by other state DOTs as well.

PROJECT DEVELOPMENT PROCESS: A NORMATIVE MODEL

The project development process provides the basic organizational structure for any DOT to fulfill its mandate. As such, the process must be structured to allow officials to control and monitor the effective and efficient utilization of project development resources. One such structure (or conceptual model) is shown in Figure 1, in which the project development process is shown to consist of four phases: planning, project development, final design, and advertising and construction. Although it is important to establish this clearly defined and systematic procedure for the overall process, it must never be so rigid that some flexibility cannot be incorporated without destruction of the fundamental objectives of the process.

In order to manage the project development process, it is important to have control points at which decisions can be made on resource allocation based on an assessment of priorities and previous resource commitment. To illustrate what is meant by controlling the flow of a project, a simplified model of the project development process is shown in Figure 2. The gates or points at which key decisions should be made and previous decisions reviewed are shown in Figure 3. Many projects will be examined at the beginning of the process and decisions will be made as to which projects should be developed further. A policy committee of DOT officials, various subcommittees, or the agency heads should make basic decisions on priorities at the beginning of each phase as well as at other intermediate decision points.

At each decision point, there should be clear policy guidance on what types of projects should be advanced. For example, deferred-maintenance projects or those that advance economic development might be given top priority. The criteria at each decision point should thus be clearly articulated by top management.

One of the important characteristics of the project development process should be the insulation from outside influence of technical activities that occur between decision points. The individuals responsible for these activities are thus capable of determining what they can actually produce, given current demands and resources. The manager of each of the appropriate phases should be viewed as a gatekeeper who participates fully in all decisions as a project passes from one phase to the next. Thus the gatekeeper function is one of providing a realistic estimate of what is feasible in project development given the other responsibilities of a particular organizational unit.

Rather than allowing projects to enter the pipeline on a continuous basis, it would be worthwhile to establish batches of projects at the decision points so that trade-offs can be made. Such a system would permit an assessment of the resources needed to complete the project and would also provide a better opportunity for DOT personnel to judge the project interconnectedness and geographical distribution. Knowing which projects are entering any particular phase of the process allows one to reallocate resources to adjust for the different times it will take for projects to complete the process.

Project status information is necessary at the decision points to determine which projects should progress to the next phase and to determine where bottlenecks in the process are likely to occur.

Figure 1. Conceptual model of project development process.

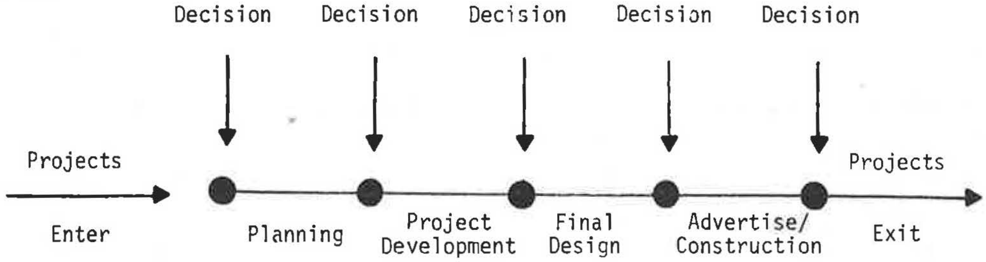
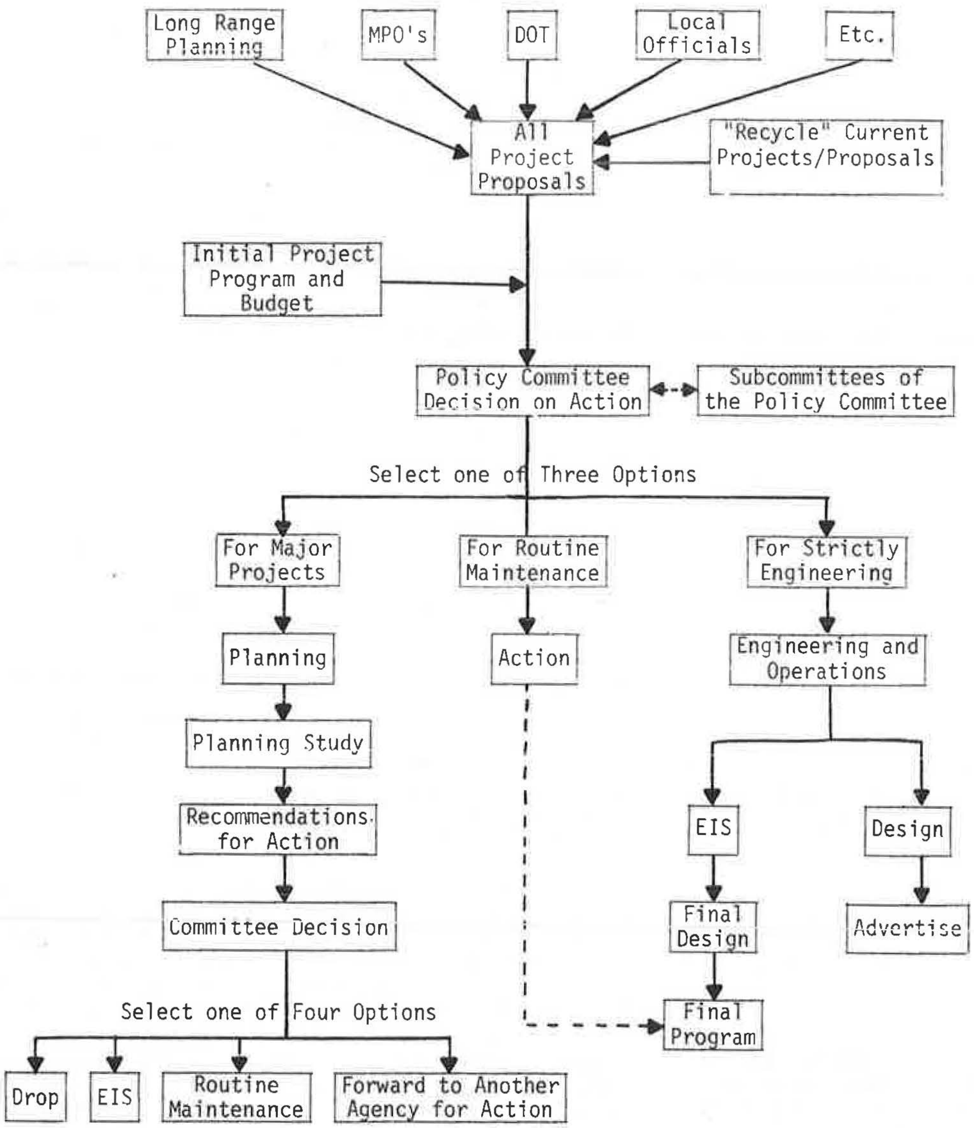


Figure 2. Simplified model to control project development process.



This information need requires some form of management information system (MIS) to produce the information on a timely and consistent basis.

Because the decision points are considered gateways to the next project development phase, different types of meetings will be necessary. For example, meetings will be needed to decide which projects deserve to go into planning, into project development, or into construction; other meetings might be necessary to assess the progress of the most critical projects; still others might be necessary to examine the relationship between the program and the budget. In each case specific types of information would be needed to support decision making.

APPLICATION OF THE NORMATIVE MODEL

The model of program development just described provides an image of a process that recognizes valid external inputs into program development and yet provides internal agency controls that order the process systematically. Several aspects of this model, especially as it relates to the New Jersey case study, merit special attention.

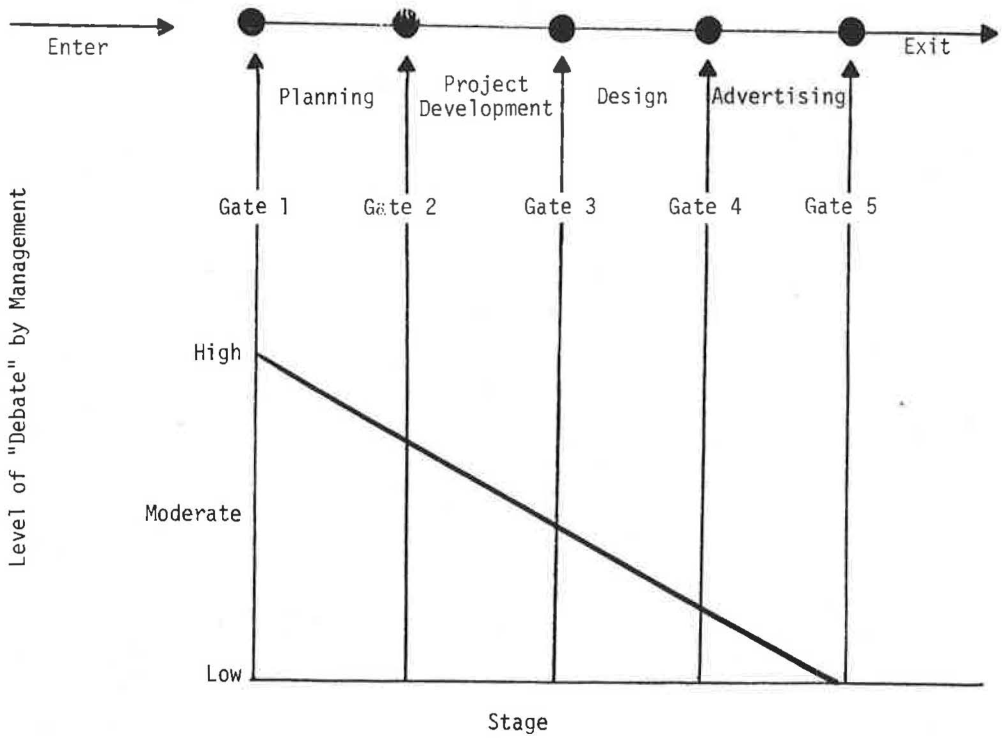
Organizational Mechanism

Some organizational mechanism is necessary to guide the program development process. In the model discussed earlier, the departmental policy committee provides this guidance. For such a committee to work, however, its roles and responsibilities must be clear. Further, regular meeting schedules must be established and agendas prepared in advance.

Schedule

It is also essential that an agreed-on schedule be established for obtaining inputs to the development of a realistic multiyear program. In order to obtain these inputs in a timely fashion, clear communication must be established that will (a) clearly but briefly describe the process used in establishing the program, (b) specify the organizational responsibility for the submission of information so that ambiguity concerning individual responsibilities both inside and outside the department is eliminated, and (c) describe the consequences of failure to meet schedules as indicated.

Figure 3. Role of policy committee.



Functional and Financial Categories

In order to relate DOT objectives to program implementation and success, the program should be developed by placing projects into various functional and financial categories. The agency head must establish clear program objectives for each program type, and the policy committee must relate these objectives to cash flow and realistic budget considerations.

Program Support

It is essential that both personnel and financial resources be scheduled realistically and accurately in order to establish credibility concerning the ability of the DOT to produce and support the established program.

Communications Plan

The DOT must develop a communications plan that describes a clear rationale for establishing priorities and that will establish the credibility of the DOT with its many constituencies as new projects are proposed in the future.

MIS

An MIS that provides useful and reliable information to the DOT officials is a critical component of a program development process. There are five major characteristics of such a system that must be considered for the MIS to successfully support the model shown in Figures 1, 2, and 3.

Relation of MIS to Decision-Making Structure

The information system must be related to the structure of decision making. For example, if the structure of decision making for project development follows a process that, in general, consists of planning, project development, engineering and design, and advertising and construction, the information system (or systems) must be capable of providing information in each step. Major decision points that occur in this project development process should be supported with the information necessary for informed decisions.

Relation of MIS to Decision-Making Purpose

The information provided by the information system should be related to the purposes of decision making. This requires that major actors identify the information necessary for them to make decisions. Often higher levels of management do not need excessively detailed information on every project beginning or currently in progress. Their measure of agency performance is much more aggregated than the project information generated by the organization. However, middle-level managers might well need specific details on tasks not accomplished and the reasons for the delay. The information system must thus respond to the differing needs of the management structure in an agency.

Relation of MIS to Decision-Making Level

The information system must provide consistent, reliable, and timely information for all levels of management decision making. In many organizations, there are often many different units that provide information on each individual project. Depending on how this information is obtained and how the major reporting terms are defined, these different units could provide inconsistent and even conflicting information on individual projects. One common solution to this problem is to have a unified data base for all reporting functions that is formatted at a level sufficient to provide the most detailed information necessary for midlevel management needs but that can be easily aggregated to provide the information required by higher-level management. This information must also be updated periodically to fit the needs of the decision-making process.

Ease of Use

The mechanics of using the information system (initial project input, updating, and information retrieval) must be easy to understand and use. The usefulness of any information system depends to a large extent on its level of difficulty. If a large amount of manual effort is needed to obtain and organize information, the information system is likely to be costly and create inefficiencies in the use of personnel. The initial effort of developing the information system and of institutionalizing it within the agency will most likely require substantial amounts of resources (in terms of funds, personnel, and time), which should be expected by top management. A successful information system, however, should have the capability to maintain and update the data base with minimal resources.

The updating procedures should be easily understood and carried out by those who have the primary information sought. Thus if line managers in the organization are periodically required to report information on project status to a centralized office, the forms for doing so must be easily used and the line managers must view this task as important enough to warrant their time. Ideally the systems should be structured so that those whose timely input is needed get some short-term benefit from providing it in terms of usable information.

Care in Establishing MIS

Implementing an information system must be carefully undertaken; care must be taken to establish credibility, utilize existing resources to the greatest extent possible, and provide for future development of the information system. Because information is so important for the effective operation of an organization and given the often large number of organizational units involved in information flow, establishing an information system can become a complex and controversial effort within an agency. Serious thought must be given to the strategies that can be used to set up such a system, e.g., whether an agency should completely overhaul its information-processing capabilities and issue directives.

CONCLUSIONS

Many state transportation agencies are facing serious cutbacks in staff and funding resources at the same time that demands for improvements to the transportation infrastructure increase. Although much research has been undertaken on the techniques that can be used to set priorities in program development, little work has been done on program development as an organizational process. The program development process in one state DOT has been examined here and a normative model of such a process has been formulated. Although specific to this organizational context, the results of this analysis appear applicable to other DOTs as well:

1. The project development process should be viewed and explained to constituent groups as consisting of a specified number of phases. In this study the phases were planning, project development, final design, and advertising and construction. Specific decision points should exist between these phases at which the worth of projects determines whether they enter the next phase. A policy committee or its subcommittees should make these decisions.
2. The projects should be batched at these decision points to permit easier assessment of tradeoffs.
3. The policy committee meetings should be structured to permit specific tasks to be accomplished. For example, there should be meetings to decide which projects should progress to the next phase. In these meetings, officials responsible for undertaking the next work assignment should be present to determine whether the DOT has the capability to undertake the project.
4. Staff resources should be provided to the policy committee and its subcommittees that reflect the specific purposes of the meetings.
5. Policy and decision rules should be provided by top management at each decision point to permit attainment of priorities. These decision rules should be fine-grained and specific enough so that committee members know exactly what is wanted and staff work appropriate to these concerns can be prepared. For example, the DOT secretary might want to develop ratios of project types that should pass each decision point by type of project (reconstruction, new capacity, bridge rebuilding, and so on).
6. When each project comes to a decision point in the process, it should be analyzed to determine benefits and costs and incremental benefits and costs associated with big projects rather than modest solutions.
7. The decision to move a project to another phase should be based on the comparison of benefits and costs. Although this comparison is not the only factor in setting priorities among competing projects, only those projects that show more benefits than costs should be processed.
8. An MIS is critical to the success of a program development process. A unified data base, including cost schedules and budget information, is the basis for such a system.

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Economic Evaluation of Highway Investment Needs

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FHWA has been required by Congress to prepare biennial reports on the condition of the U.S. highways and the need for highway investment since 1968. Although these needs reports have become more sophisticated with each edition, they still fall short of a full economic analysis of highway investment. The role that economic analysis might play in needs reports is explained, the use of economics in past reports is evaluated, the general categories of benefits and costs that should be considered are outlined, and quantitative benefit-cost evaluation for determining highway needs is illustrated.

The purpose of economic analysis is to ensure that society's resources are put to their best use, including the allocation of resources among various public-sector activities and between public and private uses. The principal tool in the economic evaluation of public programs is benefit-cost analysis. In barest outline benefit-cost analysis involves four steps: the prediction of all the desirable and undesirable effects of the programs or projects under consideration; the valuation of these effects in common terms, usually dollars; the calculation of the net benefits, or the difference between benefits and costs for each project or program; and a choice among alternatives based on their net benefits. Where quantification is uncertain, alternative assumptions and trial values can be substituted to assess the robustness of conclusions.

BASIC EVALUATION CRITERION

If the planning question involves different levels of funding for a single project or program, such as alternative levels of government funding for highway improvements, the alternative with the largest positive net benefit should be selected. Another way of stating this rule is that the scale of the project or the program should be expanded to the point at which the marginal benefits from further expansion just equal the marginal costs or, equivalently, the marginal net benefits from expansion are zero.

The U.S. highway system constitutes a stock of capital facilities that have been built up over time by investing in the system at a rate faster than it wears out. Investment is a flow of resources for some time period (typically dollars per year), and the negative of investment is depreciation, which is the loss in the value of the capital stock over a period of time. Highways depreciate from use, from the weather, and from functional obsolescence. If depreciation exceeds investment in the same time period, the net effect is disinvestment; i.e., the capital stock is worth less at the end of the period than at the beginning. The efficient level of net investment in any particular time period may be positive or negative.

IMPORTANCE OF HIGHWAY INVESTMENT

Highway capital expenditures (including new construction, reconstruction, and major resurfacing but excluding patching and other routine maintenance) by all levels of government have been declining both in real terms and as a share of total expenditures since the mid-1960s, but they still amounted to approximately $20 billion in 1980. This level of investment is insufficient to offset the depreciation of the existing system; one estimate places actual depreciation at more than twice current expenditures (1). A variety of investment options is now available, including

1. Increasing investment to the level at which the highway system can be restored to some previous status of condition and performance and then maintaining the system in that condition,
2. Allowing the system to continue to deteriorate to a status at which it can be kept stable at some given level of capital replacement expenditure, or
3. Within any of the foregoing options, concentrating investment in those portions of the system that warrant stronger pavements, smoother surfaces, or increased lane capacity.

Expansion of the system, in the form of net additional lane miles of highway, is not being seriously considered in the range of alternative investment levels.

FEDERAL ROLE IN EVALUATION

The need for an economic analysis of highway investments is particularly acute at the federal level, because the federal government plays a large role in the financing of highway investments. Although federal funds account for only about one-quarter of all spending on highways, they comprise more than half of all capital expenditures. Evaluating the appropriate division of responsibility for financing highway investments among the federal, state, and local governments is beyond the scope of this paper, but if the high level of federal involvement continues, economic analysis of highway investments at the federal level is imperative.

Particularly important at the federal level is a broad economic analysis of future highway investment levels with roughly the same scope and time frame as the current FHWA highway needs reports. This analysis need not involve a detailed economic evaluation of every highway segment but rather a simpler evaluation of a representative sample of segments. The analysis therefore would not be reliable for deciding how much to invest in particular highway segments, but it could suggest desirable investment levels in the aggregate. Such an analysis would be useful in deciding how much resource to allocate to highway investment as opposed to other private and public uses and, within highway investment, how much to allocate to the different systems and improvement types.

OTHER LEVELS OF GOVERNMENT

More detailed evaluations of individual highway projects would by and large be conducted by the state or county highway departments that were responsible for specific highway improvements, although in the case of federally aided highways such analyses probably should be reviewed by FHWA. Federal review is particularly important in the case of the Interstate program, because the large federal share of project expenses and the project-specific nature of the federal grants may give state and local governments strong incentives to overinvest in Interstate improvements.

In short, if the FHWA highway needs report were to include a full economic analysis of alternative aggregate highway investment levels, this could be extremely useful in deciding how much should be spent on highway investment overall. Such a needs report would not answer every investment programming question and in particular would have to be supplemented with a variety of more detailed economic evaluations at the state, metropolitan, and individual project level. Nevertheless, this type of broad analysis is necessary to determine the appropriate total investment levels.

ECONOMIC ANALYSIS IN PAST NEEDS REPORTS

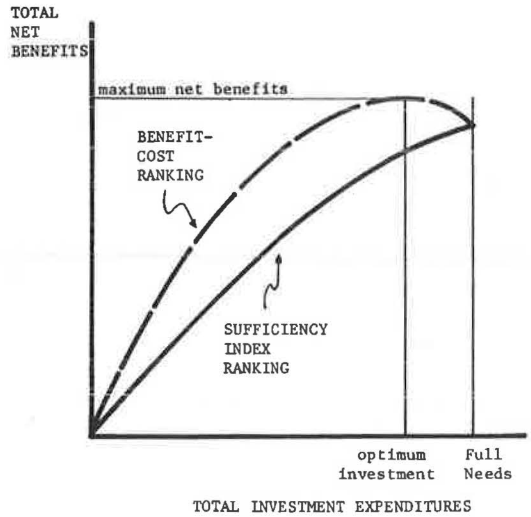
Although FHWA's periodic reports to Congress on highway investment needs have become increasingly sophisticated since the first edition in 1968, they do not yet include an economic evaluation of highway investment levels. Early versions of the report uncritically summarized needs assessments prepared by the states, with an emphasis on completion of the Interstate system and its associated costs. The 1974 report, however, introduced the notion that the performance of the highway system should be used as a measure of the effectiveness of highway investment.

In the 1981 report (2), FHWA refined its analytic model and improved the data on existing highway conditions. Minimum condition standards were developed for different types of highways based on minimum conditions judged acceptable from an engineering, performance, and safety perspective. The composite condition index was also revised and relabeled a performance index to avoid confusion with the 1977 report. FHWA calculated the investment levels necessary to meet the standards for minimum conditions from 1980 through 1995 and defined these funding levels as full highway needs. FHWA also estimated that about 85 percent of the full-needs funding would be required just to maintain highway performance at 1978 levels and that substantial deterioration in performance would occur if funding remained at current levels. Priority rankings for investment at less than full needs was accomplished by means of sufficiency ratings, which attempt to place segments with the most critical deficiencies at the head of the list for improvements.

Although FHWA recognizes that these needs assessments do not constitute a full economic evaluation of highway investments, it has sought to incorporate economic considerations into the analysis. Both the 1977 and 1981 reports include graphs of the relationship between alternative investment levels and the composite highway condition or performance indexes in an attempt to summarize the trade-off between economies in highway spending and the performance of the highway system. The minimum-condition standards established in the 1980 report reflect a concern about balancing the benefits and costs of highway investment; lower standards for traffic speeds and other conditions are prescribed for highways located in urban than those in rural areas because of the extraordinarily high costs of urban highway improvements. Thus under full-needs funding traffic speeds are allowed to fall below minimum standards on some urban highways.

Although FHWA's needs reports have been dramatically improved over the past decade, they still provide little guidance for the economically efficient allocation of resources to highway investment. The most fundamental problem is the lack of assurance that minimum-condition standards and sufficiency ratings incorporate the appropriate balance of costs and benefits to society from additional highway investments. Standards may be based on sound empirical information and the best professional engineering judgment, but they do not explicitly evaluate the costs and benefits of imposing a particular standard on a particular type of highway relative to a higher or lower standard for the same highway. Thus there may be conditions under which higher standards would be justified by the incremental benefits and other conditions under which imposing the standard calls for costs that exceed the incremental benefits. Sufficiency ratings are based on a scoring and weighting system that, again, does not evaluate the incremental net benefits of one type of improvement relative to those of another type of improvement. The investment guidance offered by standards and sufficiency ratings may represent the optimum or it may not, but these methods do not provide the information that allows those questions to be answered.

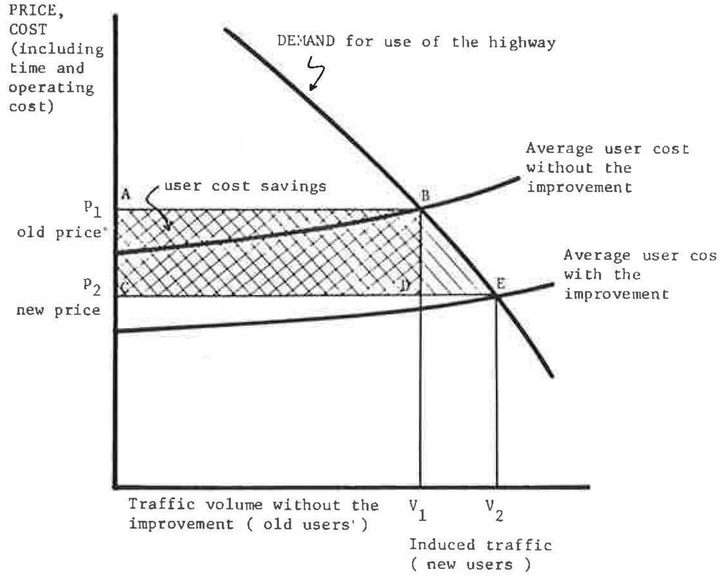
Figure 1. Conceptual comparison of benefit-cost rankings with sufficiency index rankings.



The relationship between standards and sufficiency ratings, on the one hand, and benefit-cost evaluation, on the other, can be illustrated with the diagram in Figure 1. Highway investment expenditures are measured along the horizontal axis. System performance is measured along the vertical axis, in this case in terms of the total net benefits generated by the associated investment level. The lower curve is the ordering of projects based on sufficiency ratings up to the level required to remove deficiencies, which is referred to as full needs. The upper curve indicates (hypothetically) that a ranking of projects based on incremental net benefits would be similar to that based on sufficiency ratings but would reorder the rankings so as to move projects with greater net benefits higher up (to the left in the diagram) on the list. Also the point at which additional projects no longer generate benefits that exceed their costs is determined, labeled as the optimum investment level. The optimum level could be either higher or lower than full needs but most probably is lower, as shown.

FHWA understands the shortcomings of past needs reports and is moving toward a full economic analysis for a future report. The agency has been delayed in incorporating economic analysis, in part because of the various methodological problems and data uncertainties. A few of these methodological problems are peculiar to the evaluation of highway investment projects, but many of them are encountered in the evaluation of other types of investments as well. To assess the problems and opportunities, it is necessary to review the nature of the benefits and costs of highway investment and the way in which they are valued in economic analysis.

Figure 2. User benefits from highway investment.



BENEFITS AND COSTS OF HIGHWAY INVESTMENT

The conventional practice in economic analysis is to value the various impacts of a program or project at the dollar amount that consumers or businesses are willing to pay to avoid or enjoy them. This practice implicitly assumes either that the distribution of income among individuals is regarded as acceptable or, alternatively, that problems of income redistribution will be solved by other government programs and policies, such as welfare programs, social security payments, or graduated income taxes.

Price to Highway Users

In applying the willingness-to-pay concept to the case of highways and most other transportation facilities it is important to recognize that the price that highway users pay to use the facility includes not only the fees that the government charges for highway use (e.g., in the form of tolls or excise taxes on motor vehicle fuel) but also the inputs that the users supply in the form of the time they spend traveling on the highway and the operating costs and depreciation of their motor vehicles. For most highway users, the value of these user-supplied inputs greatly exceeds the fees charged by the government for highway use. Consequently to measure the willingness of highway users to pay for marginal increases in highway services one must also measure directly the time and operating costs that they spend in using the highway.

One of the principal effects of most highway investments is to reduce the effective price (in travel time or other user-supplied inputs) that must be paid to use the highway. In economic analysis when a project reduces prices to users, the measure of benefits to those who would have used the facility at the old price (e.g., without the improvements) is the difference between the old and the new prices. The old (or existing) users would pay the old price without the investment (and some would be willing to pay substantially more), but with the investment they need pay only the new lower price, so they benefit by the amount of the difference. In the case of highways, that difference is the reduction in time, operating costs, and other user-supplied inputs.

The benefits to users are shown graphically in Figure 2. The demand curve shows how the volume of traffic on the highway segment would increase as the average price for using that highway (including the user's travel time and vehicle operating cost) declines. The region under the demand curve can be interpreted as the maximum amount that highway users would be willing to pay for use of the highway. In Figure 2 an investment in the highway segment reduces the price of using the highway from P_1 to P_2 and thereby increases the volume of highway traffic from V_1 to V_2. Each of the V_1 old users would have been willing to pay at least P_1 to use the highway but now have to pay only P_2, so they each benefit in the amount of the difference $(P_1 - P_2)$. The total benefit to these old users is thus $(P_1 - P_2)$ times V_1, which is the crosshatched rectangle ABCD. The new users were not willing to pay P_1 for the highway but are willing to pay at least P_2, so they each benefit by something less than the difference $(P_1 - P_2)$ or, as an approximation, one-half the difference. The total benefit to the new users is thus $1/2(P_1 - P_2)$ times their number $(V_2 - V_1)$, which is indicated by the shaded triangle BDE.

For most highway improvements, the valued impacts can be divided into four major categories: direct benefits to highway users, indirect economic benefits, civil and military defense, and environmental and social benefits and costs.

Direct Benefits to Highway Users

The principal benefits of highway investment are the reduction in the inputs that highway users must supply to use the highway system, such as savings in travel time for drivers and passengers, savings in the inventory and related costs of goods in shipment, and in some cases reductions in vehicle costs and depreciation and in accident rates.

Savings in travel time for drivers and passengers can be among the most important of the gains from highway investments. Investments that increase the capacity of the highway system (such as increased mileage, additional lanes, improved access controls, and more favorable alignments or grades) generally have a larger impact on average traffic speeds and travel time than those designed to maintain physical conditions (such as resurfacing and reconstruction), unless the physical conditions have been allowed to deteriorate significantly before the improvement.

For commercial or business highway users the savings in travel time can increase productivity and result in more effective output per workday. Thus a common assumption is that such time savings should be valued at the hourly compensation that these workers are paid by their employers. The same employers may also save on vehicle ownership costs, because the improvement in travel times should reduce the required number of vehicles as well.

For nonbusiness highway users, such as commuters, shoppers, vacationers, and others, the travel time savings increase the amount of time they can devote to nontransportation activities, such as work, leisure, and sleep. Because time devoted to nonbusiness travel and to other private activities is not directly traded on markets, it is difficult to value the savings it represents. Various studies have attempted to impute willingness to pay for savings in nonbusiness travel time, however, by examining the trade-offs between travel time and money that travelers make when faced with a choice between, for example, using a high-speed expressway on which a toll is charged or a slower parallel arterial street on which there is no toll (3).

For a business using truck transportation, the improvements in average traffic speeds caused by highway investment will also reduce delivery times and in some cases may make the time of delivery more predictable. Faster delivery allows the firm to keep smaller inventories of goods, both because goods spend less time in transit and because the firms can rely on quick shipments rather than large warehouse inventories to meet unexpected surges in demand for their products. Improved delivery reliability also lowers inventory requirements, because inventories held to protect against the possibility of unusual shipment delays can be reduced. The value to the firm of this benefit is often calculated as the savings in interest that the firm would have had to pay to finance the larger inventory.

Highway investments also may reduce the frequency and severity of accidents, although the relationship between some types of highway improvements and accident rates is not completely clear. Upgrading an arterial street to partial access control or to full expressway standards usually reduces the overall accident rate per vehicle mile substantially, for example, although the reduction in rates for accidents involving fatalities and serious injuries is smaller than the reduction in rates for accidents involving only property damage. Improvements in alignment, grades, lane width, and pavement condition may also reduce accident rates, although the relationships are generally not well understood. Valuing changes in accident rates is, of course, difficult because accidents involve not only property damage and medical expenses, for which market values are probably a useful guide, but also suffering and loss of life, for which values are obviously much more difficult to establish.

Indirect Economic Effects

Transportation is seldom desired as an end in itself but rather as a means toward some other end, such as producing or distributing goods and services, earning a living (in the case of commuters), shopping, or vacationing. As a result, improvements in highway services or reductions in the cost of highway use inevitably produce a variety of indirect impacts throughout the economy, many of which may be regarded as beneficial.

It is important to understand, however, that these indirect benefits, with few exceptions, merely reflect a transfer of the direct benefits in reduced highway user costs from the highway user to other parties and as such cannot be counted as separate and additional benefits from highway investment. Land values increase at sites that are made more accessible, for instance, because the direct reduction in time and operating costs gained by highway users traveling to and from sites enables them to pay a higher rent for the use of the land. In short, the landowner captures part of the direct savings to the highway user in the form of higher rents.

Similarly a manufacturer will move to a site that has a lower rent or consolidate operations in larger plants or warehouses because the reduction in highway transportation cost now makes this location or scale of operation more profitable. The savings from relocation or consolidation therefore can be no greater than the direct reduction in highway user costs that the highway improvement would allow; otherwise the firm would relocate or consolidate even without the highway improvement. In essence the manufacturer chooses to translate part of the savings in direct transportation costs into savings from new locations or methods of operation.

Indirect benefits might in theory be measured instead of measuring benefits to highway users. However, one would have to assume that all the direct benefits were passed on to indirect beneficiaries, which seems unlikely, or alternatively carefully estimate the amount of direct benefit retained by highway users. Moreover, because the indirect benefits take so many different forms and accrue to so many different parties, they are substantially more complicated to estimate than direct benefits. Given all these difficulties, it is better to use estimates of direct benefits to highway users as the measure of the gains from highway improvements.

FHWA has not estimated indirect economic impacts in past highway needs reports, although it has prepared estimates of the effects of highway investment on the gross national product (GNP), the consumer price index (CPI), and productivity indexes for the 1982 report. The agency intends these estimates to illustrate the large numbers of indirect beneficiaries from highway programs. As the agency recognizes, however, the detailed effects of highway investment throughout the economy are difficult to incorporate into conventional macroeconomic forecasting models, so the estimates may be subject to substantial error. More critically, because the changes in the GNP, the CPI, and productivity are indirect economic impacts, they should not be regarded as reliable measures of benefits or costs for the purpose of evaluating highway programs. Measures such as changes in the CPI and GNP may not capture many benefits of highway use, for example, because not all the benefits are likely to be passed along in the form of lower prices or increased production of goods and services. The impact of highway investment on the GNP and inflation may also depend as much on the current strength of the economy as on the merits of the investment; in other words, almost any major public works program is likely to stimulate the economy during a recession or add to the risk of inflation during a strong recovery.

Emergency Military and Civil Defense Benefits

Investments in the highway system may also improve its utility in the event of war or a national disaster. Highways play a critical role in military plans to mobilize and embark active and reserve units quickly in the event of a war. Because most military installations, defense industries, airports, and other strategic facilities rely on highway access, highways would also be central to the continuing supply and support of a war effort. The experience of the last two world wars suggests, moreover, that few resources can be spared for major transportation investments during a sustained war effort, and thus military highway needs should be anticipated, if possible. Finally, highways perform critical functions during earthquakes, floods, nuclear accidents, or other disasters by helping to bring relief supplies into or evacuate people from a stricken region.

Estimates of the value of the highway system for military and civilian defense purposes are limited, but this lack may not be critical to the economic analysis of alternative highway investment levels. The system of highways that is desirable for most emergency military and civil defense purposes probably is, with a few exceptions, substantially smaller than the system desirable for ordinary commercial and personal travel. Exceptions might include access roads to military installations as well as special overhead clearances or structural requirements for the passage of oversized military equipment. Thus, although the defense benefits from the basic U.S. highway system are undoubtedly enormous, marginal defense benefits from any alternative expenditure levels under serious consideration are likely to be relatively small. With allowance for the selected highway segments and facilities just noted, it therefore may be reasonable to ignore defense benefits in the economic evaluation of most marginal changes in highway investment levels.

Environmental and Social Impacts

In addition, highway investments and the traffic and land use changes that they generate may impose environmental, aesthetic, and social costs on neighboring communities, although sometimes they create environmental or social improvements as well. In the case of air pollutants, for example, increased traffic stimulated by the highway improvements may increase concentrations of pollutants in surrounding neighborhoods. But if the highway improvements eliminate stop-and-go traffic or idling at stoplights or reroute traffic to expressways or other facilities away from residential areas, pollution concentrations in neighboring communities may actually decline. Similarly, added traffic volumes and new highway facilities can increase noise levels, be unsightly, and have a blighting effect on the surrounding area. Improvements that are shielded by landscaping and other design treatments or investments that relocate traffic away from residential zones may actually improve noise levels and the aesthetic quality of neighborhoods. Valuing these changes in air and noise pollution or visual blight is, of course, extremely difficult, although estimates of the willingness to pay for cleaner and more pleasing environments have been constructed (4).

Finally, highway investments may increase energy consumption and thereby add to certain social costs associated with increased petroleum use that are not fully reflected in the market prices paid by highway users for fuel. In particular, there may be some justification for an additional cost to society beyond those included in market fuel prices, because of national security problems caused by increased dependence on foreign oil, although the magnitude of this social cost is obviously difficult to measure. Some highway improvements, particularly in urban areas, could actually reduce fuel consumption because the gains in fuel efficiency from reducing congestion may offset increases in fuel consumption from greater highway use. On rural highways where current average traffic speeds are already high, however, improvements are almost certain to increase fuel consumption by allowing even higher traffic speeds.

Table 1. Annualized unit costs of improvements by functional system.

	Cost per Lane Mile ($000s)							
	Rural				Urban			
Improvement Type	Int	Art	Col	Loc	Int	Art	Col	Loc
Reconstruct to freeway standards	180	180	–	–	420	260	490	–
Reconstruct with added lanes	170	170	110	40	430	240	230	–
Reconstruct with wider lanes	190	190	140	90	370	250	200	–
Major widening	130	130	120	110	810	370	410	–
Minor widening	60	60	30	30	240	90	130	–
Reconstruct as is	130	130	80	30	320	170	140	–
Resurfacing with shoulder improvement	44	44	33	22	132	44	44	–
Resurfacing	22	22	15	10	–	–	–	–
Isolated reconstruction	40	40	20	10	–	–	–	–
Traffic engineering	–	–	–	–	–	–	–	–

Note: Int = Interstate, Art = arterial, Col = collector, Loc = local service.

EMPIRICAL ESTIMATION OF BENEFITS AND COSTS

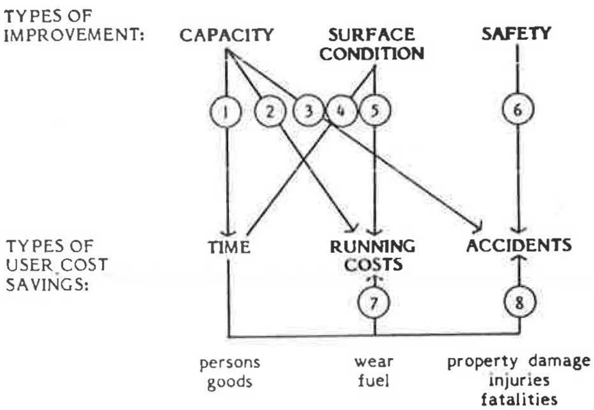
Benefit-cost analysis can be applied at various levels of detail from a comprehensive analysis of all benefits and costs for a wide range of possible improvements on a large number of individual highway segments to a more streamlined analysis of a limited number of improvement alternatives and prototype segments. For the purposes of the national highway needs report, which are to recommend aggregate investment levels and broad improvement categories rather than specific improvements on specific segments, a prototype-based analysis is suitable. Such an analysis is carried out in the remainder of this section at a level of detail that is considerably simpler than that to which the needs study should ultimately aspire. Nevertheless, it demonstrates the feasibility of applying benefit-cost analysis by using the data and general procedures of the existing FHWA investment analysis process.

Types of Improvements and Their Costs

As a first step toward simplification, the various types of investment projects have been grouped into 10 categories, as was done for the purposes of the needs study. These categories, listed in Table 1, range from minor resurfacing of existing mileage to reconstruction to freeway standards. Although greater detail and different categories may eventually emerge from subsequent studies, these 10 categories allow at least a demonstration of the methods that would be used to fill the analytic gap between individual project evaluation and aggregate program needs.

The first five of the improvement types listed increase highway capacity by large amounts in the case of freeways and small amounts for minor widenings. As a matter of practice, almost all these improvements result in a resurfacing. The second group of improvements is primarily directed at pavement rehabilitation, which improves surface quality and may also increase pavement strength. Isolated reconstruction includes projects designed primarily to correct alignment deficiencies on rural road segments and traffic engineering improvements on urban segments. Neither construction in new locations nor traffic engineering improvements, which represent an almost unlimited set of traffic management schemes, were considered further.

Figure 3. Relationships between highway characteristics and benefits.



Total unit construction costs per mile for each improvement type, by urban and rural functional road system, were developed from Tables 4-5, 4-6, 4-7, and 4-8 of FHWA's 1981 highway needs report (2). The costs per mile are based on actual state experience averaged across the country. Construction costs for rolling terrain on facilities that have four or more lanes (after the improvement) were used as the representative unit cost for rural road improvement schemes. Unit construction costs for urban road segments assume a four-lane facility (before improvement) in a built-up region. All construction costs are on a per-mile basis with the exception of major widening, which is on a per-lane-mile basis. Total construction cost per mile was converted to an equivalent annual cost by applying a capital recovery factor of 10 percent.

Selection of Prototype Segments

Each of the eight functional systems listed in Table 1 is treated as a separate prototype. Because simplified relationships between improvement types and user impacts are used, the specifications of the prototypes need not be detailed. For example, the estimated benefits from resurfacing do not depend (in this analysis) on the number of lanes, only on the volume of average daily traffic (ADT). Whenever the functional relationships are developed in greater detail, the characteristics of the prototypical road segments will also need to be spelled out. These include the profile of use by time of day, the mix of vehicles by size and performance characteristics, the distribution of heavy vehicles by axle load factors, the capacity of the segment, and the number of lanes, length of grades, and other relevant geometrics.

Evaluation of each improvement category on each functional system was done on a per-mile basis, as if each mile were a separate facility. Total investment levels are then the result of multiplying the costs of justifiable improvements by the mileage meeting specified conditions. Prototype segments are used to represent the functional systems and then expanded to portray the system as a whole.

Relationships Between Investment and Benefits

For some given level of use, investment in improvements enhances the performance of the highways, which is then manifest in benefits to users. Better surface quality increases travel speeds and reduces vehicle wear and operating costs. Increased capacity reduces congestion and costs related to congestion. Guardrails, medians, better sight lines, better geometrics, and so forth, may reduce accidents and also increase speeds.

Interactions among the different user impacts complicate the quantitative analysis of benefits. Most improvements have some impact on all of the benefit categories, often indirectly. Capacity improvements that allow speeds to increase above 45 mph may increase the number of fatalities, even though accidents are reduced overall. Travel speeds also affect running costs. When impacts move in opposite directions (e.g., increased speed is offset by increased running costs and fatal accidents), the net effect is especially hard to assess.

Figure 3 shows the various relationships that are relevant to estimating benefits of road improvements, not all of which were explicitly addressed in the current analysis:

1. Capacity-increasing improvements reduce the volume-capacity ratio and congestion, thereby reducing travel times. Traffic engineering relationships allow for a great deal more precision than was attempted here, although the effect is explicitly estimated.
2. Reduced congestion reduces speed-change cycles and hence lowers running costs. This factor is not directly included.
3. Reduced congestion is generally believed to reduce the number of accidents. No account is taken of the effects of congestion on accident costs in the following estimates.
4. Improved surface condition reduces travel times by providing a smoother running surface, a benefit included in the estimates.
5. Surface quality also affects running costs through increased tire and vehicle wear and wasted energy absorbed in higher fuel consumption. This factor is included.
6. Better safety structures and geometrics undoubtedly have an effect on accidents, but too little is known about the quantitative relationships to estimate the value of such improvements here. Safety improvements may also affect speed.
7. Increased speed (more than 30 mph) increases running costs, but no account is taken of this factor in the benefit estimates.
8. Speed also increases the severity of accidents, which may at least partly offset travel-time savings through increased fatalities. No allowance is made for this effect.

Some of the omitted relationships could be easily incorporated into the analysis, but their quantitative effects are small. Most of the omissions, however, are due to lack of adequate information. No attempt was made to estimate changes in negative externalities, such as air and noise pollution.

Congestion Profiles

Benefits from adding capacity depend heavily on the distribution of travel over the day. High volumes of daily traffic could be handled by the average two-lane road without significant delays if the daily traffic were spread uniformly across 24 hr. More typically, demand for vehicle trips varies over the day. Additional capacity generates benefits during periods when demand is high enough to cause vehicles to interfere with one another, but during the remainder of the day the benefits are small. It is therefore necessary to make assumptions, described elsewhere (5), to translate ADT data by functional system into measures of congestion.

Prototype Segment Benefit-Cost Evaluations

The net benefit of a specific highway investment is

Table 2. Minimum threshold volume for justifying improvements by functional system.

	ADT (000s)							
	Rural				Urban			
Improvement Type	Int	Art	Col	Loc	Int	Art	Col	Loc
Reconstruct to freeway standards	60	60	–	–	61	25	45	–
Reconstruct with added lanes	57	57	41	25	61	23	21	–
Reconstruct with wider lanes	63	63	32	11	54	24	18	–
Major widening	43	43	35	31	117	36	37	–
Minor widening	20	20	9	8	35	9	12	–
Reconstruct as is	15	15	9	3	36	16	13	–
Resurfacing with shoulder improvement	5	5	4	1	15	4	4	–
Resurfacing	2	2	2	2	6	3	4	–
Isolated reconstruction	3	3	2	1	–	–	–	–
Traffic engineering	–	–	–	–	–	–	–	–

Note: Int = Interstate, Art = arterial, Col = collector, Loc = local service.

obviously dependent on many factors. Fundamentally, however, the value of a road improvement is directly related to the number of users who will benefit over the lifetime of the improvement. If benefits are stated in terms of dollars gained per vehicle mile of travel on the particular facility type and for the particular improvement type, the final controlling parameter is the volume of traffic. The benefits are estimated as the average unit cost savings over the lifetime of the project.

Because the costs for any given improvement on any prototype segment are treated as fixed (not related to vehicle volumes) whereas the benefits increase with traffic, there is always some level of traffic that will result in user benefits that exceed the costs of the improvement. If the volume on the particular segment exceeds the minimum threshold, the benefits of the improvement exceed the costs. Threshold volumes by functional system and improvement category, as calculated from the assumptions and data described earlier, are presented in Table 2.

The final step in the evaluation is to determine how many miles of highway in each functional class are deficient with respect to the improvement type and carry traffic volumes that exceed the relevant threshold. Total expenditures that are justifiable on a benefit-cost evaluation basis are then the sums of the warranted expenditures for each improvement type on each functional system.

Adjustments to 1981 Full-Needs Estimates

If the shares of improvements for each type that meet benefit-cost thresholds are applied to the 1981 full-needs expenditures, a picture can be obtained of the degree to which each improvement type is likely to generate net benefits on a particular functional system. Robust conclusions cannot be drawn from these trial figures (5), but the kinds of conclusions that might be supportable with a more extensive benefit-cost analysis are these:

1. A large share of the full-needs resurfacing expenditures on all functional systems can be justified on the grounds of user benefits.
2. Capacity-increasing expenditures are harder to justify, especially on the lower-volume rural systems. Network consolidation within these systems could alter this conclusion.
3. The effects of highway improvements on accident cost savings, which are omitted from this analysis, must be better understood in order to properly evaluate future highway investment programs.

Much of the information needed to refine these results is available in the FHWA's Highway Performance Monitoring System files but could not be utilized within the small scale of this pilot analysis. There are also, however, some important gaps. The next step is to carry out a more thorough economic evaluation of alternative investment levels as a means for determining overall highway needs.

CONCLUSIONS

Although the empirical analysis of highway investment alternatives has not been carried out here to a depth that would allow recommended levels of expenditure to be presented, it is clear that economic evaluation can be used for this purpose. Existing FHWA data will support a benefit-cost analysis of investment levels at least as well as they support the current analysis based on minimum standards and sufficiency ratings. In summary, the following conclusions may be stated:

1. The application of benefit-cost evaluation to the determination of highway investment needs is feasible and can be readily carried out within the scope and scale of FHWA's highway needs study and
2. Benefit-cost evaluation is the only credible approach for addressing the fundamental questions of optimum program levels and efficient improvement categories.

The application of economic analysis to highway investment needs reveals many important weaknesses in both the data and the structural relationships between highway improvements and benefits, but these shortcomings can be offset by properly focused research. Given the current conditions under which highway investment decisions take place, highway planners can no longer be content to simply rank projects by priority within a budget set by someone else. Economic analysis gives planners a means for participating in determining the size of the budget.

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Integration of Land Use, Transportation, and Energy Planning in Midsized Cities

MARY KIHL AND TIM FLATHERS

Broad-based concerns about long-term efficiency in using energy resources cannot be addressed primarily by the modification of the travel behavior of individuals. Alternatives that depend on redirecting travel patterns must be explored. The current study focuses on the use of such land use planning policies as the encouragement of infill and the development of neighborhood service centers as means of affecting modifications of travel patterns. After an analysis of the experiences of a national sample of 10 midsized cities, it was concluded that 10 years after the 1974 Arab oil crisis the potential for redirecting development patterns in midsized cities has only begun to be recognized. Whether such changes can significantly affect transportation patterns remains to be seen.

Almost a decade has elapsed since the Arab oil embargo awakened sensitivities to the finite quality of energy resources. In the last 10 years numerous strategies have been employed by federal, state, and local governments in an effort to facilitate energy conservation. However, many of these strategies appear to have been directed toward short-term solutions. Broad-based concerns about the long-term efficiency in using energy resources appear remote and somewhat unreal to those concerned about personal efficiency and convenience in tripmaking.

Consequently energy conservation measures cannot rely primarily on voluntary individual modifications of travel behavior. Other alternatives must be explored, alternatives that depend on modification of travel patterns rather than travel behavior. The current study focuses on land use planning techniques as a means of affecting change in travel patterns.

The potential for land use changes in redirecting travel patterns has long been acknowledged (1). The advent of regional shopping centers and suburban industrial parks sparked by the completion of limited-access highways in the 1960s diverted travel from the central business district (CBD), whereas strip development stimulated traffic congestion along the highways leading into most American cities. Within individual cities land use regulations have helped define the urban forms that have in turn defined travel patterns. Presumably local and municipal governments armed with a variety of land use regulations and with the cooperation of private investors can also become catalysts in redirecting urban growth and consequently travel patterns. Whereas federally assisted highway projects helped to scatter urban residents into automobile-dependent suburbs, revised land use plans initiated by local government and carried out with the cooperation of investors might potentially help restore more energy-efficient environments (2, pp. 521-525; 3). The current study considered the extent to which city planning efforts have formally or informally accepted that challenge in the decade since 1973.

The procedure involved, first, a comparison of available land use planning maps and planning documents for the years before 1974 and after 1974 and future projections for each city in the sample. Second the planning strategies used in the sample cities were assessed and finally a typology was developed indicating levels of coordination in energy conservation, transportation, and land use planning. Given the small sample of cities and the need for qualitative assessment, an in-depth statistical analysis was not possible.

The focus for the study was a sample of 10 midsized cities with standard metropolitan statistical areas (SMSAs) ranging from 100,000 to 200,000. This population class was selected for two primary reasons. First previous studies that have attempted to link urban form and energy use have generally focused on larger cities such as Atlanta, Baltimore, Buffalo, Denver, and Fort Worth (4,5). The experience of midsized cities has yet to be documented. Second recent census reports note considerable changes in the population bases of medium-sized cities. Presumably they would also have experienced considerable land use changes over the last 10 years. An initial sample of 54 cities was selected from among the 93 SMSAs in this population class. This sample included clusters representing established and expanding cities, Eastern and Western cities, and geographically confined and unconfined cities. Requests for plans, maps, and other specific types of data were sent to the planning offices in each of these cities. Twenty-four cities responded, but even with a follow-up, reasonably comparable data were only available from 10. Fortunately, as shown in Table 1, the final sample of 10 cities represented the variation in location, growth rate, and terrain specified initially.

STUDY SAMPLE OVERVIEW

If cities' planning efforts are to be reviewed in terms of progress toward creating a more energy-efficient environment, it is first necessary to develop a definition of that environment. The absence of any clear consensus on what constitutes such an environment is evident in the contradictory reviews given specific land use alternatives.

Arguments focus on whether infill and cluster development are workable approaches to conserving energy. Some maintain that infill reduces trip length and consequently conserves energy, whereas others argue that infill implies increased density and congestion and thereby saves little in terms of energy (6-8). The well-known study Cost of Sprawl, prepared by the Real Estate Corporation in 1974, included transportation costs to far-flung suburbs as support for its argument in favor of cluster development. Critics continue to attack that work's encouragement of increased density (9,10). However,

Table 1. Sample cities categorized.

City	Location	Terrain	Growth Rate
Amarillo, Tex.	West	No constraint	Stable
Asheville, N.C.	East	Severe constraint	Stable
Danbury, Conn.	East	Mild constraint	Expanding
Elkhart, Ind.	East	No constraint	Stable
Fort Collins, Colo.	West	Mild constraint	Expanding
Grand Forks, N. Dak.	West	No constraint	Moderate expansion
Lawton, Okla.	West	No constraint	Moderate expansion
Lubbock, Tex.	West	No constraint	Stable
Provo City, Utah	West	Mild constraint	Moderate expansion
Wilmington, N.C.	East	Severe constraint	Stable

if infill could proceed at the density of surrounding neighborhoods, it would find greater support (11, pp. 88, 102-103; 12).

Similarly, arguments regarding the energy conservation potential of multipurpose activity centers focus on the relative savings generated by reduction of trip length versus expense because of increased traffic volume on smaller arterials. Greene (4) discusses studies referring to a 30 to 50 percent savings in energy because of polynucleated development. A larger consensus could be formed regarding the benefits in terms of energy conservation of neighborhood service centers that divert shopping and professional trips to locations closer to residences and thereby reduce the frequency of longer trips to regional shopping centers (1, pp. vi, 2-3; 13). Because such neighborhood centers serve a geographically defined population base, congestion is not increased substantially.

For purposes of this paper the definition of a more energy-efficient urban environment will be built on planning concepts with broad bases of support: residential infill accompanied by neighborhood service centers. Although these concepts focus primarily on energy conservation derived from reoriented shopping and service trips, infill also provides the opportunity for shortening those work trips, particularly those oriented toward the CBD. [The clustering of worksites in decentralized activity centers, a concept parallel to that of neighborhood service centers, would prove to be less workable in smaller cities with limited numbers of basic employers (14).] What follows is a descriptive analysis of the land use planning efforts of the study sample with special reference to the degree to which concerns for an energy-efficient environment visibly affected planning practice.

The planning experience of each city is unique because of variation in socioeconomic, political, and geographic characteristics. These differences dictate the specific nature of responses to broad-based challenges such as those provided by energy shortages. Nevertheless, one would expect that well-publicized national concerns would invite some type of response, either through formal documented planning efforts or through more informal directional planning (15).

The cities in the study sample represent a range of planning responses as well as a wide variety of demographic and geographic characteristics. The 1975 estimated population for most of the cities in the sample was about 55,000, although Lubbock and Amarillo had populations of 163,525 and 138,743, respectively, in 1975 (16,17). Population density also varied. The median was 2,400 per square mile although the range extended from a low of 1,242 for Danbury to a high of 3,880 for Grand Forks. The population of most of the cities increased moderately during the period but that of Asheville decreased by 3 percent in the period 1970 to 1975 whereas that of Fort Collins increased 73 percent from 1960 to 1970 and 29 percent from 1970 to 1975. Although Amarillo declined 8 percent in the period 1960 to 1970, it recovered with a 9 percent increase from 1970 to 1975.

The basic housing stock of most of these cities was predominantly single family, although Grand Forks had only 31 percent single-family units in 1970. Amarillo, on the other hand, had 83 percent single-family dwellings. An indicator of potential for land use changes is the percentage of change in housing stock over a 10-year period. Variation in this figure was considerable; it ranged from a low of 6 percent in Asheville to a high of 114 percent in Danbury. Economic indicators included the variation in median family income, which ranged from a low of $6,986 in 1970 in Wilmington to a high of $11,439 in Elkhart. The percentage below the poverty level ranged from 5.5 percent in Elkhart to 14.9 percent in Asheville and Lawton in 1970 (16,17).

Statistics on vacant land were not available for all cities, but among those reporting, the amount of vacant land within city limits decreased substantially after 1973. (Figures on land use categories and other observations on land use were developed from the appropriate land use plans and maps supplied by city planning offices.) The 3,415 acres of vacant land in Grand Forks in the 1960s declined to 1,462 in the latter part of the 1970s, whereas the 25,199 acres in Asheville declined to 21,582 acres. For the same period the acres of land in streets and rail in Asheville increased only 2 percent, whereas the developed land increased 8 percent. In Danbury the proportion of developed land increased from 38 to 56 percent, whereas the proportion of roads and utilities increased only 2 percent, from 7 to 9 percent. Such figures suggest infill, either directed or natural. This observation is supported by a comparison of the land use maps of the cities in the study sample. Among the cities supplying sets of land use maps, which included a map from around 1970, a current map, and a future-projection map, all showed considerable infill.

All the cities are well served by railroad and highways. Each of the cities is served by the main line of at least one major railroad and five cities are served by more than one. Interstate highways or limited-access toll roads are also available for all but two cities and those have four-lane major highways. With these excellent transportation facilities it is not surprising that the cities have established light and heavy industry. Industrial parks have been established in at least six cities.

Each of the cities has a multipurpose CBD and most have written plans underscoring the need to strengthen the CBD. Nevertheless, all have regional shopping centers, and strip development is apparent in the maps supplied by all the cities in the sample. Future land use maps of all but one of the eight cities supplying them indicate the continuation of linear development patterns. For seven of the cities neighborhood service centers existed well before 1973. More recent maps indicate continuation of this configuration in four of the cities and some semblance of this pattern in four additional cities.

Nevertheless, despite these apparent similarities in land use maps, the planning orientation of these cities varies considerably. For example, only three of the cities have plans that formally link energy conservation and land use. For only four of the cities do the plans explicitly indicate an effort to direct growth on the periphery. The need to respond to population growth signaled a directed planning response in only three of the cities. Two of these were opposed to further growth, whereas one was encouraging it. The other four cities currently experiencing considerable growth had developed no unified planning response.

For purposes of this study it is important to note that the formal plans of only four of the cities (Asheville, Grand Forks, Lawton, and Amarillo) expressly linked land use and transportation planning, whereas the plans of the three others (Fort Collins, Lubbock, and Provo City) implied such a relationship. The remaining three cities gave no indication of this linkage in their planning documents. Among the four cities clearly linking transportation and land use planning only three (Ashville, Grand Forks, and Lawton) noted the additional link between transportation planning and energy conservation.

PLANNING STRATEGIES ASSESSED

A closer look at the strategies associated with transportation and land use planning is warranted. The available planning documents for each of the 10 cities were thoroughly reviewed. (Questions used in the data collection may be obtained from the authors.) Responses gleaned from the documents were recorded and verified through a series of follow-up telephone interviews with officials of the planning departments of each city. The resulting data were then tabulated and cross-tabulated in an effort to uncover possible associations between planning objectives and planning strategies. Although the small sample of 10 inhibits any statistical analysis, the results provide indications that can form the basis for further inquiry.

The procedure revealed elements of what would constitute a more energy-efficient environment in each of the 10 cities in the sample. However, few of the cities had unified planning strategies seeking to relate those elements in an environment that would reduce the need for lengthy tripmaking.

As indicated previously, all the cities have experienced infill within the last 10 years. However, in only five of the cities was contiguous development an expressed planning objective. Only three of those cities have sought to reinforce this objective by directing growth at the periphery. Although the plans of all but one of the cities in the sample decry the continuation of linear development, the specific steps needed to redirect that development are less well defined. Fort Collins, Danbury, and Amarillo indicate plans for more clustering of commercial development, whereas Grand Forks and Lubbock plan to encourage more general compacting of residential and commercial development. Wilmington, a city with a stable population base, has begun plans to redirect commercial activity from strip development along highways to vacant land and buildings closer to the CBD. On the other hand, Lawton and Asheville indicate no plans to vary the current pattern of linear development. Plans for Provo City include a new shopping center near the periphery. The benefits to be derived from infill and contiguous development were primarily expressed in terms of potential savings in city services and utilities. Nevertheless, two-thirds of those communities that were attempting to plan for contiguous development were also developing planning strategies that would link transportation and land use planning. This association generated a chi-square value significant at the 0.02 level. The association with the planning strategies for energy conservation was far less apparent. The need for energy conservation was mentioned in the planning documents of only three of the cities emphasizing contiguous development.

As indicated earlier, 7 of the 10 cities in the sample provided early evidence of small retail establishments located in largely residential neighborhoods. However, only three of the cities specifically presented neighborhood service centers as part of a planning strategy. Four additional cities had land use maps that implied plans for some form of neighborhood service centers.

The appropriate service area for neighborhood centers varied from walking distance (0.25 mile) in Fort Collins to about 4 miles in Danbury. The average was about 1 mile. As with infill, association between the concept of neighborhood service centers and transportation planning was considerable. Seventy-one percent of those cities that either explicitly or implicitly suggested adherence to the service-center concept also discussed the linkage between transportation and land use planning. Within the majority of cities linking service centers and transportation planning, neighborhood service centers were perceived as serving a radius of 1 mile or less.

Among the cities in the sample, transportation was equated primarily with automobile trips. Several cities had no mass transit systems, and of those with bus lines, few found them well used. For most of these smaller cities the population density and configuration made mass transit an unrealistic alternative. Bicycles appeared to provide a more workable alternative to the automobile and their use might well reinforce the need for neighborhood service centers. In Fort Collins, for example, the need to accommodate bicycles for shopping and work-related trips was explicitly presented.

An aggregate review of the characteristics of those cities pursuing either service-center development or infill indicated no clear pattern. There was little association between service-center development and an indicator of new development (the number of new houses built in 1975) and no association between directed growth on the periphery and development of service centers. Service centers were apparently inserted into existing neighborhoods. As such they would have potential for redirecting trips.

Efforts to relate the tendency toward infill or service-center development or both with socioeconomic characteristics or geographic characteristics of the cities in the sample indicated no significant correlations. For example, there was no significant association between population growth rates within the cities and planning strategies involving infill.

Economic indicators such as percentage below the poverty level or median family income similarly proved to be unrelated to a propensity to pursue directed growth. The degree of limitation to expansion imposed by the terrain, although providing an impetus for infill or directed growth in some cities, was not necessarily a determining factor. For example, 50 percent of those cities with severe geographic limitations were pursuing infill, whereas 60 percent of those with mild limitations and 100 percent of those with no limitations were encouraging infill. Where growth is not naturally diverted by the terrain, more formal planning strategies may well be deemed necessary.

STRATEGIES AS RELATED TO PLANNING PRACTICE

A closer look at the cities in the sample is needed to further understand the inclination to employ elements of a planning strategy in moving toward a more energy-efficient environment. The cities in the sample fell into three groups with respect to their efforts to redirect land use and thereby travel patterns. One group was assertively promoting such changes; a second group was responding when the need for such changes became obvious locally; and the third group was pursuing a laissez-faire, nondirective planning approach. The specific characteristics of the cities varied considerably. However, it is possible to develop a rough typology indicating the forms of land use planning practice most likely to redirect travel patterns and thereby increase energy efficiency.

Cities Assertively Changing

The most assertive group of cities in the sample included the growing cities of Fort Collins and Grand Forks and the relatively stable city of Wilmington. Lubbock was the most assertive with regard to one element of the energy-efficient environment although less effective with regard to the other. It was nevertheless included with the assertive group.

Fort Collins has formally recognized the association between land use, transportation, and energy use. The city plan states (18, p. 32): "When higher density development is combined with energy efficient locational criteria, the result is the reduction in the length of roads and utility systems which decreases costs of development, drain on city resources and usage of fuel." Both infill and service centers are encouraged (19, pp. 20,21). According to a telephone interview with the Fort Collins Planning Department in May 1982, two small service centers with grocery stores were complete and a third was under construction. The development of such centers is specifically associated with efforts to improve traffic circulation. A land guidance system fosters contiguous development through cooperation with private developers. The system passes the costs of increasing sewage and water lines along to the developer, an approach that has acted as an effective deterrent to linear or strip development (19, pp. 1, 5-8). Within the last 5 years an increasing amount of residential development has been in multifamily units, a trend responding to public demand.

A contrasting but nevertheless directive approach has been attempted in Wilmington. Although Fort Collins continues to absorb increased population, Wilmington is an older, more stable settlement. Nevertheless, it shares with Fort Collins the dissatisfaction with strip development and efforts to encourage infill. Vacant lands were identified in a survey that is now to be extended to identifying vacant floors of buildings. Rather than advocating the development of new service centers, Wilmington is attempting to create multiuse centers in existing commercial areas. Higher-density development near those centers will be encouraged so as to make them available to larger numbers of people. Energy conservation is clearly indicated as a primary concern in developing this strategy. Implementation will be encouraged by limiting extension of utilities outside the existing service area. According to a telephone interview with the Wilmington Planning Department in May 1982, this informal approach was selected because it would have been difficult politically to change the well-established zoning pattern.

A more comprehensive form of coordinating land use and transportation planning is evident in Grand Forks. Grand Forks went through a period of rapid growth from 1975 to 1979 and is now attempting to direct that growth into a more energy-efficient environment. Energy conservation is indicated as a community goal (20, p. 131); the policies to be used to achieve this goal include allocating land uses to reduce trip lengths and to increase the usefulness of mass transit. Plans call for development of activity centers linking both employers and shopping centers. The location of a shopping mall south of the city in 1979 is now perceived as a mistake in the sense that it violated the general directive toward contiguous development, but a telephone interview with the Grand Forks Planning Department in May 1982 indicated that infill is now being encouraged in the vacant land between the mall and the rest of the city. The primary planning tool encouraging both infill and neighborhood service centers is the planned urban development (PUD), which in Grand Forks includes grocery stores as well as mixed residential uses. PUDs are also specifically indicated to support making mass transit more useful by increasing population densities (20, pp. 95, 102). Strip development is being attacked by restricting direct access from major highways.

Lubbock has employed modern technology to redirect land use planning. A coordinate-based computer program is used to identify current land use and simulate alternative future uses. The results of the simulation form the basis for zoning and effective comprehensive planning. The concept of the neighborhood service center has been actively pursued as an alternative to strip development, and commercial enterprises are now clustered in nodes 1 mile^2 apart.

Infill, on the other hand, has enjoyed little political support. As the land use plan indicates (21, p. 54): "Before infill will take place public opinion, leading attitudes, and market preferences will have to be changed." A liberal annexation policy has generated a considerable amount of vacant land within the city and the city lacks effective tools to encourage infill without private initiation. The resulting scattered development has reinforced the dominance of the automobile, although the transportation plan indicates that the development of alternative modes is essential. Without redirected residential land use the transit improvement program has been reduced to rather ineffective efforts to lure riders out of their cars. A denser population base would have made mass transit a more usable travel alternative (22, p. 83).

Cities Responding to Outside Stimuli

The second group of cities--those responding to outside stimuli in relating land use and transportation planning--includes Amarillo, Provo City, and Elkhart. All three have experienced a leveling off of their population growth rates and consequently no longer have obvious pressure for directed growth. Only Provo City is constrained by its terrain and is consequently trying to encourage higher-density development.

None of these cities is currently advocating neighborhood service centers. A telephone interview with the Provo City Planning Department in May 1982 revealed that Provo City had instituted some service centers but that they had not been successful financially because of lack of cooperation from developers; no new centers are planned. According to a similar interview in Elkhart, "Ma and Pa" groceries are reemerging. Energy conservation is not a stated goal in any of these cities. Contiguous development, on the other hand, is proceeding in all three cities. Elkhart, with little undeveloped land, is using utilities to direct growth and is encouraging cluster development through PUDs. Flexible development standards are encouraging infill in Amarillo. Provo City is attempting to widen its strip development into more intensive commercial development through PUDs.

In advocating these changes the cities note the association between transportation and land use. The plan for Amarillo notes, for example, that there are no functioning elements of a city that are more interdependent than the transportation system and land use (23, Sec. 4, pp. 3-18). Transportation benefits to be derived from orderly contiguous development are, however, presented in terms of reduced traffic congestion, and the accompanying benefits in energy conservation are not indicated. Linkage between these strategies and an increasingly useful mass transit system is also overlooked.

Cities Using Laissez-Faire Approach

The third group of cities--those adopting a primary laissez-faire approach to land use transportation planning--includes the rapidly changing cities of Danbury and Lawton and the relatively stable city of Asheville. All three of these cities have considerable commercial strip development, and both commercial and residential development is continuing to expand outward rather than moving toward infill. Some neighborhood shoping opportunities exist, but none of the cities has a defined policy to encourage their development. Linear growth dominates. In Ashville linear development is encouraged in part by the steep terrain, but in all three cities the lack of effective planning tools has inhibited efforts to redirect growth. Sprawl is encouraged in Asheville by a state law prohibiting this city from charging higher utility rates to customers outside the city limits (24; telephone interview, May 1982). In Lawton sprawl continues because of consistently low property tax rates (telephone interview, May 1982), and in Danbury it is encouraged by the lack of any specific plan either for redirecting growth or for encouraging contiguous development (telephone interview, May 1982). For all three cities traffic congestion is presented to be a problem, but none of them has attempted to reduce that through revised land use planning. Political opposition has discouraged instituting new concepts such as cluster development or PUDs. For none of these three cities is energy conservation a stated or implied goal, especially not for Lawton where local supplies of oil are abundant and energy use is, in fact, encouraged.

CONCLUSION

In general the experience of these 10 cities indicates a rather limited response to the challenge provided by energy shortages. Only two cities have developed comprehensive planning approaches incorporating land use strategies to redirect transportation patterns. Nevertheless, some of the cities have begun to take steps that will potentially change travel patterns.

Although the origin-destination data necessary to support claims in changes in travel patterns were not available from the cities in the sample, it was possible to use available land use maps as a rough surrogate to note changes in distance between residential areas and shopping facilities. The approximate distance between the center of each major residential area and the closest commercial center was calculated on pre-1970 maps, current maps, and maps of projected future land use. This process naturally cannot document whether individual residents indeed travel to the closest commercial region, but it does indicate the potential for such trip-length reduction. The process revealed considerable variation among the six cities supplying the necessary land use maps.

As expected, Grand Forks registered a considerable decrease in distance to shopping facilities. Elkhart and Amarillo, cities in the second group described earlier, also provided evidence of reduced potential shopping-trip distance (30 and 10 percent, respectively). The maps for both Lawton and Danbury, cities in the third group, indicated potential increases in future shopping-trip distances (20 and 8 percent, respectively). The case of Lubbock, the city actively pursuing service centers but not encouraging infill, reinforces the need for an integrated approach to redirection of land use. Maps for Lubbock indicate a 4 percent potential increase in shopping-trip distance by 1990 given current trends. Unfortunately, information regarding work-trip distance could not be derived from the land use maps.

Those cities that have begun to redirect land use development demonstrate the variety of planning tools used in this attempt and by extension in redirection of transportation patterns. The comprehensive land guidance system employed in Fort Collins supports the enthusiastic endorsement given that approach by planning scholars (25, pp. 193-309). It provides a framework by which to steer land use policy through a generalized set of regulations developed and supported by private developers as well as by the general public. The flexibility associated with this system permits changes in short-term planning needed to address long-term objectives. Flexibility in land use planning is also equated with the PUD. The PUD and the mixed residential cluster development employed in Elkhart similarly provide flexibility in land use planning (26, p. 78). Mixed residential cluster development as in Elkhart and Grand Forks is credited with saving energy through reduced trip distance and increased density and with enhancing the usefulness of mass transit (27, pp. 55-58). None of the cities in the sample has experimented with such concepts as transfer of development rights, which have been used in larger cities to redirect development (28).

Although the flexibility of some current planning techniques facilitates the redirection of land use, midsized cities have also been fairly successful in using more traditional approaches such as variable utility rates and limited sewage line expansion. Even zoning changes can be effective (29, pp. 70-72; 30, pp. 228-237). Cities with planning objectives indicating a need to redirect development patterns have generally been able to effect at least some changes in land use with whatever approaches were supported politically (31, pp. 88-99). Outside regulations or public lack of concern inhibited others from pursuing similar strategies.

In summary, the potential for redirecting development and changing the configuration of midsized cities from expansion and sprawl to more compact contiguous development has been recognized. However, the key elements forging the links between land use, transportation, and energy are not city size, terrain, location, or the use of specialized planning techniques but rather public determination, a positive political climate, and clearly defined planning objectives. Whether the reorientation of land use can significantly affect transportation patterns and thereby conserve energy remains to be seen. Ten years after the Arab oil crisis, efforts to encourage energy conservation through integrating transportation and land use planning are still in their infancy.

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Transportation Evaluation in Community Design: An Extension with Equilibrium Route Assignment

RICHARD PEISER

An integrated model of transportation and land use is developed for the purpose of evaluating alternative community master plans. Equilibrium route assignment is combined with the conventional four-stage transportation model to calculate the overall economic benefits of alternative urban planning decisions. Problems of measuring benefits associated with elastic trip demand and demand shifts are also examined. The model is used to evaluate planning alternatives for a 7,500-acre suburban community. It is especially adapted to the problem of evaluating a subcommunity within the context of a larger metropolitan area. Equilibrium route assignment provides an efficient low-cost method of determining route flows and the cost implications of various road networks and land use decisions.

Land use planning and transportation planning should go hand in hand. However, with few exceptions transportation analysis is performed only after land uses and densities have been set. The analyses are often performed in order to determine which road should be improved or whether a new road should be added, but they are rarely performed before the land use decisions are made that overburden existing transportation facilities.

The purpose of this paper is to demonstrate the application of transportation modeling to land use decision making with particular reference to master plans in communities of about 2,000 to 20,000 acres. Although other factors such as environment, soils, drainage, and public service are also an integral part of land use decision making, the current model focuses on the interrelationship between land use and transportation. An integrated model of transportation and land use is developed for the purpose of choosing among a series of land development and road network alternatives in a suburban community.

One of the major problems in transportation modeling is route assignment--the determination of which routes, among several alternatives, trip takers will choose to reach their destinations. Route assignment is particularly important in land use planning because it can be used to determine which transportation facilities will be burdened by a given land use change and when roads and other facilities will become congested.

Equilibrium route assignment as developed by

LeBlanc (1) provides an effective algorithm for route selection. The output includes traffic volumes and travel time delays on all road (or transit) links for a given transportation network. Because trip takers choose their destinations in part by their perception of how long it will take to get there (or how costly it will be), the output of the route-assignment function then becomes an input to the trip-distribution function. A general model equilibrium is reached in which trip distribution reflects the equilibrium travel times on alternative routes and route assignment reflects the equilibrium trip distribution.

The paper is divided into two parts. In the first section the general model and the related assumptions behind consumer surplus measures of transportation benefits are described. In the second section the application of the model to master plans for a 7,500-acre suburban community is described. The model proves to be an effective tool in planning land use and transportation--one that is cost-effective and easily carried out within the typical budget and data-collection constraints of submetropolitan communities.

THE MODEL

The model uses a traditional approach that has four main steps: trip generation, trip distribution, modal split, and route assignment. The general approach is described by Wilson (2) and is found in most transportation-planning models.

When transportation modeling is used to evaluate master-plan decisions, the central problem is one of evaluation of cost-effectiveness. Certain models such as Putman's (3) provide more detail than the model described here, but the very complexity limits their usefulness in evaluating a series of alternative master-plan decisions.

Cost-effective transportation and land use evaluation depends on obtaining sufficient information for the required decision and foregoing detail that either requires costly data collection or does not contribute significantly to the decision. The model described here takes all of its data from the master-plan proposals for a community. Although the application is to a new community of approximately 7,500 acres (3 by 4 miles), the model is just as easily applied to planning decisions at a larger subregional or regional scale. It also can be used for incremental planning decisions--road improvements and zoning changes.

Unlike transportation and land use models based on a Lowry approach (4), in which residential land and other land uses are allocated alternatively, this model takes land use, road, and transit network design information as given. The model then solves for the aggregate transportation cost of all users within the system. Alternative land use configurations or road networks or minor changes to the original plan are evaluated in the same way. The preferred design emerges as that plan or configuration that has the lowest aggregate cost.

In the case in which implementation, such as the development of a 7,500-acre community, will take place over a number of years, the evaluation is based on the present value of projected costs to all current transportation users for each year:

$$PV = \sum_{t=1}^{N} (1 + r)^{-t} [f(TDC_t)] \tag{1a}$$

where

$$TDC_t = \sum_i \sum_j \sum_m \sum_s T_{ijmst} C_{ijmst} \tag{1b}$$

and

TDC_t = total daily transportation cost in year$_t$,
T_{ijmst} = trips from origin zone i to destination zone j by mode m along route s in year t, and
C_{ijmst} = generalized cost of that trip.

Generalized cost is based on the mode of travel and includes all direct costs such as vehicle operating costs and fares plus all indirect costs such as travel time and waiting time. T_{ijmst} captures all trips taken along a particular route by a particular mode. The product of T_{ijmst} and C_{ijmst} represents the total travel cost for all trips along a particular route by a particular mode. Thus, by summing these products for all routes and modes between all destinations, one obtains an estimate of total transportation cost for the system.

The total present value (PV) of all costs represents the sum of costs for all trips taken within the community over the projected life (t = 1 to N). If alternative master plans are to be analyzed for the same development, as in the case illustration that follows, it is sufficient to measure TDC_t under the assumption that travel demand each year is the same for different plans. However, if different growth rates for the community are likely to result from different master plans, the extension of total daily costs (TDC_t) to annual costs and then to PV according to Equation 1 is necessary in order to select the best plan.

Considerable useful information is derived from the analysis of each alternative, including trip information for each route and for each mode at peak travel times and nonpeak travel times. Weak spots in the system design emerge from the loading on individual links in the road or transit system. Because the entire planning program is evaluated for any change in the transportation or land use plan, externalities and secondary effects such as destination and route changes in distant zones are included in the evaluation for even incremental changes in land use or transit system design. The general scheme for the model is shown in Figure 1. The four stages are outlined in the following.

Trip Generation

The first stage of the model is trip generation. Trips are generated as a function of the land use and density in a given zone. A single land use may generate several trips of different purposes. For example, a residence will generate home-to-work trips, home-to-shopping trips, home-to-school trips, and home-to-recreation trips.

Trip Distribution

The second stage of the model is trip distribution, which is calculated by using a singly constrained gravity model (2,5,6):

$$T_{ij} = a_i O_i D_j \exp(-\lambda C_{ij}) \tag{2}$$

subject to

$$\sum_j D_j = \sum_i O_i \tag{3}$$

where

T_{ij} = number of trips from origin zone i to destination zone j,
O_i = number of trips originating in zone i,

D_j = number of trips ending in zone j,
C_{ij} = generalized cost of such a trip,
$\exp(-\lambda C_{ij})$ = trip decay function, and

$$a_i = 1/\sum_j D_j \exp(-\lambda C_{ij}) \quad (4)$$

where a_i ensures that Equation 3 is satisfied.

The land use plan to be analyzed is subdivided into geographic zones for purposes of calculating trip movements. Trip generations O_i are a function of the residents and workers located in each zone as of year t. Origins and destinations are determined by trip purpose and time of day. They include home to work, home to school, home to recreation, home to shopping, work to shopping, and so forth, subdivided according to rush-hour and non-rush-hour trips. For simplification, trip takers are not differentiated by income, education, job status, and other characteristics found in the logit models of McFadden and others (7-9). Although assignment of the resident population to certain neighborhoods according to socioeconomic characteristics improves the accuracy of the trip-distribution calculations, the data requirements often go beyond the information that is available at the time that transportation and land use decisions are being made. This is particularly true when a new development is being planned.

Modal Split

Modal split is calculated for four modes: walking, car, bus, and taxi. Like trip distribution, modal split is a function of generalized cost, which includes operating costs, time en route, waiting time, parking, walking time to transit stops and from parking lots to buildings, modal comfort, and congestion:

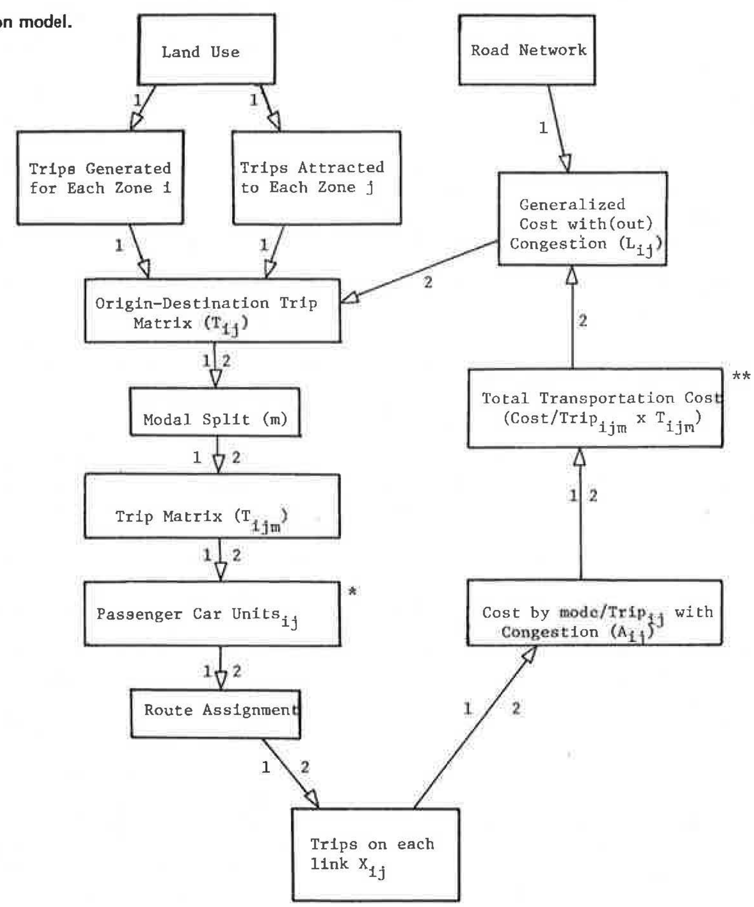
$$T_{ijm} = \exp[-\alpha f(C_{ijm})]/\sum_M \exp[-\alpha f(C_{ijm})] \quad (5)$$

where α is the sensitivity constant and $f(C_{ijm})$ represents the functional relationship between generalized cost and mode m for trips between zones i and j.

Route Assignment

Route assignment is performed by using an equilibrium route-assignment procedure developed by LeBlanc (1) and based on the Frank and Wolfe (10) algorithm for quadratic programming. The road network is catalogued as a series of road links (g,h) between each intersection with flows (x^j_{gh}), where gh represents the road links along a trial route connecting origin zone i to destination zone j. Given the road network, the trip table indicating the total number

Figure 1. Flow diagram of transportation model.



* Bus = 3 passenger car units

** Total Transportation Cost is used for comparing different plans

Numbers denote iteration
1 = First iteration
2 = Second and subsequent iterations

of vehicles per unit time from origin zone i to destination zone j (T_{ij}), and a congestion function [$A(X_{gh})$], the equilibrium traffic flows can be found by solving the following nonlinear programming problem:

Minimize

$$\sum_{\text{links gh}} \int_0^{X_{gh}} A(q)dq \qquad (6)$$

subject to

$$T_{ij} + \sum_g X^j_{gi} = \sum_h X^j_{ih} \qquad (7)$$

(Flow originating at i going to j plus all flows passing through i for j on links gi equals flows leaving i for j on links ih.)

$$X_{gh} = \sum_j X^j_{gh} \quad \text{(definitional)} \qquad (8)$$

$$X^j_{gh} \geq 0 \quad \text{(nonnegativity)} \qquad (9)$$

Equilibrium traffic flows among all available routes between any pair of origin (i) and destination (j) zones are calculated so that the generalized travel cost is the same for all the possible routes connecting the two zones. In equilibrium, no trip takers can save money by switching to an alternative route.

Trip distribution, modal choice, and route assignment are endogenous to the model because they are a function of generalized cost, which is of course a function of travel distance and travel time between zones according to mode and route. These are calculated through an iterative process shown in Figure 1 in which the first iteration assumes that everyone takes the shortest route and the lowest-cost mode. After the first iteration, generalized costs between each pair of zones are adjusted as a function of congestion and travel times calculated in the first iteration. Trip destinations may be altered when distant zones become less costly to reach than nearer zones because of congestion. After several iterations, the system converges to a stable equilibrium in which no trip taker can save money by switching destinations, modes, or routes.

One limitation of the current model is that only single trip purposes are allowed for each trip. Thus trip takers are not allowed to combine several destinations into a single trip. Another limitation is that although trip destinations are a function of the transportation network, trip generations are not. Trip generation is fixed as a function solely of land use and density in each zone. Although these limitations do not affect one's choice among several master-plan alternatives, they do affect the degree of preference. When transportation costs are weighed against other nontransportation factors, the degree of preference as measured by the difference in present value between plans can alter the ultimate planning decision. These limitations suggest future improvements to the model.

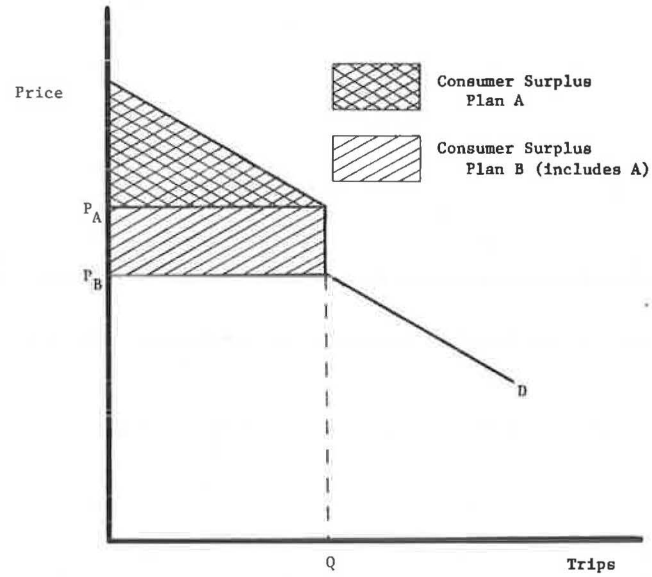
More detailed equations and parameters are described later in this paper.

ISSUES IN TRANSPORTATION MODELING

Economists tend to have trouble with the traditional cost-minimization rules for transportation decision making. In one sense, the model described here uses a cost-minimization rule for evaluating alternative planning programs. However, when alternatives are being compared to a base plan, the preferred decision rule is the maximization of net benefit.

Cost-benefit analysis in transportation planning

Figure 2. Consumer surplus for inelastic demand.



is well known (2,5,6,8,11-13). When changes are made in a transportation plan, benefits to users can be divided into three parts (6): (a) benefit (costs) to those who make the same trip as before, (b) benefit (costs) to those who have changed their destination or mode of travel, and (c) benefit to those induced to travel for the first time (i.e., newly generated trips).

When demand for transportation is assumed to be perfectly inelastic in the relevant region of the demand curve, one can choose between alternative plans strictly on the basis of which plan costs less. This is so because benefit to users remains constant according to a Marshallian concept of consumer surplus.

Figure 2 shows that for inelastic demand, the consumer surplus associated with alternative plans is the area between the demand curve (D) and the price. If the complexities of transit pricing can be ignored and it can be assumed that users correctly perceive and then base their transportation choices on generalized cost, trip price can be construed to be the same as generalized cost. Consider a case in which two transportation plans, A and B, are compared. The user population is the same for the two plans and determines the demand curve shown in Figure 2. Suppose that demand is perfectly inelastic in the region in question (Q). Under these circumstances, the plan conferring the greater benefit to its users will be the one having the larger consumer surplus, namely, the one that provides equal benefit (D) at lower cost (P_B). Thus, plan B is preferred to plan A.

Major difficulties arise when demand is elastic. First mere estimation of the demand elasticity itself can pose major difficulties (14). Second measurement of the consumer surplus or benefit requires that users be divided into two groups: those who would have taken trips at the original price level under plan A and those who are induced to travel by the lower prices under plan B. The benefits of lower cost to the first group of users can be measured by the approach shown in Figure 2 for inelastic demand. The problem is how to measure benefit for those induced to take new trips. If one looks only at cost, total transportation costs for all trips will likely be higher under the lower-cost plan B because of the added number of new trips.

However, although total costs may increase, total benefit should at least be equal to plan A or the new trips would not be taken. Presumably total benefit in plan B will in fact increase. The appropriate measure of net benefit to new trip takers is the added consumer surplus, approximated by triangle ABC in Figure 3. Various approximations have been developed for measuring net benefits from generated travel, such as the rule of half (15). The precise benefit is the integral under the demand curve (ABC). But unless one knows precisely what the shape of the demand curve is, an accurate measurement of this area is problematical. Some investigation into the functional form for elastic demand has been performed by Lerman and Louviere (16).

A related problem in evaluating alternative transportation networks and improvements arises from changes in land use density, which may cause a shift in total travel demand. Figure 4 shows the simplified case in which the original demand (based on the original trip takers) is inelastic in the relevant region, but a land use change (say from agricultural to residential) causes a shift in demand from D_1 to D_2. If the shift in demand does not cause any change in prices (prices remain at P_A), any increase in demand will confer a net increase in benefit on the community (area ACDG). However, if the shift in demand causes an increase in prices (prices increase to P_B), the net benefit due to the demand shift is represented by the difference between the added benefits to the new users and the added costs to the original users (area ABEG minus area P_ACBP_B). This measurement requires an explicit determination of benefit from knowledge about the actual demand curve, a problem that was avoided altogether in Figure 2 and for the most part in Figure 3.

Figure 3. Consumer surplus for elastic demand.

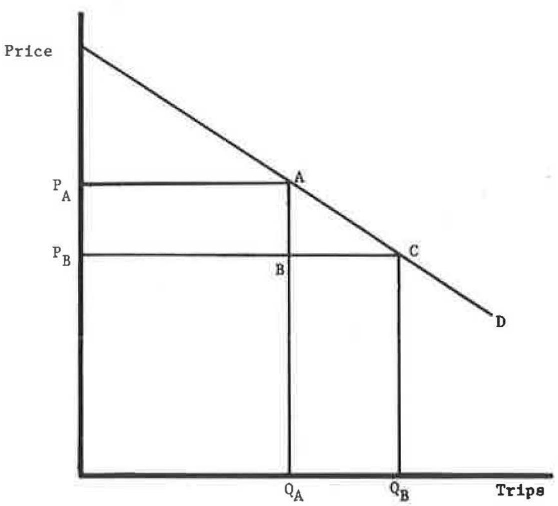
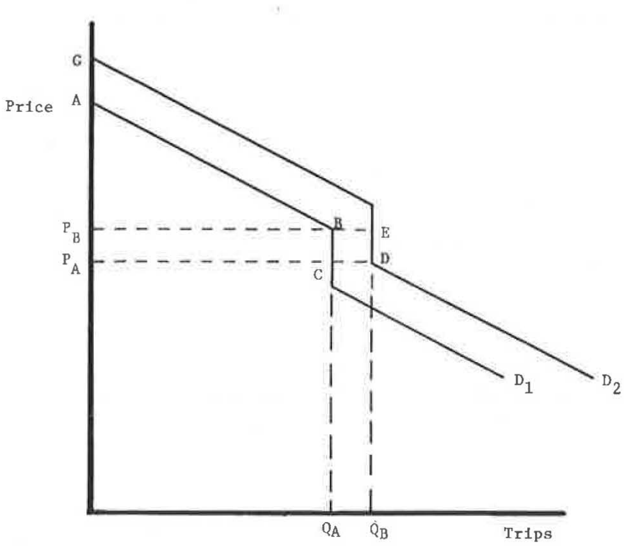


Figure 4. Consumer surplus for shift in demand.



In the model presented here, it is a simple matter to evaluate the increase in congestion costs and other costs for the original users (P_ACBP_B), who continue to make the same trips under the new demand schedule as under the old. However, measuring the added benefit to the new users requires some assumptions concerning the value to them of making the new trips. Presumably the value of the trip is at least equal to its cost or the trip would not be taken. The measurement of net benefit associated with the trip (value minus cost) assumes a knowledge of what the trip taker would be willing to pay to take the trip rather than just what it actually costs him. Such knowledge is beyond the scope of the current model.

Another problem in applying transportation models to planning decisions concerns the fact that most small urban communities are not self-contained (17). That is, in modeling transit trips for a subarea within a larger metropolitan area, numerous trips will either originate or terminate outside the boundaries of the subject area. Once outside the area, the trip taker's benefit is independent of any planning decisions associated with the subject area. In this paper, only that portion of each trip that takes place inside the subject area is considered. There may be externalities associated with trips once they are outside, but in such cases the costs or benefits must be included as a separate part of the evaluation.

CASE ILLUSTRATION

In this section a case study is presented of the application of the model to a new 7,500-acre community on the suburban fringe of Houston, Texas. At issue is the selection of the better master plan from two alternatives. The two master plans are shown in Figures 5 and 6. Plan A (Figure 5) is the final master plan that was adopted by the developer of the 7,500-acre project. Plan B (Figure 6) represents an alternative master plan showing how the community would likely have developed under typical Houston suburban sprawl (18). The road pattern in plan B tends to follow road easements in existence at the inception of development, whereas in plan A the road plan was a new design around the proposed development. In terms of land use, plan A follows a design approach similar to that of Columbia, Maryland, and other new towns; intensive land uses such as shopping and industry are located at interior sites, easily accessible to residents of the community. By contrast, in plan B intensive land uses are located along major access roads where they have greater visibility and are more easily reached from outside the community than under plan A. Although comparison of the two plans offers insight into the costs of urban sprawl, it is used here to illustrate the application of the transportation model and in particular the equilibrium route-assignment pattern of the model.

The two plans are designed to serve the same population and employment. Therefore, the land use budgets are the same; that is, the acreage alotted to each major land use is the same between the two

Figure 5. Plan A.

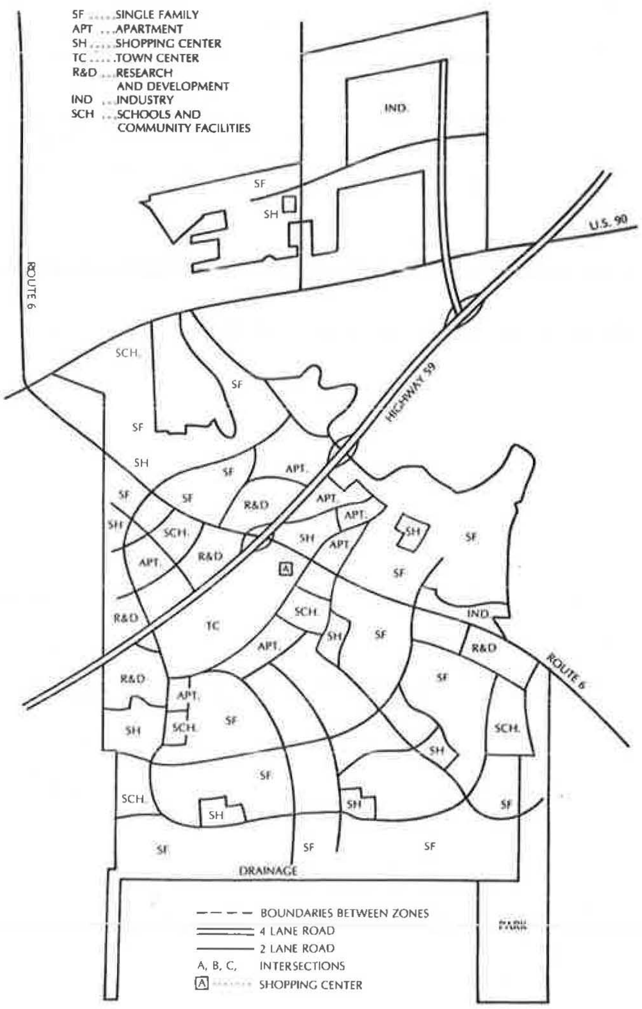
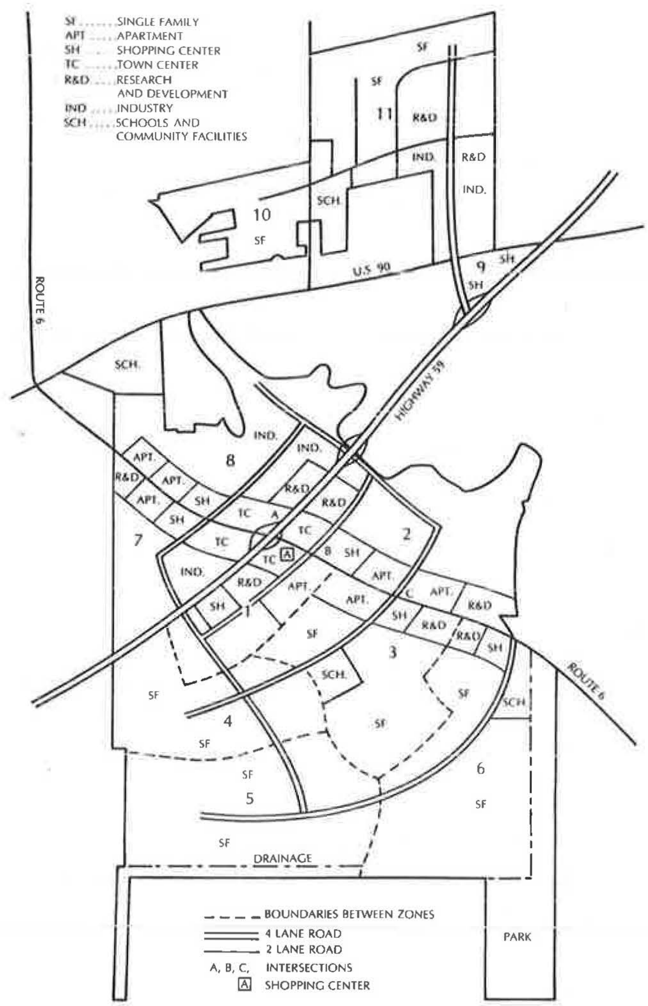


Figure 6. Plan B.



plans. However, the road networks are different and the locations of various land uses throughout the two plans are different.

Each plan is divided into 11 zones based on the location of highways, creeks, and other major geographical features. The zones range in size from 36 to 1,424 acres and may include only one land use or several different land uses in each zone.

The master plan catalogs nine different land uses, each associated with an average density of development. The densities shown are appropriate for development in Houston. These are given in Table 1.

The distribution of land uses in each zone for plan A is shown in Table 2. A similar matrix is determined for plan B based on the master plan. Greater precision can easily be obtained by dividing the subject area into more zones or more land uses. However, because the application here is to the problem of choosing between alternative master plans before any development has occurred, the choice of 9 land uses and 11 geographic zones provides sufficient detail.

Excluding open space, there are eight land uses, which are grouped into six characteristic populations based on the densities in Table 1 and the land use distribution in Table 2. Characteristic populations, which are described by such terms as number of dwelling units (DU) or square footage of industrial space, are used to determine trip generation and trip distribution. They are a function of acres (by zone and land use) and density:

$$C(i,lu) = ACRE(i,lu) \cdot DEN(lu) \tag{10a}$$

where C(i,lu) is the number of DU per acre or square footage of office or industrial space in zone i of land use (lu) (one zone may have several land uses) and DEN(lu) is the density of development (e.g., 6.5 DU/acre).

Categories of similar space such as residential units are aggregated to form six characteristic populations, shown in Table 3.

$$POP(i,z = j) = C(i,lu = j0) + \ldots + C(i,lu = j1) \tag{10b}$$

Table 1. Population and development density by land use.

Land Use	Density of Development
Low-density residential	6.5 DU/acre
High-density residential	29.5 DU/acre
Strip commercial	10,000 ft^2/acre
Town center and office	30,000 ft^2/acre
Research and development	15,000 ft^2/acre
Industrial	10,000 ft^2/acre
Community facilities (school)	Actual number of seats by zone
Neighborhood shopping	10,000 ft^2/acre
Open space	—

Note: DU = dwelling unit.

Table 2. Acreage distribution by land use and zone for plan A.

	Acreage by Zone									
Zone	1	2	3	4	5	6	7	8	9	Total
1	0	13	49	99	0	0	10	0	69	240
2	269	76	30	51	83	70	10	7	303	899
3	233	35	0	0	35	0	55	14	77	449
4	383	50	0	0	65	0	10	6	107	621
5	727	0	0	0	0	0	72	8	398	1,205
6	690	0	0	0	91	0	92	7	544	1,424
7	40	20	77	0	137	0	14	0	169	457
8	288	96	71	0	30	0	87	7	276	855
9	0	0	17	0	19	0	0	0	0	36
10	145	0	0	0	0	0	10	7	79	241
11	0	0	0	0	0	890	0	0	218	1,108
12	Outside subject area	–	–	–	–	–	–	–	–	–
Total	2,775	290	244	150	460	960	360	56	2,240	7,535

Note: Land use categories are as given in Table 1.

Table 3. Characteristic populations by zone for plan A.

	Population by Zone					
Zone	1 Office and Industry (ft^2 000s)	2 Shopping (ft^2 000s)	3 No. of Dwelling Units	4 Recreation (no. of people)	5 No. of School Seats	6 No. of Hotel Rooms
1	2,970.	490.	377.	8,000.	1,000.	1,000.
2	3,475.	370.	3,952.	4,000.	1,000.	0.
3	525.	140.	2,529.	3,000.	1,000.	0.
4	975.	60.	3,939.	4,000.	1,000.	0.
5	0.	80.	4,725.	4,000.	4,000.	0.
6	1,365.	70.	4,485.	1,000.	5,000.	0.
7	2,055.	770.	840.	2,000.	1,000.	0.
8	450.	780.	4,656.	1,000.	4,000.	0.
9	285.	170.	0.	0.	0.	400.
10	0.	70.	942.	1,000.	1,000.	0.
11	8,900.	0.	0.	0.	0.	0.
12-15 (outside subject area)	0.	0.	46,777.[a]	0.	0.	0.
Total	21,000.	3,000.	73,222.	28,000.	19,000.	1,400.

[a]46,777 DU are assumed to exist outside the community in order to supply the 56,000 jobs not filled internally (1.2 workers/DU).

where j0 and j1 denote land uses that are aggregated to form characteristic population j.

Trip generations are then calculated from Equation 11 according to nine trip purposes (k):

$$P(i,k) = POP(i,z) \cdot RP(k) \quad (11)$$

where

$P(i,k)$ = trips generated from zone i by trip purpose k,
$POP(i,z)$ = characteristic population z in zone i, and
$RP(k)$ = rate of trip production by trip purpose k.

There are nine trip purposes, each associated with a rate of trip production based on one of the characteristic populations. For example, a DU will generate three types of trips: home to work, home to recreation, and home to school. Trip production rates are shown in Table 4. Outside trip generations are actually assigned to four exterior zones (12, 13, 14, 15), one for each main access point to the community from each direction.

Finally, the origin-destination (O-D) trip matrix is derived from Equation 2:

$$T_{ijk} = A_{ik} O_{ik} D_{jk} \exp(-\lambda C_{ij}) \quad (12)$$

where

T_{ijk} = trips from zone i to zone j by trip purpose k,
O_{ik} = trips originating from zone i by trip purpose k,
D_{jk} = trips attracted to zone j by trip purpose k,

$$A_{ik} = 1/\sum_j D_{jk} \exp(-\lambda C_{ij}) \quad (13)$$

λ = parameter for decay rate of attraction between zones, and
C_{ij} = function of generalized travel cost between zones i and j.

Table 4. Parameters for trip production by characteristic population.

Trip Purpose		
From	To	Rate of Trip Production
Work	Work	0.25 trip/100 ft^2 of office and industrial space
Work	Shopping	0.4 trip/100 ft^2 of office and industrial space
Home	Work	1.2 trips/DU
Home	Shopping	1.0 trip/DU
Home	Recreation	1.0 trip/DU
Home	School	0.75 trip/DU
Hotel	Work	0.5 trip/hotel room
Hotel	Shopping	0.25 trip/hotel room
Hotel	Recreation	0.25 trip/hotel room

Traffic Flows

Trips by trip purpose are aggregated into three main traffic flows (Q) representing rush-hour travel, non-rush-hour travel, and recreation or non-work-hour travel.

$$Q(i,j,v) = \sum_k T_{ijk} \quad (14)$$

where k is trip purpose (see Table 4). For rush-hour travel (v = 1), k = 1,3,6,7; for shopping travel (v = 2), k = 2,4,8; and for recreation travel (v = 3), k = 5,9. For purposes of evaluating sytem capacity and congestion, rush-hour trips (v = 1) are of primary concern.

Modal Split

Modal split is determined from the trip matrix that results from Equation 14. Although the availability of particular modes may conceivably affect the trip distribution (for example, transit availability may contribute to destination choice), the current model is simplified in this regard. All modes are considered to be available for all trips. Clearly a route-specific public transit system would enhance this part of the model.

Modal split is determined by multiplying the trips from zone i to zone j by an admittance factor for mode m:

$$T(i,j,v,m) = Q(i,j,v) \cdot AF(m) \quad (15)$$

where T(i,j,v,m) is trips from zone i to zone j by traffic flow v and mode m and AF(m) is the admittance factor from mode m. The admittance factor is the ratio of the relative admittance factor for mode m to the sum of relative admittance factors for all modes:

$$AF(m) = RAF(i,j,m)/\sum_m RAF(i,j,m) \quad (16)$$

where RAF(i,j,m) is the relative admittance factor for mode m ($0 \leq RAF \leq 1$).

The relative admittance factor is in turn calculated from cost data for mode m and the distance from zone i to zone j:

$$RAF(i,j,m) = \exp(-ak_4) \quad (17)$$

where a is the sensitivity constant (0.003 assumed) and

$$k_4 = COST(i,j,m)/SAF(m) \quad (18)$$

$COST_m$ is defined for each mode as follows (parameter values are shown in Table 5):

Walking:

$$Cost(i,j,1) = TIMECOST \cdot CT(1) \cdot D(i,j)_s \quad (19)$$

Car:

$$COST(i,j,2) = PK + TIMECOST \cdot CT(1) \cdot WD(2) + D(i,j)_s\,[TIMECOST + OPCOST(m)]\,CT(2) \quad (20)$$

Bus:

$$COST(i,j,3) = F(3) + TIMECOST\,[WT(3) + CT(1) \cdot WD(3)] + D(i,j)_s\,[TIMECOST + OPCOST(m)]\,CT(3) \quad (21)$$

Taxi:

$$COST(i,j,4) = F(4) + TIMECOST \cdot WT(4) + D(i,j)_s\,[TIMECOST + OPCOST(m)]\,CT(4) \quad (22)$$

Table 5. Main parameters for modal-split equations.

Parameter	Mode: Walking	Car	Bus	Taxi
Average speed (miles/hr) [R(m)]	3	30	15	30
Fare ($) [F(m)]	-	-	0.25	0.80
Operating cost ($/mile) [OP(m)]	-	0.15	-	1.25
Parking cost (PK)	-	-	-	-
Average walking distance (ft) [WD(m)]	-	50	1,000	0
Average waiting time (min) [WT(m)]	-	-	10	15
Social acceptability factor [SAF(m)]	0.25	2.0	1.0	0.5

where

$D(i,j)_s$ = distance between zone i and zone j along route s measured in seconds at 30 mph,
TIMECOST = value of time in cents per second ($3.60/hr assumed),
OPCOST(m) = operating cost of mode m,
CT(m) = speed conversion factor for mode m relative to automobile,
F(m) = fare of mode m,
R(m) = speed of mode m (mph),
WD(m) = walking distance to mode m,
WT(m) = waiting time for mode m,
PK = parking cost,
OP(m) = operating cost or per-mile fare of mode m, and
SAF(m) = social acceptability factor for mode m (a measure of the relative convenience and availability of mode m).

Passenger-Car Units

For purposes of determining congestion on various road links, the trips by mode calculated in Equation 21 are translated into passenger-car units (PCUs) according to the following formula:

$$PCU(i,j,v) = \sum_m T(i,j,v,m)/LOAD(m) \quad (23)$$

where PCU(i,j,v) is PCUs from zone i to zone j during traffic flow v and LOAD(m) is the load factor for mode m in terms of trips taken. Load factors are as follows:

Walking: $LOAD(1) = 10^{10}$ (walking trips do not affect congestion),
Car: LOAD(2) = 1.5,
Bus: LOAD(3) = 3 car lengths/25 passengers = 0.12, and
Taxi: LOAD(4) = 1.

PCUs provide a method for translating passenger trips into vehicular units. For example, a bus uses the road space of three cars but has a load factor of 25 passengers. Thus, the road space per passenger is only 0.12 car length. The PCUs become inputs to the route-assignment procedure.

Route Assignment

Travel time [D(i,j)] between zones appears throughout the preceding equations. In the initial iteration, travel time is based on the mean free travel time between zones, assuming no congestion. Later iterations take into account congestion as a function of the PCU volume on each road link connecting each pair of zones.

Travel time per driver on each road link (gh) is a function of the mean free travel time plus congestion as shown in Figure 7:

$$W_{gh} = a_{gh} + b_{gh}(X_{gh})^4 \quad (24a)$$

where

W_{gh} = average travel time per vehicle on link gh where g is the originating node and h is the terminating node for each link in the network,
a_{gh} = mean free travel time between nodes g and h,
b_{gh} = congestion parameter (the parameter is a function of the road capacity), and
X_{gh} = traffic flow per unit time.

Travel time between zones is found by summing the travel times of each link along the shortest path connecting each pair of zones:

$$D(i,j)_s = \sum_{gh=1}^{t} W_{gh} \quad (24b)$$

where $D(i,j)_s$ is travel time between zones i and j along route s composed of links gh = 1 to t.

At each iteration of the route-assignment procedure, a new shortest path between zones i and j is determined based on the sum of travel times on individual road links connecting the two zones. The procedure converges to a stable equilibrium in which the shortest path between zones cannot be improved by switching routes. The route-assignment routines allocate trips to each link so as to minimize the sum of the areas under the volume delay function (W_{gh}). At its minimum value, the objective function (Equation 6) is the sum of the areas under the average travel time functions shown in Figure 7 (W_{gh}) up to the equilibrium flows x_{gh}. These areas have no (known) economic interpretation. Integrating Equation 24a results in the following:

$$F(x_{gh}) = \int_0^x (a_{gh} + b_{gh}X^4)dX = aX + (b/5)X^5 \Big|_0^x = ax + (b/5)x^5 \quad (25)$$

where $F(x_{gh})$ is the area under volume delay function W_{gh} at volume x_{gh} and x_{gh} is the number of trips on link gh.

The sum of these areas for all links is

$$F(X) = \sum_{gh=1}^{t} a_{gh}x_{gh} + (b/5)\, x_{gh}^5 \quad (26)$$

The LeBlanc route-assignment procedure determines F(X) for an initial trip allocation. The procedure is one of sequential solution of linearized approximations followed by a line search. This is accomplished by evaluating the gradient of F for the current set (K) of trips X^K where $X^K = (x_{11}, \ldots, x_{1n}, \ldots, x_{m1}, \ldots, x_{mn})$ for all links gh in order to obtain the optimal direction of change:

$$\nabla F(X_{gh}) = a_{gh} + bX_{gh}^4 \quad (27)$$

If Y^K represents the new set of values for X^K satisfying the optimal direction of change and conservation of flow constraints, a one-dimensional search is performed for α to minimize $G(\alpha)$:

$$\text{Min } G(\alpha) = \text{Min } F[\alpha Y^K + (1-\alpha)X^K] \text{ for } \alpha\epsilon(0,1) \quad (28)$$

Finally a new set of route-assignment values for the next iteration of X^K is found:

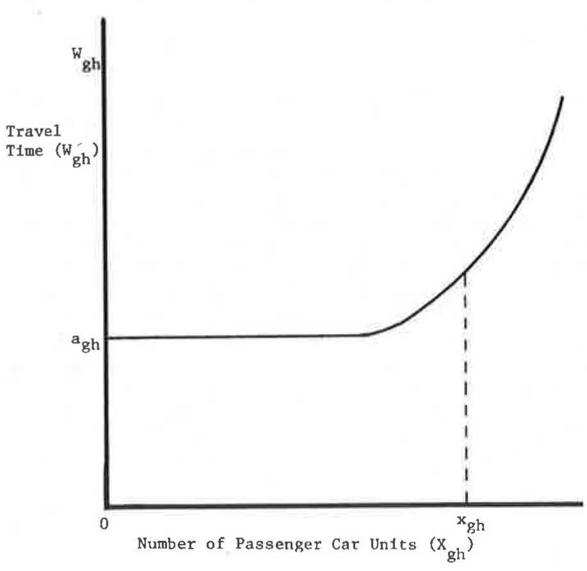
$$X^{K+1} = \alpha Y^K + (1-\alpha)X^K \quad (29)$$

The process is repeated beginning with Equation 27 until F(X) in Equation 26 is minimized within a stipulated margin of error.

Although primary output of the route-assignment routine is the number of trips (x_{gh}) on each link, the journey time between zones can easily be found from Equation 24b.

The travel times between zones are for a car traveling 30 mph. Cars, buses, and taxis are all assumed to be subject to the same congestion so that the travel time for other modes traveling at different speeds can be obtained through a simple transformation.

Figure 7. Average travel time per vehicle along link gh.



Travel Cost

At each iteration of the model, total daily transportation cost (TDC) is calculated from the trip matrix [T(i,j,v,m)] and cost per trip by mode [COST(i,j,m)]:

$$TDC = \sum_i \sum_j \sum_m \sum_v COST(i,j,m) \cdot T(i,j,v,m) \quad (30)$$

For simplification, trip cost is not differentiated between traffic flows (v). Travel times are based on congestion from peak-hour traffic and thus tend to bias total transportation costs toward the high side.

At successive iterations, new values for travel time D(i,j) are calculated from the route-assignment routines. These values become inputs for the next iteration of the main model beginning with Equation 12, as shown by the feedback loop in Figure 1.

RESULTS

The road networks for the two plans are shown in Figures 8 and 9. Plan A has 39 nodes with 104 links; each pair of nodes is connected by two links, one for each direction. Plan B has 41 nodes and 132 links.

Both plans are connected to the region outside the subject area by the two main highways that pass through the community and that are, of course, common to both plans--US-59 and TX-6. The point at which each highway enters the community is treated as a separate zone for purposes of allocating inward- and outward-bound external trips. Because the major point of entry to Houston is from the northeastern end of US-59, approximately 75 percent of the external trips pass through zone 12.

TDC in the two plans is shown as follows. After four iterations of the model, total costs converge toward a stable figure:

Iteration	Plan A ($)	Plan B ($)
1	497,200	498,600
2	609,400	692,100
3	608,734	630,080
4	608,750	630,126

It is immediately apparent from the preceding figures that plan A has lower transportation costs than plan B. Because the two plans serve identical user populations by assumption, they confer equivalent benefits to each user group. Therefore, plan A, which provides equal benefit at lower cost than plan B, is the preferred plan.

In the preceding case study, trip generation was assumed to be perfectly inelastic, that is, lower trip costs in plan A were not assumed to induce any additional travelers. However, following the argument presented earlier, the benefits of elastic demand would accrue more to plan A than to plan B because the lower trip costs in plan A would generate more new trips. Unless the added trips are so numerous that there is a major impact on congestion, the inclusion of elastic demand serves only to enhance the current preference for plan A.

Several useful observations can be made from the TDC values given previously. Because the first iteration of the model is based on travel time with zero congestion in which everyone takes the shortest path between origin and destination, iteration 1 indicates that TDC differs only marginally between the two plans. However, congestion cost can be determined from the TDC values by comparing the congestion-free cost of iteration 1 with that of iteration 4. It is apparent that congestion is worse in plan B, adding approximately 26.5 percent to TDC as compared with 22.4 percent in plan A.

At this point fine tuning the selected master plan can easily be done. Points of congestion are immediately apparent from a comparison of mean free travel time on each link with actual travel time. Land uses can be shifted, and roads can be added to the plan or widened at major bottlenecks. Table 6 shows a comparison of traffic values on three road links that are common to both plans. Because of the greater dispersal of land uses in plan B, traffic is more evenly apportioned over different roads. However, the absence of several connecting roads causes total transportation costs in plan B to be higher than those in plan A. If one could look at the OD trip matrix and the travel time on individual links, one could see how the location of land uses and the

Figure 8. Plan A road network.

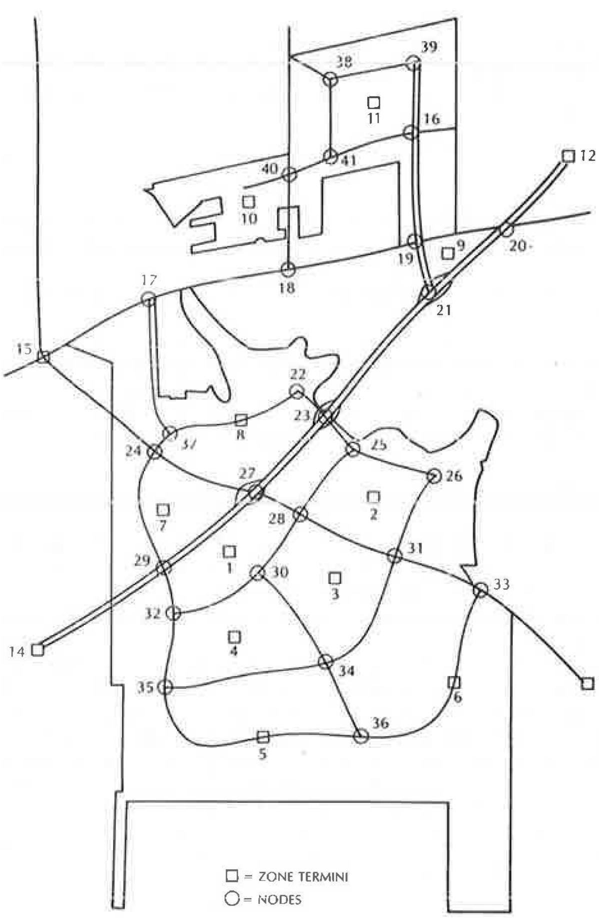


Figure 9. Plan B road network.

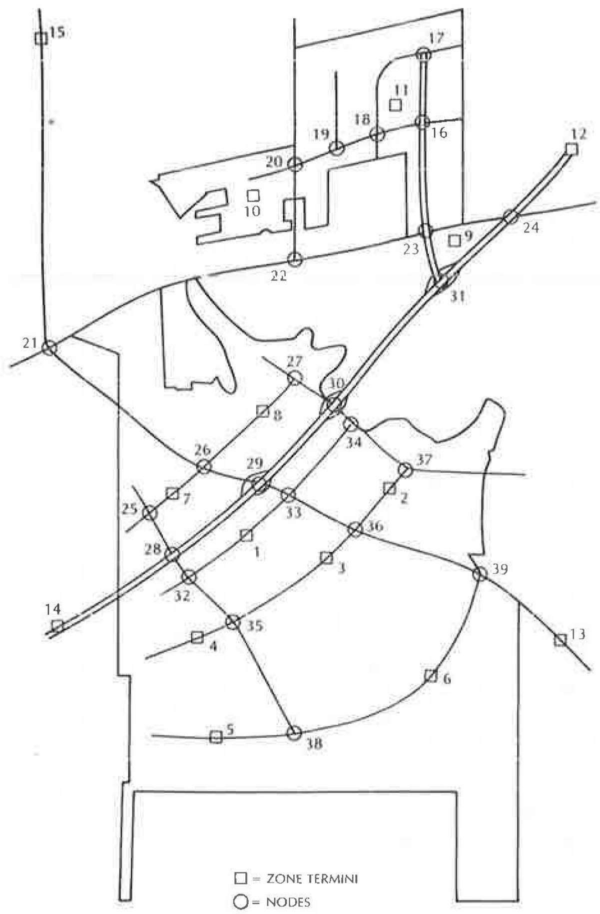


Table 6. Comparison of traffic volumes on individual road links.

Plan A		Plan B	
Link[a]	Volume[b]	Link	Volume
27-28	7,277	29-33	5,369
24-27	519	26-29	1,646
23-25	4,044	30-34	3,586

[a]Numbers refer to intersection nodes in Figures 8 and 9.
[b]PCUs per rush-hour period (3 hr in the morning and 3 hr in the afternoon).

road network each contributes to traffic flows and trip costs within the community.

CONCLUSIONS

Transportation and land use planning is replete with complicated computer models for evaluating trip movements. Typical models have two major shortcomings when applied to land use planning: They do not provide any single summary measure of total cost for use in selecting the best plan from several alternatives and it is expensive and time-consuming to run them.

The model presented here is especially well suited for planning at the community or suburban level within a larger metropolitan area. The impact of individual land use changes or real improvements on traffic flows and total transportation costs can be determined within a context of total information. In other words the effects on all trip movements within the system can be observed for even minor changes in the development plan or transportation network. Congestion points can be seen immediately and suggested changes in the master plan can be tested easily.

The model provides key information for making planning decisions in a cost-effective manner. Input data are assembled strictly from land use and transportation network information that can be taken directly from the master plan of a community. On a CDC 6600 computer, this model executes in less than 10 sec for a plan of 15 zones, 41 nodes, and 132 links. The equilibrium route-assignment routines converge to a stable equilibrium in seconds and provide useful information concerning traffic volumes and congestion on individual links.

A major problem in land use planning today is that despite the availability of sophisticated analytical tools, few planning departments take advantage of them to test the impact of various land use and transportation decisions. Although such tools are used more often for major capital investments such as mass transit systems, they are needed most for land use and transportation decisions that cities and counties make every day. The model presented here is intended to address that need by providing key measures of the economic impact of zoning, land use, road improvement, and transportation network decisions that determine community design.

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Parking-Requirement Reduction Process for Ridesharing: Current Practices, Evolving Issues, and Future Directions

STUART J. TENHOOR AND STEVEN A. SMITH

Current U.S. practices in instituting the process of reducing parking supply requirements when ridesharing at the development site reduces parking demand are reviewed. Key issues regarding developer support for such reductions, how programs are legally guaranteed and monitored, and who pays for such reductions are discussed. Finally recommendations on factors to consider when such a process is carried out are presented.

Because of rising land costs and local government's desire to reduce the economic, environmental, and energy problems associated with single-occupant vehicle commuting, both the public and the private sectors have sought methods of mitigating these problems. Concern about these high costs has resulted in the emergence of transportation system management (TSM) actions. TSM advocates short-term, low-capital-cost efforts to improve transportation system capacity. Parking management and ridesharing are two key, mutually complementary TSM techniques.

The control of parking supply is an important local tool for dealing with rising parking construction costs and congestion. The supply of parking in urban areas is controlled most frequently through off-street parking requirements for developments contained in the local zoning ordinance. In most jurisdictions a minimum number of parking spaces is required to be constructed in conjunction with a proposed development, although some cities are also imposing maximum limits on parking.

Parking requirements have been traditionally established to ensure that sufficient parking will be provided off public streets. Thus, the primary objectives were to enhance access, improve traffic circulation, and prevent neighborhood parking problems and other potential nuisances. It is now apparent that the parking code can also be effectively used as an instrument for managing traffic through provisions favoring ridesharing and public transit.

Ridesharing is the generic term used to describe a range of alternatives to single-occupant vehicle commuting, such as carpooling or vanpooling. Ridesharing not only helps to ease congestion problems but also decreases the number of parking spaces required at a building site through a reduction in the number of vehicles required to transport a given number of people. Ridesharing strategies have most often been focused on the work trip and thus primarily on office and industrial land uses.

One way to measure the effectiveness of a ridesharing program is to determine how it affects vehicle occupancy rates or the average number of persons per vehicle. Higher vehicle occupancy rates mean less parking demand at the employment site. To make vehicle occupancy figures meaningful, some background on national statistics is helpful.

The national work-trip automobile occupancy rate in 1977 was about 1.3. This is less than the 1.4 reported in 1969, probably reflecting continuing increases in automobile ownership. These figures provide a base from which to evaluate current parking demand figures at office or industrial land uses and then to evaluate anticipated parking demand reductions caused by ridesharing programs.

Assuming a typical vehicle occupancy rate for a major employer of 1.2 with a minimal ridesharing program, an increase to a vehicle occupancy rate of 1.6 would produce a 25 percent demand reduction. For example, subscription bus service was used by one major employer in this investigation, which reduced parking demand by more than 40 percent. Many other examples exist of employers with highly successful ridesharing programs.

The success of ridesharing is highly dependent on private-sector action. The off-street parking requirements afford a natural opportunity to encourage more private-sector participation in ridesharing to the mutual benefit of the public and private sectors. This opportunity exists in the offering of reductions in the minimum parking requirements for those developers or landowners who agree to institute certain ridesharing measures at the proposed site. These reductions can offer a significant economic benefit to developers and at the same time promote ridesharing, which increases the person capacity of the transportation system.

A list of some of the techniques that may be appropriate for inclusion in a parking-requirement reduction process is given in the following. The advances made in the use of these techniques by a number of jurisdictions are evaluated, some key issues in confronting this process are discussed, and some insight on future use of these techniques is provided.

1. Measures related to ridesharing
   a. Employee transportation coordinator,
   b. Locally sponsored ride-matching service,
   c. In-house rideshare matching,
   d. Preferential parking for high-occupancy vehicles (HOVs),
   e. Subsidized parking cost for HOVs,
   f. Flextime or other work-schedule program conducive to ridesharing,
   g. Vanpool or buspool service, and
   h. Monitored employee travel modes.
2. Measures related to public transit
   a. Employer-subsidized transit passes,
   b. Parking reductions based on proximity to transit,
   c. Elimination of parking cost subsidies,
   d. Daytime shuttle services, and
   e. Transit amenities.
3. Other parking management techniques
   a. Maximum parking requirements:
      A. Absolute maximum and
      B. Maximum with floor area ratio or financial penalties if exceeded;
   b. Fringe parking (allow a percentage of parking to be supplied at off-site location with transportation provided to the site); and
   c. Shared parking (share parking spaces with another use that has nonoverlapping peak parking demand).
4. Other TSM actions
   a. Pedestrian and bicycle facilities and
   b. Priority treatments through traffic operations.

CURRENT PRACTICES

In Figure 1 some of the developments to date are summarized in the creation of parking-requirement reduction processes for ridesharing in a number of jurisdictions across the country. Although it is not an all-inclusive list, for the most part it represents the state of the practice of these techniques. The experience of several of the jurisdictions is discussed below.

Because of the significant variation in local land use law and the methods of encouraging ridesharing, it is difficult to establish a consistent classification of local parking-requirement reduction processes for ridesharing. Generally, however, these approaches appear to fall into three general categories.

The first category is the ridesharing incentive option. This method requires the addition to a zoning ordinance of a provision by which an applicant may reduce the minimum parking requirement by a certain percentage (up to a maximum) proportionate to the strength of a ridesharing incentive program to be provided continuously for the life of the building. This method has been instituted in several jurisdictions such as Sacramento, California; Schaumburg, Illinois; and Bellevue, Washington.

The second technique establishes a performance standard in the zoning code for application generally or on a case-by-case basis. In this type a vehicle trip-generation standard that cannot be exceeded or an automobile occupancy standard that must be achieved is established for a given development. The standard can be calibrated according to geographic region and set low enough that an applicant has to rely on alternative modes of transportation to serve the building. Both Fairfax, Virginia, and Dallas, Texas, have experimented with this approach, granting approval to individual development sites contingent on their meeting maximum trip-generation or automobile occupancy criteria.

The final category is mitigating measures. This approach, used in high-growth regions, mandates actions that new developments must carry out to obtain development approval. Santa Cruz and Sunnyvale, California, and Seattle, Washington, have each used this approach. In-depth descriptions of how several local jurisdictions have undertaken their selected approaches are given in the following.

Bellevue, Washington

A suburb of Seattle, Bellevue has a rapidly expanding central business district (CBD). In February 1981 Bellevue enacted a comprehensive zoning amendment called Modification of Parking Space Requirements. That section empowers the planning director to grant adjustments to the minimum parking requirements in any CBD zone for landowner actions to encourage ridesharing provided any adverse impacts on adjacent property will be adequately mitigated. The director is also instructed to require such covenants or agreements as are needed to ensure compliance.

Eleven ridesharing techniques that constitute effective alternatives to automobile access are enumerated as illustrative of programs that landowners may institute to qualify for a maximum of 50 percent reduction in the requirements. Those techniques were listed previously in Figure 1.

Schaumburg, Illinois

Another developing suburban area similar to Bellevue recently instituted the ridesharing incentive option. Schaumburg sought to meet its goals of increasing work-trip vehicle occupancies approximately 10 percent by permitting a maximum 40 percent reduction from the 4.0 spaces per 1,000 ft^2 required for offices. The applicability of such provisions is limited to buildings having at least 50,000 ft^2 of floor space, and developers must submit evidence to the Zoning Board of Appeals of participation in an approved carpooling program, other activities like flextime or preferential parking to further encourage HOV use, or transit access within 0.5 mile of the site.

Sacramento, California

In July 1981 the city of Sacramento revised its parking requirements to institute both parking maximums and minimums for office uses in its downtown district and also created a code section labeled In-Lieu Vehicle Parking Substitution Measures sanctioning several ridesharing techniques. Under this change, three specific techniques and a fourth omnibus category, limited only by a developer's inventiveness and reasonableness, were created only for office uses in the C-3 zone of the CBD. Landowners under this section may receive a 60 percent reduction for new or expanded offices and a 100 percent reduction for office conversions provided a use permit is obtained.

Under the provisions of the first technique, each preferential carpool space so designated may be used to eliminate 2.5 unmarked parking spaces. Included within this technique is a requirement that the owner accept responsibility for enforcement and permit the state ridesharing office to circulate ridesharing information and user surveys. The maximum reduction attainable under this technique is 15 percent.

The second method permitted is landowner purchase of a year's worth of monthly transit passes at the current pass rate for each required space reduced for a 25-year term. This agreement is entered into at the time the building permit is approved for placement in a joint transit fund account for annual payment to the local transit agency. A third technique permits provision of additional bicycle parking facilities at a rate of one additional parking space for each required space omitted. A maximum reduction of 2 percent of the required parking spaces is permitted. A final catch-all measure permits a parking reduction for other measures that would adequately and effectively meet employee and patron transportation needs generated by the office building.

Sunnyvale, California

The city of Sunnyvale has established both minimum and maximum parking requirements for industrial uses only. Although it does not expressly permit reductions in parking space requirements, the city does require ridesharing-related traffic mitigation measures at the stage when the building permit or new use and occupancy permit is obtained when the planning board determines that the site requires it.

The city considered several transportation mitigation measures in the spring of 1980, selecting preferential carpool parking and bicycle parking as acceptable mandatory mitigation measures for imposition on landowners. Alternative work schedules, company-sponsored carpools and vanpools, or bus passes are encouraged as voluntary measures.

Like other jurisdictions, Sunnyvale's changes are quite recent, and thus there have been no measurable long-term effects. Planning staff there confirm, however, that at least three facilities have actu-

Figure 1. TSM actions contained in selected U.S. zoning ordinances.

Jurisdiction	Type of Area	ETC*	Participating in Ride Matching Service	Provision of HOV* Parking Spaces	Flex-Time Work Hours	Parking Charges	Provision of HOV's	Transit Passes HOV Cost Subsidy	Provision of Transit or RS Amenities	Contribution to Transportation/RS Fund	Company RS* Program	Other 4/	Implementation	Enforcement	Reductions Permitted	Comments
Bellevue, WA.	CBD (12,000) 1/	X	X	X	X	X	X	X	X	X			When landowner accepts reduction, takes responsibility	"Such covenants and guarantees as necessary."	Up to 50 percent	Very comprehensive ordinance.
Dallas, TX.	2 Large mixed-use developments; 1 CBD, 1 Suburban	O	O	O		O			O				Developer agreement to mitigate high trip generation rates	Approval conditioned upon self-enforcement and effective program.	None requested	This is a site specific reduction but principles are same.
Los Angeles, CA.	City of 3 Million	Potentially all: Landowner must submit plan											Landowner submits plan outlining TSM tactics	Covenant and/or contractual obligation to develop needed off-street parking	Staff sets based on site transportation study; maximum 40%	Ordinance passed March 1983
Montgomery Co., MD.	Several CBD's with low density, developing mix		O	O		O				O	O		Optional developer or county responsibility	Land or parking space set-aside; payment to RS fund; revoke permit	10 percent county program; 10 percent employer program; 20 percent maximum	Further review due before passage; long-term enforcement key issue.
Orlando, FLA.	City Population 132,000	Potentially all 5											Landowner pays trust fund cost per space reduced	Authority in planning and development dept.; control permit issuance	Maximum of 20 percent	Only TSM trust fund ordinance in U.S.
Placer Co., CA.	20 Miles N.E. of Sacramento; Rural but developing	X	X	X		X		X	X			X	Required of all new development with sufficient employment	• Civil penalties • Criminal: misdemeanor	No maximum; commensurate with trip generation reductions proven.	Community supports as necessary to control growth.
Sacramento, CA. (City and County)	CBD (C-3)	O		X 3	O	O	O	X	O			X O	When landowner accepts reduction, takes responsibility	Landowner self-enforcement	-60 percent new or expanded office -100 percent office conversions	Instituted both maximum and minimum in CBD, C-3 zone: changes under study
Schaumburg, IL.	Village 1 (30,000)	X	X	X	X	O	X	X	X	X	X	X	When landowner accepts reduction, takes responsibility	Landowner records a covenant which must be present in all leases. Land set aside required	Maximum to 40 percent for buildings over 50,000 sq. feet	Implemented summer 1982; very comprehensive in scope.
Seattle, WA	CBD	X	X	X			O	X 2		O			Requires landowner to implement through State environmental law	City agency funded by transportation fee.	Currently parking maximums, 1 per 1500 sq. feet.	Required of 14 developments through 1982. Primarily used for office or mixed use development.

1/ Total employment
2/ Development approval contingent upon provision of HOV parking spaces.
3/ 15 percent maximum reduction for this method.
4/ Other includes: bicycle lockers/showers (or) shuttle service or subscription bus
5/ TSM trust fund could be used to finance any technique listed above.

KEY:
X = Implemented
O = Proposed
RS = Ridesharing
ETC = Employee Transportation Coordinator
HOV = High Occupancy Vehicle (i.e., car/vanpool, bus, etc.)

ally been required to remove excess parking and have complied by either landscaping the spaces or providing recreational amenities.

Dallas, Texas

Although Dallas has no specific section within its zoning code that permits reductions in the amount of off-street parking required in exchange for ridesharing techniques, it has granted a significant parking reduction to a huge mixed-use facility in exchange for the developer's guarantee to provide vanpooling access to the site, which was calculated to reduce the total number of peak-hour vehicle trips by 20 percent.

The Dallas approach proposes a TSM strategy to attain a vehicle occupancy level of 1.4 for peak-hour work trips. This target is based on current levels of ridesharing in carpools, vanpools, and transit that have been attained elsewhere in the country or in the Dallas region coupled with guarantees of management strategies such as variable work hours. The combination of strategies here is designed to reduce evening peak-hour trips by 20 percent for the total development of 2 million ft^2 of office space and 1 million ft^2 of retail and hotel space. Retail use in the complex began in the fall of 1982; office and hotel space is still under construction.

Seattle, Washington

Although not as broad-based as the Bellevue plan, Seattle's efforts demonstrate its role as a ridesharing innovator. Seattle is one of several jurisdictions with maximum parking requirements for its downtown region made possible by excellent transit service and high densities in downtown land uses. Parking space demand in downtown Seattle, where most of the ridesharing promotion efforts have been targeted, is approximately 0.5 to 0.6 space per 1,000 ft^2 of office space. Outside the downtown region Seattle uses traditional minimum-parking requirements.

The process used in Seattle has been to condition the granting of building permits on developer agreements to set aside a significant number of dedicated carpool and vanpool spaces. At least six buildings under construction in 1982 or recently completed have received approval under this method.

Seattle has no zoning ordinance provision that permits landowners to institute ridesharing incentives in exchange for parking reductions. Through the state environmental authority, it deals with developers individually, letting them develop proposals to increase vehicle occupancy rates while seeking such actions as the institution of HOV parking spaces, which are relatively easily monitored and enforced.

EVOLVING ISSUES

Experience to date with a parking-requirement reduction process for ridesharing has demonstrated that many factors affect the success or failure of such provisions. Although there is still too little experience to say conclusively which combination of provisions will produce the most effective ridesharing incentives, we can say that the following criteria are necessary for a successful set of ridesharing provisions in a local zoning ordinance:

1. Validity: There must be a valid relationship between parking and the TSM measure (e.g., the number of parking spaces reduced for a landowner commitment to ridesharing must be related to the degree of increased ridesharing expected to result from the actions taken).
2. Attractiveness to the private sector: It should create the necessary financial or development incentives for the provisions to be used by the private sector.
3. Legality: It must be legal and enforceable.
4. Flexibility: The code must allow room for adjustments to a wide variety of circumstances.
5. Simplicity: The code must be easy to understand and administer.
6. Protection of public interest: It should protect the public interest by maintaining good planning practices (e.g., minimize residential parking problems).

Issues relating to the above criteria are discussed in the following sections.

Validity

A parking-requirement reduction process for ridesharing must have a sound technical relationship between parking demand and the ridesharing techniques employed. For example, one must have a reasonable estimate of the impact that TSM strategies such as preferential HOV spaces and flextime have on the number of parking spaces required.

From the public agency's perspective, the concern is that the ridesharing measures instituted produce a reduction in parking demand comparable to the reduction granted in the parking supply. Ideally both the public agency and the developer would like to know the percentage of reduction in parking that might be attributable to such measures. A number of ridesharing and TSM measures that have potential for inclusion in a parking-requirement reduction process have been listed.

Unfortunately the effectiveness of these strategies has not been adequately quantified, and although attempts to develop such relationships have been and are being made, it is unlikely that anything more than rule-of-thumb numbers will be available. An infinite variety of variables can govern measures such as a ridesharing coordinator (e.g., employer size, employer type, many employers versus a single employer), and the effect of such measures can vary widely in degree of emphasis (some employers will have more aggressive ridesharing coordinators than others).

The resolution to this dilemma will lie in developing adequate definitions and performance criteria for each ridesharing measure and assigning reasonable effectiveness estimates (e.g., automobile occupancy increases) to each. These definitions and performance criteria must be specific enough for the public agency to determine whether the intent of the incentives has been satisfied by the developer or landowner. The agency must not allow the actions promised by the developer to be so loosely defined that there is little hope of holding him to his commitment should he want to back out of his obligations for financial or other reasons. He may conform to the letter of his initial promise without complying with the intent.

One method of specifying parking reductions that can relieve public agencies from some of the pressure of developing accurate definitions is a performance-standard approach rather than a ridesharing-incentives-option approach, defined earlier in this paper. In the performance-standard approach, the developer commits himself to achieving a specified level of ridesharing, expressed in terms of number of carpoolers and vanpoolers, the level of average automobile occupancy to be achieved, a trip-generation rate reduction, or some other quantifiable measure of program effectiveness. As long as the chosen measure can be monitored, the burden of estimating the effectiveness of the various ridesharing measures remains with the developer or landowner, and there will be fewer chances of a confrontation over the interpretation of a definition. To assist the developer or landowner in making the assessments of potential effectiveness, however, transportation professionals should actively seek ways to improve their knowledge of the relationship between ridesharing and parking demand.

One attempt to quantify the relationship among parking demand, automobile occupancy, ridesharing incentives, and other factors was made in a study by JHK and Associates (1). With a data set of 42 office buildings, regression equations were developed correlating several dependent variables, including parking demand and automobile occupancy, with various characteristics of the building, parking arrangements (including parking supply and cost), and transportation service factors. An independent variable consisting of a composite ridesharing-incentive index was constructed to attempt to link the level of ridesharing support to changes in the dependent variables, particularly automobile occupancy. This index consisted of a scale between 0 and 10 derived by assigning a set number of points for each aspect of a ridesharing program in effect at a site (e.g., one point for the provision of preferential carpool spaces and two to four points for a vanpool program, depending on the level of commitment by the employer). The 42 sites included a wide range of building and employer sizes and were located in either suburban or outlying CBD settings.

The results indicated that the ridesharing index was able to explain more of the variation in automobile occupancy than any of the other nine dependent variables, with an R^2 of 0.57. The resulting regression equation was

Automobile occupancy = 1.14 + 0.065 (ridesharing index).

No attempt was made to correlate individual components of the ridesharing index (such as the existence of preferential HOV spaces) with automobile occupancy. Several of the sites had very high automobile occupancies (up to 2.37), which had a substantial impact on the coefficient of the ridesharing index.

The equation would suggest that, on the average, one could expect to achieve an automobile occupancy of approximately 1.8 for the most extensive investment in ridesharing in a suburban setting as long as certain other conditions were also satisfied (e.g., there is a sufficiently large employment base).

Although the regression equation proved reasonable, it is of limited practical value in establishing ridesharing commitments for zoning ordinances. The contribution of the multitude of individual ridesharing actions to increased automobile occupancy has not been isolated, and the degree to which given actions are performed varies widely among employers. Additional quantitative analyses are needed to improve our ability to make effectiveness estimates.

Attractiveness to the Private Sector

Although on the one hand parking reductions for ridesharing must not permit abuses nor endanger the well-being of communities and neighborhoods from a traffic standpoint, they must entice developers from a financial standpoint to assume the risks that may be necessary. Some jurisdictions require ridesharing actions as necessary mitigation measures, making them mandatory for all developers of employment-intensive uses. In this case the attractiveness of the ridesharing provisions is not as much of an issue as the overall attractiveness of development. Certain locations may be so inherently attractive to developers that mandatory ridesharing mitigation measures will not dampen developer enthusiasm for the site. On the other hand, this approach applied to less attractive developments may be the deciding factor in discouraging new development or redevelopment. The economic, land, use, and development objectives of a given jurisdiction will be the determining factor as to the applicability of an optional versus a mandatory ridesharing provision.

If the optional approach is selected, the provisions must be attractive enough (in terms of reduced parking construction costs and so on) for developers to want to take advantage of them. This will mean that the public agency must incur some risk but with the expectation that ultimately there will be more efficient use of land and transportation resources. The public agency must gauge the attractiveness of ridesharing provisions to developers by computing the potential economic benefits and costs to all parties from the process. To be reasonably attractive, there should be at least a 2:1 ratio of benefits to costs over the long term. Economic analyses have indicated that the benefits of the program to the employees may actually outweigh the savings to the developer, particularly when land costs are low and structured parking is not involved.

Legality

Enforcement uncertainty has emerged as a significant stumbling block to more widespread use of ridesharing provisions in local zoning ordinances. Political decision makers have wanted assurances that the developer making the agreement to institute certain ridesharing actions will in fact follow through. So far there have been several primary issues relating to enforcement. These include

1. The proper legal mechanism to use as the basis for enforcement,
2. The types of penalties or disincentives to employ, and
3. The transferability of the commitment to subsequent landowners.

Because of the great variety in local zoning practices, it is safe to say that a variety of enforcement techniques will be necessary. In the last section of this paper some of the most commonly used and most promising alternatives are outlined. Until more experience has been gained with ridesharing provisions and their ensuing enforcement problems, it will be difficult to determine the enforcement strategies that will be most effective. For instance, there apparently has been only one court challenge to a legal guarantee executed for a parking-requirement reduction process. The issue that is currently being litigated in San Francisco is the constitutional authority of a local jurisdiction to assess development mitigation fees.

Public agencies must not discourage developers interested in taking advantage of the provisions by setting unreasonable enforcement goals. Many developers and major employers are as yet unaware that there are economic and other benefits of ridesharing and that ridesharing programs can and do work. To overplay the potential for failure because of disregard of commitments will defeat one of the purposes of introducing ridesharing provisions, that is, to more widely expose ridesharing and its potential to the private sector. Certainly enforcement problems must be anticipated, but abuse has been minor to date.

Flexibility and Simplicity

In drafting a parking-requirement reduction process for ridesharing, flexibility and simplicity are key criteria by which to judge the final product. Simplicity, or making the provisions easy to understand, will increase the likelihood of their being used. Unduly complex provisions may create uncertainty and discourage developers from taking the time to carefully evaluate and consider the process. Lack of simplicity may also foster citizen distrust, causing the provisions to be perceived as a further complication of development-related transportation problems.

Likewise, there must be enough flexibility in the provisions to allow them to be tailored to a variety of circumstances. For example, certain employer types are more capable of instituting certain ridesharing provisions, and local land conditions or other factors may favor one approach over another. The provisions should not preclude the options that may be best suited to a given situation.

Protection of the Public Interest

Protection of the public interest is related to the enforcement issue but is somewhat broader. It reflects the need for balance in parking policy between the economic development interests and the protection of the street environment, particularly the residential street environment. Near residential areas one must be more cautious in the magnitude of parking reductions granted and should contemplate what can be done to relieve any adverse impacts if the developer does not achieve the reductions in parking demand expected. Residential parking permit programs can be instituted to relieve some of the impacts, but their existence is no excuse for poor planning practices.

Other Issues

There are several other issues that need examination but that do not fall neatly into any of the categories discussed previously. One such issue has to do with how the ridesharing provisions combine with the other provisions in the zoning ordinance. The ridesharing provisions have greatest potential when applied to office and industrial uses, because most successful ridesharing programs have been employer-sponsored and focused on the work trip. An important prerequisite to instituting a parking-requirement reduction process for ridesharing is to have an acceptable base from which to make those reductions. If the base office requirement, for example, is already low, there will be little incentive for further parking reductions. If the reductions are taken in this setting, an inadequate parking supply and the accompanying traffic and aesthetic problems will likely result. Reductions from an already low requirement are illogical. The best way to avoid these problems is to have a reasonable base from which to reduce requirements.

Also frequently mentioned is how those who finance developments resist having less parking, because in the development community, sufficient parking has always been a prerequisite for development success. Lenders are therefore an important group to educate in the potential benefits of ridesharing and associated parking reductions. This educational process will gain momentum as more localities introduce ridesharing provisions, but transportation professionals must be ready to demonstrate the benefits and likelihood of success of these projects.

Another issue with which many jurisdictions grapple is the degree to which zoning ordinance provisions should be negotiable on a case-by-case basis. Although a highly negotiable approach affords a high degree of flexibility, it places a substantial burden on both the public agency and the developer to prove their case and frequently results in an adversary relationship. It does little to foster mutual trust, may result in unnecessary delays or cancellations of projects, and consumes additional staff time in both private and public sector. In addition, the final resolution of negotiated parking reductions often must be based on the same data or same precedents each time. This argues for establishing a ridesharing provision that has more rigid guidelines based on the best available data with enough flexibility to enable a response to the more unusual circumstances. Localities may want to retain the right to negotiate on large developments but let the smaller routine developments be addressed directly by provisions in the ordinance.

FUTURE DIRECTIONS

Essential Ingredients of Ridesharing Provisions

Experience to date has indicated that there are certain components that must be present in a set of ridesharing provisions for it to satisfy the criteria discussed in the previous section. These are

1. Specification of the ridesharing options to be employed,
2. Method of negotiation or agreement,
3. Monitoring procedures, and
4. Enforcement techniques.

Specification of Ridesharing Options

Potential TSM options were listed previously. There must be a mechanism for relating these to the probable impact on parking demand, either identified explicitly in the ordinance itself or in some other document that can be used as the technical basis for the parking reductions granted. As experience with these techniques increases, it will be desirable to develop more rigid guidelines on the reductions allowed for given developer actions. Specific ridesharing reduction formulas, as crude as they may be and have been, will help streamline the process and eliminate some of the uncertainty that developers may otherwise feel when entering into a development proposal.

Method of Agreement

When a developer exercises the option (or is required) to institute ridesharing actions, there must be a legal, binding agreement stating the responsibilities of both the public agency and the developer or landowner. The agreement should set forth not only all the terms and conditions but also any penalties to be imposed in the event of noncompliance. Some of the possible approaches to this agreement are

1. Contract,
2. Land covenant,
3. Performance bond,
4. Building permit conditions,

5. State environmental enabling authority to control landowner actions that degrade the environment, and
6. TSM development fee or trust fund.

All of these have been instituted in some form or another, but space does not permit a description of each here. The applicability of each method will vary depending on each jurisdiction's governmental and legal structure. There is too little experience to demonstrate the superiority of any one of these techniques, and the workability of the techniques will often be determined by local laws and practices. Special mechanisms may exist in some local jurisdictions that offer a unique opportunity better suited to local development practices than one of those just listed.

Monitoring Procedures

The monitoring element of a parking-requirement reduction process comprises the means by which compliance or noncompliance is determined. If certain standards are to be met, it must be determined whether in fact the standard has been satisfied. Monitoring determines whether enforcement is necessary. Monitoring could range from a simple checking to see whether the landowner is generally following through on his commitments to ridesharing or other techniques to a more elaborate quantitative assessment through automobile occupancy surveys and other data analyses. This is certainly a procedure in which public agencies will be concerned with simplicity, because they generally cannot afford to spend a great deal of time and effort in most monitoring processes. In some cases fees could be assessed to developers who benefit from significant parking reductions to help offset the cost of program monitoring.

Enforcement

The enforcement procedure has been one of the most controversial parts of the parking-requirement reduction process for ridesharing to date. Although it is hoped that the need to exercise enforcement procedures would be rare, mechanisms must be available to protect the public interest when ridesharing actions are agreed on. It must be determined not only what enforcement stages will apply to the original landowner should his commitment fail, but also how enforcement procedures will be made applicable to subsequent owners of that property. Again several options are available as follows:

1. Land set aside or the addition of more structured parking,
2. Fines (this is a criminal action, not a civil action),
3. Forfeiture of performance bond,
4. Revocation of use and occupancy permit,
5. Development moratorium,
6. Contempt-of-court citations, and
7. Liquidated-damage contractual penalties.

Each jurisdiction may have different agencies that would enforce the options just listed. The prescribed enforcement measures should be specified in the agreement, but the timing and actual enforcement of a violation must be predetermined. As mentioned, the city of Seattle has been using environmental legislation as the basis for enforcement. Agencies should select those elements that are most compatible with the zoning approach or parking mitigation methods in their jurisdiction.

Research and Information Needs

A review of the experience to date and of the issues that have evolved indicates several important needs for the future development of ridesharing and TSM provisions for local zoning ordinances. Some of these needs are as follows:

1. Improved technical information on the relationship between ridesharing measures and parking demand (both developers and policy makers may continue to have reservations about moving forward with such provisions unless clear evidence is presented of the potential benefits and the likelihood of success of the program),
2. Better knowledge of how lenders perceive such provisions and creation of an educational process to familiarize key groups with the purpose and benefits of ridesharing provisions,
3. Better methods of providing assurances that commitments will be fulfilled without unduly discouraging developers from participating in the program of parking reductions in exchange for ridesharing commitments, and
4. Continual updating of parking-requirement reduction processes for ridesharing nationwide and dissemination of information on the subject as it becomes available.

In addition, several general rules are offered to guide the future development of ridesharing and TSM provisions. First, it is important to think comprehensively. There are many competing objectives that come into play in the development process. Certain transportation objectives (such as promoting more efficient modes of travel) cannot be isolated from others. The desires and impacts on the many groups with an interest in land development, parking, and transportation must be considered. Further, all such parties should be involved in the process to avoid creating provisions that are not used by private development. Participants should include developers, citizens, employers, attorneys, lenders, and public agency staff of various disciplines. There must particularly be a keen awareness of how the development community views such actions.

Second, the political process must be considered. The zoning ordinance is a legal tool controlled by politicians who must deal with many other issues besides transportation and are generally unfamiliar with what can be accomplished with ridesharing. The case must be presented concisely, clearly, and forcefully, indicating how these concepts will benefit the public at large. This educational process must reach developers, demonstrating how ridesharing actions can present substantial economic benefits that outweigh the risks perceived.

Finally, it is important to think in the long term; ridesharing acceptance will not occur overnight. Deliberate efforts will be necessary to bring about a change in attitudes about ridesharing and its role in local zoning controls. The inclusion of a parking-requirement reduction process for ridesharing affords an excellent catalyst for educating the private sector about ridesharing. It can now be viewed as a realistic and useful tool sanctioned by local legislation. Thus, in effect, this process institutionalizes a concept that may play a key role in America's transportation future.

ACKNOWLEDGMENT

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REFERENCE

1. Parking Policies Study for Montgomery County, Maryland. JHK and Associates, Alexandria, Va., 1982.

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Prediction of Land Use Traffic Impact

C.E. HALLAM AND G. PINDAR

The current procedures for prediction of the traffic impact of proposed land use developments and their parking requirements are based on historical and nonquantitative assessment procedures, which has in many cases led to the preparation by local governments of inappropriate parking codes. Research recently undertaken in New South Wales, Australia, aimed at provision of a more quantitative basis for impact prediction. Surveys were conducted at sites in each of the following land use categories: motels, service stations, car dealerships, dealers of car accessories and tires, hotels, road transport terminals, warehouses, recreation, fast food sites, factories, licensed clubs, office blocks, shopping centers, home units (apartments), homes for the aged (retirement villages), and restaurants. Survey results were analyzed by using linear regression techniques. Descriptive models, where able to be developed, are presented in the form of regression equations. Use of these models should take into consideration their accuracy and the range of independent variables for which they are applicable. In situations where it was not possible to develop models, proposed land use developments may be compared with developments surveyed in the study that possess similar characteristics, and a subjective assessment may be made. The use of the survey data as a standard data base should be of considerable value in maintaining a common standard of impact assessment. The models should improve the accuracy of impact prediction and assist in the development of more reliable parking codes and design guidelines. The degree of transferability of these results to countries other than Australia requires further research.

A major research project has recently been completed by the Traffic Authority of New South Wales, Australia, the aim of which was to develop reliable methods for predicting the impact of particular land uses on traffic conditions. To date, such predictions have been based primarily on subjective historical bases. This research has aimed at putting predictions and assessments on a more quantified basis. The resulting models should be used with caution, and due consideration should be taken for their stated accuracy and ranges of applicability. It was not possible to develop models for every aspect of land use studied. In these situations if a proposed development has similar characteristics to those of one of the survey sites, a direct comparison of the developments could give an indicative estimation of traffic impact.

Information was collected and analyzed on (a) person and vehicle flows generated by the development, the time at which such flows are at a peak, and person and vehicle flows generated during the on-street peak vehicle hour and (b) the parking provision necessary if the parking demand is to be met on site without constraint. The land uses studied in this research were motels, service stations, car dealerships, dealers of car accessories and tires, hotels, fast food sites, road transport terminals, warehouses, recreation, factories, licensed clubs, office blocks, shopping centers, restaurants, homes for the aged, and home units. These land uses, many of which occur in strip development, were selected because they occurred most frequently in development applications submitted for comment to the Traffic Authority. The results can also be used to develop more comprehensive strip development control policies. With changing emphasis from construction to transport system management techniques, the most effective use of the existing road system is becoming increasingly important. Thus planners should ensure that adequate protection is afforded to preserve the integrity of current and future arterial routes.

SURVEYS

For each land use, with the exception of shopping centers and home units, 10 examples were chosen for survey that exhibited a range of types and size of development. Further, the sites chosen were geographically diverse in order to reflect socioeconomic factors (particularly vehicle ownership) and public transport availability. Sites of fairly recent construction with on-site parking provision were preferred. For shopping centers, 33 sites were surveyed. For home units, surveys were conducted by means of postal questionnaire surveys. Of the 2,000 questionnaires distributed, 544 valid replies were received.

With the exception of home units, information was collected by conducting interviews with users and site management personnel together with measurements of person and vehicular flows and parking accumulation. Site and floor areas were measured on site.

Surveys of office blocks, factories, licensed clubs, and some shopping centers were conducted in 1978. The remaining surveys were conducted in 1979 with the exception of restaurants, home units, and homes for the aged, which were conducted in 1981. Surveys were conducted for a period of one day per site except for three of the shopping centers, at which 6-day counts were conducted. In the case of home units, information was requested for one specific day.

ANALYSIS

In consideration of the relatively small number of sample points, the use of complex statistical methods was not considered appropriate, particularly in view of the intended general use of the results. The emphasis was thus on simpler manipulations based on multiple linear regressions.

The resultant models should be used with due consideration for their accuracy. The accuracy is expressed in terms of the correlation coefficient (R^2).

Checks made in the analysis were that multicol-

Table 1. Regression equations for motels.

SPECIFIC IMPACT	INDEPENDENT VARIABLE USED FOR PREDICTION	EQUATION	FIT R^2	RANGE OF INDEPENDENT VARIABLE
Total Vehicle Trips, TVT (over 7 survey hours)	Floor area - building, A_B	$TVT=8+0.067A_B$	0.94	530 - 3,400
Peak Vehicle Trips, V	Floor area - building, A_B	$V = 1+0.015A_B$	0.92	530 - 3,400
Vehicle Trips - a.m. peak, V_A	Employees, E	$V_A=2+1.76E$	0.88	2-18
Vehicle Trips - a.m. peak, V_A	Floor area - building, A_B	$VA=0.009A_B$	0.80	550-3,400
Vehicle Trips - p.m. peak, V_p	Floor area - building, A_B	$V_p=1+0.008A_B$	0.90	"
Parking Supply Required, PS_R	Number of Units, N Employees, E	$PS_R=N+0.5E$	-	-

Table 2. Regression equations for service stations.

SPECIFIC IMPACT	INDEPENDENT VARIABLE USED FOR PREDICTION	EQUATION	R^2	RANGE OF INDEPENDENT VARIABLE
Peak Trips, Petrol - IN, PP	Area of Site, A_S	$PP = 0.015\ A_S$	.85	1,110 - 4,570
Peak Trips, Total - IN + OUT, PT	Area of Site, A_S	$PT = 32+0.030A_S$	.84	1,110 - 4,570

linearity of independent variables did not occur and that the coefficients of the independent variables were significantly different from zero. Aspects of the statistical analysis are discussed in more detail later.

Prediction of peak vehicle trips enables assessments to be made of the impact of the development on the surrounding road system and is usually indicative of the worst-case situation. Average vehicle trips is also a useful parameter in this regard, which gives a picture of the total vehicle trip generation over a long period of time. (In all cases, unless specified to the contrary, trips are two-way totals.) Prediction of peak parking accumulation allows a check to be made on the proposed on-site parking provision. As discussed later, the worst-case situation is based on the days surveyed rather than the highest or 10th-highest hour of the year.

DESCRIPTIVE MODELS

Motels

Data were collected at 10 sites. Surveys were conducted from 7:00 to 10:00 a.m. and 4:30 to 8:30 p.m.

The independent variables, as represented by area of site (A_S), area of building (A_B), number of units (N), accommodation capacity (AC), and employees (E), showed some multicollinearity; A_B, N, AC, and E had strong relationships. Although A_S could be combined with any of these variables, in no case did such a combination offer any increase in accuracy. In fact, A_S had a correlation coefficient of 0.00 for every dependent variable examined. The most important equations developed are given in Table 1.

Service Stations

Data were collected at 10 sites. Surveys were conducted from 7:00 to 10:00 a.m. and 3:30 to 6:30 p.m.

A_S correlates with road frontage length (F), number of pumps (P), and parking supply (PS). A_B is reasonably independent of the other independent variables. F correlates with P. The equations that were developed are given in Table 2.

Five of the service stations studied were self-service and five had attendants and higher generated trips. Nevertheless, the generation rates, expressed as peak trips and petrol per area of site, were not significantly different for the two categories.

A common situation in which knowledge of the traffic generation characteristics of service stations is necessary is that in which a developer wishes to convert a current service station, often uneconomical or disused, into a different land use. A disused service station has zero traffic generation. Such comparisons of alternative land uses should be based on normal generation rates. The argument that a proposed development has greater traffic impact than the current disused development and as such should not be approved is a little hard to sustain unless major traffic growth has occurred since the service station was first established. However, there still should be some leeway to improve on previous inappropriate planning.

Car Dealerships

Data were collected at 10 sites. Surveys were conducted generally in the period 1:30 to 5:30 p.m. (Fridays) but with some variation to represent peak hours at each site.

Correlations between independent variables were

Table 3. Regression equations for car dealerships.

SPECIFIC IMPACT	INDEPENDENT VARIABLE USED FOR PREDICTION	EQUATION	FIT R^2	RANGE OF INDEPENDENT VARIABLES
Peak Vehicle Trips, PVT	Employees, E	PVT=2+0.57E	.86	4-97
Peak Vehicle Trips, PVT	Area of Site, A_S	PVT=0.0051A_S	.81	1,800-11,370m²
Averate Vehicle Trips AVT	Employees, E Cars on Display, C	AVT=3+0.37E +0.052C	.92	E: 4-97 C: 21-260
Average Vehicle Trips AVT	Employees, E	AVT=0.42E	.86	4-97
Average Vehicle Trips, AVT	Area of Site, A_S	AVT=1=0.0038A_S	.81	1,800-11,370m²
Peak Parking Accumulation, PA	Employees, E Car Yard Proximity, Y	PA=0.69E+3.9Y	.93	E: 4-97 Y: 0-9
Peak Parking Accumulation, PA	Employees, E	PA=3+0.89E	.86	4-97

Table 4. Regression equations for car accessory and tire dealers.

SPECIFIC IMPACT	APPLICABILITY	INDEPENDENT VARIABLES USED FOR PREDICTION	EQUATION	R^2	RANGE OF INDEPENDENT VARIABLE
Average Vehicle trips, AVT	Tyre sites	Road frontage F	AVT = 3+.28F	.86	10 - 42
Average Vehicle trips, AVT	Tyre sites	Road frontage F (M) Employees E	AVT = 2+.23F +.43E	.98	F : 10 - 42 E : 4 - 13
Peak Parking accumulation, PA	All sites	Area of site, A_S (M²)	PPA = .007 A_S	.76	400 - 2,330
Peak Parking accumulation PA	Tyre sites	Area of site, A_S	PPA = 2+.006A_S	.89	750 - 2,330

generally as expected; A_S correlated well with F and E. However, A_S did not correlate with number of vehicles on display (C), which is a little surprising. The equations developed are given in Table 3.

Predictions should not be based on artificial values of E. As shown by the strong relationship between A_S and E, there is an optimum number of employees for a given site. This is evaluated over a period of time by the development's management. The 10 sites surveyed have no doubt achieved a certain equilibrium in this regard. For a new development, if there is uncertainty about the required number of employees, A_S would be a more appropriate descriptor.

Surveys were conducted on Saturdays as well as Fridays. Comparison of the peak and average vehicle trips and peak parking accumulation showed no significant difference between the two sets of data (two-tailed t-test = 5 percent). In terms of prediction model development, the Saturday data were more inconsistent than the Friday data.

The proximity of other dealerships (Y) generally only had a minor effect on trip generation. In the case of peak parking accumulation, correlation was sufficiently high for Y to be included in the equation. This was not the case for the peak and average vehicle trip equations.

Car Accessory and Tire Dealers

Data were collected at 10 sites. Surveys were conducted during the peak 6-hr period on weekdays. This period varied from site to site. Of the 10 sites, 5 were tire retailers and 5 were car accessory outlets.

Independent variables correlated were A_S with F and PS, A_B with E, and PS with F. The strong correlation between A_S and PS (R^2 = 0.94) shows the effects of council parking codes based on A_S.

Development of descriptive models proved difficult because of the variation in the nature of the developments. In some cases, the five tire sales sites provided models applicable to that type of development. The equations developed are given in Table 4. In analyzing proposed development of car accessory and tire retailers, because comprehensive models could not be developed, a comparison of the site characteristics of the proposed site with those surveyed is recommended.

Hotels

Data were collected at 10 sites. Surveys were conducted on Fridays from 3:30 to 10:30 p.m. or later, depending on exact closing hours. It should be noted that the sites surveyed were essentially suburban taverns in which the emphasis is on social drinking rather than accommodations. None of the sites surveyed were of international standards in city central business district (CBD) environments.

Accommodation capacity (AC) strongly relates to licensed area (A_L) and number of motel units or rooms (N); the latter relationship is to be expected. E relates to a varying degree to several of the variables; these are functional relationships.

It was not possible to develop descriptive relationships for peak and average vehicle trips (PVT, AVT). The highest correlation coefficients found were in the range $R^2 = 0.51$ to 0.53. These were for the independent variable E. Development of a descriptive relationship for peak parking accumulation (PPA) was no better.

The lack of relationships, particularly between the floor areas A_L, A_S, and A_B and peak parking accumulation, points to the problems of relation of parking codes to floor areas. This is further shown by the lack of a relationship between PA and PS.

PA, however, does relate to the dependent variables PVT and AVT. These equations are included here for reference:

$$PA = 10 + 0.613PVT \qquad R^2 = 0.95 \tag{1}$$

$$PA = 15 + 0.889AVT \qquad R^2 = 0.90 \tag{2}$$

It was not possible to develop relationships for the number and percentage of short-stay vehicles. These vehicles, with a length of stay of 0 to 10 min, were considered to be representative of the drive-in liquor store traffic.

It was thus not possible to develop equations to define the traffic operation of a hotel. The data can be used to look for similarities with proposed hotel developments and estimates of traffic impact can be made accordingly.

Warehouses

Data were collected at 10 sites. These sites represent a wide variation in type of warehouse activities. Surveys were conducted for a period of 6 hr. The individual periods were chosen to represent the busiest hours of operation.

A_S strongly relates to all the other independent variables [A_B, PS, E, vehicle fleet (F), and loading and unloading bays (L)]. Correlation between each of the other independent variables is also quite strong, with the exception of F with A_B and with L. Descriptive models with single independent variables were found to be no less accurate than those with several independent variables. The descriptive equations developed are given in Table 5.

Road Transport Terminals

Data were collected at 10 sites. Surveys were conducted for a period of 6 hr. The individual periods were chosen to represent the busiest hours of operation.

The only strong relationships between the independent variables [A_S, A_B, PS_C, PS_T, F, E, and truck fleet (F_{TR})] were between F_{TR} and F and E.

The predictive equations developed are given in Table 6.

Recreation

Data were collected at 10 sites. Surveys were generally conducted in the period 4:00 to 10:00 p.m., although with some variation at specific sites. There was a wide range in traffic pattern and type of recreational land use within the sample.

Analysis was attempted for groupings of all 10 sites and of the 5 squash sites. For the 10 sites, the only strong correlations between independent variables were between A_S and PS and pools (P).

Table 5. Regression equations for warehouses.

SPECIFIC IMPACT	INDEPENDENT VARIABLE USED FOR PREDICTION	EQUATION	FIT R^2	RANGE OF INDEPENDENT VARIABLES
Peak Truck Trips, PTT	Loading Bays, L	PTT=9+.69L	.84	0- 60
Peak Truck Trips, PTT	Area of Building, A_B	PTT=5+.0007A_B	.82	2,010- 63,700
Average Truck Trips, ATT	Area of Building A_B	ATT=1+.0006A_B	.85	2,010- 63,700
Average Truck Trips, ATT	Loading Bays, L	ATT=4+.56L	.84	0- 60
Peak Vehicle Trips, PVT	Employees, E	PVT=9+.304E	.88	9- 724
Peak Vehicle Trips, PVT	Area of Site, A_S	PVT=11+.0016A_S	.83	1,920-133,000
Average Vehicle Trips, AVT	Area of Site, A_S	AVT=7+.0010A_S	.86	1,920-133,000
Average Vehicle Trips, AVT	Employees, E	AVT=8+.175E	.84	9- 724
Total Peak Parking Accumulation	Area of Site, A_S	PPA=9+.0025A_S	.95	1,920-133,000
Total Peak Parking Accumulation	Employees, E	PPA=.474E	.96	9- 724

For the five squash sites, relationships were present between A_S and PS and E. PS and E were also related. The number of squash courts (S) had negative correlations with A_S, PS, and E.

It was only possible to develop models for average person trips (APT); vehicle trip generation and parking accumulation could not be modeled.

The average number of person trips (IN + OUT) per hour at the 10 sites can be modeled by using A_S as the independent variable:

$$\text{ALL SITES APT} = 35 + 0.0042A_S \quad R^2 = 0.78 \tag{3}$$

At the 5 squash sites, a similar model was developed. Taking into consideration the smaller sample size, it also is indicative only.

$$\text{5 SQUASH SITES APT} = 30 + 0.0046A_S \quad R^2 = 0.86 \tag{4}$$

Recreational land uses are thus difficult to model. Correlation between the number of squash and tennis courts and person trip generation and parking accumulation was particularly bad; in some cases, a negative relationship was found. It is suggested that impact prediction for proposed developments be based on comparison with a similar current development.

Fast Food Sites

Data were collected at 10 sites. Surveys were conducted in the period 4:00 to 10:00 p.m. on what the management considered to be the busiest day of the week.

With the exception of seating capacity (S), strong correlations were present between the other independent variables (A_S, A_B, E, and PS). E is thus the best descriptor of the traffic generation of fast food developments. A_S is certainly indicative. One explanation of this behavior is that the number of employees is tailored to suit the demand that develops. Thus this number might be different at the time the development was established from that applying several years later. The equations developed are given in Table 7.

Table 6. Regression equations for road transport terminals.

SPECIFIC IMPACT	INDEPENDENT VARIABLE USED FOR PREDICTION	EQUATION	FIT R^2	RANGE OF INDEPENDENT VARIABLES
Peak Truck Trips, PTT	Employees, E Area of Building,	$PTT=-15+0.39E$ $+0.0007A_B$	.94	$E: 44-228$ $A_B: 650-30{,}440$
Peak Truck Trips, PTT	Employees, E	$PTT=-11+0.40E$	.89	44-228
Average Truck Trips, ATT	Employees, E Area of Building, A_B	$ATT=-7+0.18E$ $+0.007A_B$	.92	$E: 44-228$ $A_B: 650-30{,}440$
Peak Vehicle Trips, PVT	Employees, E	$PVT=10+0.44E$	.79	44-228
Average Vehicle Trips, AVT	Employees, E Area of Building,	$AVT=5+0.21E$ $+0.0010A_B$	.82	$E: 44-228$ $A_B: 650-30{,}440$
Peak Parking Accumulation PA	Employees, E	$PA=16+0.47E$	.76	44-228

Table 7. Regression equations for fast food sites.

SPECIFIC IMPACT	INDEPENDENT VARIABLE USED FOR PREDICTION	EQUATION	R^2	RANGE OF INDEPENDENT VARIABLES
Peak Person Trips PPT	Employees, E	$PPT = -120 + 46.2 E$	0.92	4 - 20
Average Person Trips APT	Employees, E	$APT = -50 + 26.2 E$	0.91	4 - 20
Peak Vehicle Trips, PVT	Employees, E	$PVT = 8 + 15.1 E$	0.78	4 - 20
Peak Vehicle Trips, PVT	Area of Site, A_S (m^2)	$PVT = -56 + 0.128 A_S$	0.75	680 - 2800 m^2
Peak Parking Accumulation, PA	Employees, E	$PA = 1 + 2.9 E$	0.84	4 - 20
Peak Parking Accumulation, PA	Area of Site, A_S (m^2) Seating Capacity, S	$PA = -6 + 0.015 A_S + 0.18S$	0.83	A_S : 680 - 2800 m^2 S : 0 - 118

Office Blocks

Surveys were conducted generally between 7:00 a.m. and 6:30 p.m. at 10 sites.

The main independent variables, gross leased floor area (A) and E, are strongly related. This is particularly evident when the area per employee is tabulated.

The equations developed are given in the following discussion.

Peak Person Trips (PPT)

The peak number of person trips (IN + OUT) in any hour can be directly estimated from A (range, 935-14,800):

$$PPT = 64 + 0.037A \quad R^2 = 0.83 \qquad (5)$$

PVT

PVT (IN + OUT) in any hour cannot be directly described by any of the independent variables. This points to the important role that mode split plays in vehicle trip generation for office blocks. This is illustrated by the range in percentage of trips by car: 8 percent (CBD) to 85 percent (Pymble). PVT can be calculated from peak-vehicle-hour person trips (PVPT), if the mode split (MS) and car occupancy (OC) are known:

$$PVT = PVPT \times (MS/OC) \qquad (6)$$

The accuracy of this equation is as good as the accuracy of the variables PVPT, MS, and OC.

PPA

The peak number of vehicles parked on site or off site but associated with the site can be directly estimated from A (range, 935-14,800):

$$PPA = 28 + 0.025A \quad R^2 = 0.82 \qquad (7)$$

If MS and OC can be adequately estimated, PPA can be calculated more accurately. Factored PPA (FPPA) takes mode-split factors out of the direct equation. A is the independent variable used for prediction (range, 935-14,800):

$$FPPA = -49 + 0.076A \quad R^2 = 0.94 \qquad (8)$$

PPA can then be calculated as follows:

$$PPA = FPPA \times (MS/OC) \qquad (9)$$

The percentage of on-site parking ranges from 16 to 99 and the average is 40 percent. On average only a third of the parking is provided on site and thus is under current conditions and only one-third of the parking is controlled by the application of on-site parking standards.

The data on length of stay are also of interest; the percentage staying less than 1 hr ranges from 11 to 61 percent with an average of 38 percent. This indicates the need for available short-term spaces, possibly requiring a specific code provision for a number of on-site visitor or short-term spaces.

Licensed Clubs

Surveys were conducted in the period 4:00 p.m. to 1:00 a.m. at the 10 sites. There was a strong correlation between the variables E and members (M). There were no other correlations between the independent variables.

The analysis was not successful in providing accurate descriptive models. A was found to be a particularly bad descriptor of trip generation and parking accumulation. Even when it was broken down into bar area, lounge area, games area, and dining area, no descriptive relationships could be found. It thus should not be used as a basis for a parking code.

Auditorium seating (S) is of only marginal importance in the overall trip generation and did not emerge as a useful variable for prediction. Thus the physical characteristics of clubs were not sufficient for the prediction of traffic impact. The only suitable descriptors are those relating to the people using the clubs, E and M.

Indicative models were developed for PPT by using E and M (range of E, 37-257; range of M, 1,400-21,000):

$$PPT = 6 + 3.89E \quad R^2 = 0.75 \qquad (10)$$

$$PPT = 132 + 0.04M \quad R^2 = 0.76 \qquad (11)$$

The time period of peak person movement (peak vehicle movement was the same) varied from 4:00 to 5:00 p.m. to 8:00 to 9:00 p.m. However, a number of trends were evident. Smaller clubs tended to have peak periods in the late afternoon, evidence of a pattern of members calling in at the club on their way home from work. The larger clubs generally had peak periods from 7:00 to 8:00 p.m. (six sites). The period 6:00 to 9:00 p.m. covers the peak movements of 80 percent of the sites.

The car use range reveals that public transport plays little part in trips to clubs. The range is small, from 77 to 98 percent (total person trips); the average is 87 percent.

PVT can only be calculated from the general relationship PVT = PVPT x (MS/OC). PPA could not be related to any of the independent variables. It can be calculated from PVT if this is known (PVT, 89-701):

$$PPA = -10 + 1.46PVT \quad R^2 = 0.84 \qquad (12)$$

Its calculation from variables known at the time a development application is made is thus a tenuous procedure. The parking supply on site bears little relationship to PPA.

Estimation of the traffic impact of proposed clubs is thus difficult. The best method would probably be to compare the characteristics of the new club with those surveyed and make a subjective assessment based on the survey results of the most representive club.

Factories

Data were collected at 10 sites. These sites represent a wide variation in type of factory. Surveys were conducted from 6:30 a.m. to 6:00 p.m.

The relationship between A and E is sufficiently strong to prevent their combined use in an equation. The total number of employees was the best variable for prediction. Little improvement in accuracy is provided by the disaggregation of employees into administration and factory categories. Floor area, either total or disaggregated into specific uses, had a bad correlation with all dependent variables investigated. It cannot be used as a predictor. In Table 8 the equations developed are summarized.

Shopping Centers

Shopping centers are an important land use for which predictions of traffic impact are often required.

Table 8. Regression equations for factories.

SPECIFIC IMPACT	INDEPENDENT VARIABLE USED FOR PREDICTION	EQUATION	FIT R^2	RANGE OF INDEPENDENT VARIABLE
Daily Total Trips TT	Employees E	TT= 103 + 1.977E	0.96	12 - 970
Peak Person Trips (a.m.) PT(A)	Employees E	PT(A) = 11 + 0.463E	0.82	12 - 970
Peak Person Trips (p.m.) PT(P)	Employees E	PT(P) = 6 + 0.645E	0.96	12 - 970
Peak Vehicle Trips (a.m.) V(A)	Employees E	V(A) = 12 + 0.250E	0.80	12 - 970
Peak Vehicle Trips (p.m.) V(P)	Employees E	V(P) = 9 + 0.308E	0.90	12 - 970
Peak Parking Accumulation PA	Employees E	PA = 20 + 0.436E	0.95	12 - 970
Daily Total C.V. Trips TC	Employees E	TC = 36 + 0.155E	0.78	12 - 970
Peak C.V. Arrivals CA	Daily Total C.V. Trips TC	CA = 1 + 0.073TC	0.94	38 - 186
Peak C.V. Departures	Daily Total C.V. Trips tc	CD = 2 + 0.080TC	0.94	38 - 186

Because of their importance, the original data base of 10 sites was extended to a total of 33 sites, covering surveys on Thursdays, Fridays, and Saturdays. At three sites, 6-day surveys were completed. The sample also included five country sites. Only a summary of the analysis is possible in a paper of this length.

The analysis is presented for four groupings of data: Thursdays (sample size, 20), Fridays (sample size, 10), Saturdays (sample size, 10), and Thursdays and Fridays (sample size, 30). The survey periods were Thursdays, 4:00 to 9:00 p.m.; Fridays, 8:00 a.m. to 5:30 p.m.; Saturdays, 8:30 a.m. to 12:30 p.m.

The independent variables A and E are highly correlated. Disaggregating floor area into department stores, [A(D)], supermarkets [A(S)], small shops [A(M)], offices [A(O)], and bars or taverns [A(B)] generally provided no improvement in prediction accuracy. Equations describing behavior on Thursdays and Fridays were developed with A as the single independent variable. For the Saturday data it was found advantageous to use two floor-area variables, A(D) and supermarkets plus small shops [A(SM)]. [These two variables do not include office or bar floor area; note that A = A(D) + A(S) + A(M) + A(O) + A(B).] Floor area is expressed in square meters. The equations developed are given in Table 9.

As can be seen from the large constants in many of these equations, trip generation predictions for smaller shopping centers are not as accurate as those for larger centers. With reference to the Saturday models, use of those models involving disaggregated floor area has been found to give inappropriate answers for some combinations of floor area. Total floor area is generally the preferred variable.

Home Units

A total of 1,970 postal questionnaires were distributed to home-unit owners, from which 544 useful replies were received and subsequently analyzed. In addition, site inspections were undertaken at each block surveyed (107 in all) to ascertain the essential characteristics of each development, including both on-site and off-site parking availability and use.

The independent variables included in the analysis were the size of the unit (U_1, U_2, or U_3, i.e., one, two, or three bedrooms, respectively) and accessibility to public transport. No significant variation was found in any of the dependent variables analyzed as accessibility to either bus or rail increased. Further, it was not possible to develop acceptable regression equations by using the number of one-, two-, and three-bedroom units in each block. Although indicative models were developed, they were rejected because they did not conform with a priori reasoning regarding the magnitude of the estimated coefficients and regression constants. In particular, the magnitude of the regression coefficients deviated significantly from the average generation rates per unit and exhibited large negative constants.

In the absence of acceptable regression equations, generation models were based on the average generation rates per unit for the survey data. The main equations developed are given in the following.

Normal Resident Parking Demand (RPD)

Predictions of RPD (the number of resident vehicles normally parked overnight at or near the unit) were based on the number of one-, two-, and three-bedroom units in the block:

$$\text{RPD/block} = 0.83U_1 + 1.09U_2 + 1.34U_3 \quad (13)$$

Peak Visitor Parking Accumulation (PVP)

Prediction of PVP (the number of visiting vehicles parked at or near each unit during the peak hour) was based on the total number of units in the block

(U_T). This peak period was between 9:00 and 10:00 p.m. on Saturday evenings. As anticipated, no relationship was found between visitor parking demand per unit and the size of the unit.

$$PVP/block = 0.23U_T \quad (14)$$

PPT

Predictions of PPT (the number of two-way resident and visitor person trips generated by each unit during the evening on-street peak period (4:00 to 7:00 p.m.) was based upon the number of one-, two-, and three-bedroom units, respectively. Hourly estimates of trip generation can be made by applying the relevant hourly percentages, viz., 4:00 to 5:00 p.m., 28 percent; 5:00 to 6:00 p.m., 34 percent; 6:00 to 7:00 p.m., 38 percent.

$$PPT/block = 1.31U_1 + 1.76U_2 + 2.44U_3 \quad (15)$$

PVT

Prediction of PVT (the number of resident and visitor vehicle trips generated by each unit during the evening on-street peak period) was based on the number of one-, two-, and three-bedroom units, respectively. Again, hourly estimates of trip genera-

Table 9. Regression equations for shopping centers.

SPECIFIC IMPACT	INDEPENDENT VARIABLE USED FOR PREDICTION	EQUATION	FIT R^2	RANGE OF INDEPENDENT VARIABLES
THURSDAYS				
Average Person Trips, AT	Floor Area, A(m^2)	AT = 802 + 0.1243 A	0.82	2400 - 77,100 m^2
Peak Person Trips, PPT	" "	PPT = 1195 + 0.1516 A	0.77	" "
Person Trips, pm. Peak, PTV	" "	PTV = 992 + 0.1223 A	0.81	" "
Peak Parking Accumulation, PA	" "	PA = 115 + 0.0388 A	0.86	" "
FRIDAYS				
Average Person Trips, AT	Floor Area, A(m^2)	AT = 292 + 0.1095 A	0.96	1,774 - 41,700 m^2
Peak Person Trips, PPT	" "	PPT = 340 + 0.1519 A	0.94	" "
Person Trips, pm.Peak, PTV	" "	PTV = 517 + 0.0915 A	0.94	" "
Peak Vehicle Trips, PVT	" "	PVT = 184 + 0.0658 A	0.89	" "
Vehicle Trips, pm. Peak V(P)	" "	V(P) = 265 + 0.0427 A	0.92	" "
Peak Parking Accumulation, PA	" "	PA = 40 + 0.0365 A	0.96	" "
SATURDAYS				
Average Person Trips, AT	Floor Area, Dept. Store A(D)(m^2) Floor Area, Supermarket + small shops A(SM)(m^2)	AT= -345 + 0.1009 A(D) +0.4371 A(SM)	0.92	A(D) : 0 - 34,600 m^2 A(SM): 0 - 14,100 m^2
Peak Person Trips, PPT	"	PPT =-243 + 0.1341 A(D) + 0.5935 A(SM)	0.91	" "
Peak Vehicle Trips, PVT	"	PVT = -95 + 0.0503 A(D) + 0.2517 A(SM)	0.90	"
Peak Parking Accumulation, PA	"	PA = -91 + 0.0331 A(D) + 0.0838 A(SM)	0.92	"
Peak Parking Accumulation, PA	Floor Area, A	PA = 57 + 0.0386 A	0.82	4,150 - 41,700 m^2
ALL DAYS				
Average Person Trips, AT	Floor Area, A(m^2)	AT = 579 + 0.1276 A	0.80	1,774 - 77,100 m^2
Peak Person Trips, PPT	" "	PPT = 946 + 0.1597A	0.75	"
Person Trips, pm. Peak, PTV	" "	PTV = 685 + 0.1228 A	0.81	"
Peak Parking Accumulation, PA	" "	PA = 69 + 0.0390 A	0.87	"
Peak Vehicle Trips, PVT	Person trips, pm. Peak Mode Split MS Car Occupancy OC	PVT = PTV x MS/OC	-	-

tion can be made by applying the relevant hourly percentages, viz., 4:00 to 5:00 p.m., 30 percent; 5:00 to 6:00 p.m., 32 percent; 6:00 to 7:00 p.m., 38 percent.

$$PVT/block = 0.88U_1 + 1.09U_2 + 1.45U_3 \quad (16)$$

Restaurants

Surveys were conducted at 10 sites on either a Friday or a Saturday evening, generally in the periods 5:00 to 10:00 p.m. and 6:00 to 11:00 p.m.

All independent variables were highly correlated with each other. In particular, A was highly correlated with the eating area (A_E), the seating capacity (S), the number of tables (T), and E. As such, all descriptive models were based on single independent variables. The main equations developed are given in Table 10.

Homes for the Aged

Ten sites were surveyed, representing a range of sizes and geographical region; they were of fairly recent construction. Two surveys were conducted, the first between 3:00 and 6:00 p.m. on a weekday and the second between 2:00 and 6:00 p.m. on a Sunday.

Strong correlations were found between the accommodation capacity (AC) and E. Accessibility to public transport (PT) yielded weak negative correlations between both of the previous independent variables.

Although predictive equations were developed for both weekends and weekdays separately, for the most part the weekend generation rates were greater than those for the weekday. Therefore, only equations relating to weekend periods are presented together with those for the total (all-week) sample.

Note that all equations use AC as the independent variable, this being the most reliable estimator. Furthermore, AC is intrinsically a more desirable predictive variable. The introduction of PT into the equations containing AC offered no increase in the prediction accuracy (the coefficient for PT was not significantly different from zero).

The equations developed are given in Table 11.

USE OF RESULTS

It is considered that the models presented can be of practical use in predicting the traffic impact and parking requirements of proposed developments. The models are only valid for the range of independent variables used to derive them. They cannot be extrapolated with confidence. Attention should also be drawn to the correlation coefficient. Ideally the prediction interval should be calculated for a given case. The 90 percent prediction interval is suggested; that is, for a given independent variable, for example, building floor area, the prediction of the dependent variable, for example, peak

Table 10. Regression equations for restaurants.

SPECIFIC IMPACT	INDEPENDENT VARIABLE USED FOR PREDICTION	EQUATION	R^2	RANGE OF INDEPENDENT VARIABLE
Peak Person Trips PPT	Seating Capacity, S	PPT = 23 + 0.782 S	0.76	60 - 220
Peak Vehicle Trips, PVT	Gross Floor Area A	PVT = 18 + 0.098 A	0.77	50 - 655
	Seating Capacity, S	PVT = 3 + 0.356 S	0.76	60 - 220
Average Vehicle Trips, AVT	Gross Floor Area A	AVT = 7 + 0.065 A	0.81	50 - 655
Peak Parking Accumulation, PPA	Employees, E	PPA = 4 + 2.702 E	0.89	4 - 32
	Gross Floor Area A	PPA = 17 + 0.094 A	o.67	50 - 655

Table 11. Regression equations for homes for the aged.

SPECIFIC IMPACT	INDEPENDENT VARIABLE USED FOR PREDICTION	EQUATION	R^2	RANGE OF INDEPENDENT VARIABLE
Peak Weekend Person Trips, PWEP	Accom. Capacity, AC	PWEP = - 2 + 0.336 AC	0.96	29 - 379
Peak Person Trips - All Week, PPT	Accom. Capacity, AC	PPT = 0.330 AC	0.98	29 - 379
Peak Weekend Vehicle Trips, PWEV	Accom. Capacity, AC	PWEV = - 7 + 0.191 AC	0.96	29 - 379
Peak Vehicle Trips, PVT	Accom. Capacity, AC	PVT = -6 + 0.199 AC	0.96	29 - 379
Weekend Peak Parking Accumulation, WEPA	Accom. Capacity, AC	WEPA = - 5 +0.171 AC	0.93	29 - 379
Peak Parking Accumulation - All Week, PPA	Accom. Capacity, AC	PPA = - 5 + 0.195 AC	0.93	29 - 379

vehicle trips, will be inside the prediction interval limits in 90 percent of the cases. In the absence of any information indicating that a high or low estimate would be more appropriate, the value as calculated by the equation should be used.

DISCUSSION

It is not feasible, in a paper of this length, to discuss the study in any detail. Instead it is the intention here to highlight the nature of the study and to briefly present the findings. Nevertheless, there are a number of points that need to be made.

Statistical Analysis

A major problem in this research was the development of descriptive models that could be used by the average engineering and planning practitioner. This requirement suggested multiple linear regression techniques as being appropriate. Thus the research could be criticized because the relationships and models developed were functional rather than causal. This is not a problem in situations where the underlying causal variables move together with the functional variables. Problems could arise when data representative of one point in time are used to predict change, if the proposed development caused a change in the overall system itself. However, given the information known at the time that a development application is made, complex behavioral models cannot be readily applied.

There are more complex alternatives to linear regression for analysis of particular independent variables. As an example, for a particular data set, models of the following forms with the correlation coefficients (R^2) as given were examined:

Model Type	R^2
$Y = ax + b$	0.85
$Y = a + bx + cx^2$	0.87
$Y = a \exp(bx)$	0.89
$Y = ax^b$	0.91

In the search for the highest R^2, it could be concluded that a model of the form $Y = ax^b$ would be most appropriate. However, would it be most appropriate for every data set? Could the prediction of confidence intervals be just as easily calculated? Could the practitioner get an adequate feel for what the model was doing? It was concluded that linear regression models were the most appropriate for everyday practical application.

However, the possible pitfalls for the practitioner must still be recognized. The meaning of the R^2 must be understood. It is a useful measure of the relative accuracy of a model when models with the same dependent variables are compared. However, as an absolute indicator of how good a certain model is, it is not, on its own, as useful.

It is not appropriate to use R^2 to compare the goodness of fit of models with different dependent variables. It is not even strictly correct to compare models with the same dependent variable but with a different number of independent variables unless correction is made for the varying degrees of freedom.

There is no absolute value of R^2 above which a model can be considered acceptable or good. One extreme data point in an otherwise grouped distribution can substantially affect the R^2. Models based on small sample sizes are particularly prone to this effect. Variable definition and the level of aggregation of the data can also have an impact.

Design Hour

Resources were not available to investigate seasonal trends in generation. Thus the results cannot be directly factored to such parameters as the 10th highest hour. Nevertheless, the results give peak results for the seasonal time surveyed. Pilot surveys, usually based on interviews of management at the particular land use being surveyed, determined the peak day of the week and obtained general indications on the peak time of the day. Before resources are used in gathering seasonal figures, the anticipated prediction interval of the end result must be considered. Such factors as car occupancy and mode split can be difficult to predict accurately beforehand. Use of the results often makes quantum changes important. For example, is an additional lane necessary to service a development? It is not possible to construct 0.35 of a lane. This type of end use makes knowledge of seasonal variations interesting but not essential except in specific circumstances.

Generation Rates for Shopping Centers

It has often been suggested that vehicle trip generation rates at shopping centers decline as the gross leased area of the centers increases. The general effect of this was observed but was difficult to quantify. In selecting the sample for the shopping centers, care was taken to get a large variation in area. Analysis was attempted by using data in specific ranges of gross leasable floor area; 5 000 m^2 and 30 000 m^2 were the dividing points. The results were inconclusive, neither proving nor disproving the hypothesis. The analysis could have been more thorough if information on the length of stay in the parking lot had been available, because this would also appear to be relevant. However, it should be pointed out that the trip generation behavior observed at sites with floor areas less than 5 000 m^2 was fairly random.

In addition, because of the proportionally greater effect of the constants in the models at this lower floor area range, subjective and comparative assessments of specific centers might be more appropriate when such new centers are assessed.

Effect on the Adjacent Road Network

The effect that the particular development proposal has on the adjacent road network must be assessed in order to provide improved facilities where necessary to safely accommodate any additional traffic on the road system and maintain the efficiency of that system. Further, it is frequently necessary to seek contributions from developers to fund such facilities where these are necessary, and as such it is desirable that the specific impact created by a particular development be quantifiable.

In this regard it is instructive to use an example to highlight the issues involved; take the case of shopping centers. The usual method of defining the traffic impact of a shopping center is as follows:

1. Survey and evaluate the existing situation in the vicinity of the development during a chosen design period, often the afternoon peak hour;
2. Define the scale of the development, floor area, parking supply, shopping mix, and so on;
3. Estimate the vehicle generation of the center during the design period;
4. Assign those trips to the road network and add them to existing flows; and
5. Evaluate the ability of the network to handle the extra traffic.

The critical word in the above sequence of activities is "add." It has long been recognized that a shopping center does not rely wholly on newly generated trips but to some degree picks up trips that were already in progress or diverts them from a short distance away. Conventional wisdom suggests that newly generated trips form the bulk of traffic to a new shopping center and that ignoring the other trips is a sensibly conservative approach, akin to the engineer's factor of safety.

In a paper by Slade and Gorone (1), however, limited research at one center in Washington, D.C., showed that only 35 percent of trips were newly generated and that 65 percent were merely diversions of trips already on the road network. Further research is needed on this. It is interesting to note that as part of the Traffic Authority surveys of shopping centers, shoppers were questioned whether the particular center surveyed was the only place in which they intended to shop. On average about 50 percent of the shoppers indicated that they would be shopping elsewhere as part of their shopping trips, which suggests that current procedures for assessing the impact of these developments do indeed need reviewing.

CONCLUSIONS

The generation models presented in this paper are somewhat limited inasmuch as they offer a simplistic static solution to what is in reality a complex dynamic phenomenon. However, it is considered that they are an improvement to the status quo and will give more useful predictions than those based on more historical and subjective bases. Although the applicability of these results in countries other than Australia has not been investigated, it is hoped that the results nevertheless will be of some assistance in furthering general research on land use traffic generation. It is also hoped that the information presented will assist in the development of more realistic parking standards.

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Public Management in a Time of Declining Resources

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In Minnesota, as in many states, construction, maintenance, and operating costs are increasing while highway revenues from gasoline consumption are decreasing. The result is a severe budgetary crisis that requires retrenchment of the organization. The retrenchment process at Minnesota's Department of Transportation (Mn/DOT) involved several different approaches. Convincing the state's highway users and Mn/DOT's employees of the necessity for making large cutbacks was deemed essential, and numerous ways of accomplishing this were used. At the heart of retrenchment are decisions about who is to be laid off and what activities and projects are to be scaled down or terminated. The department used various methods to earmark such reductions. Finally, because pressure to meet established informational and decision-making needs heightens during retrenchment, developing and putting to use tools such as computer systems and packages becomes more important.

Transportation agencies today are faced with the problem of how to make the transition from growth to decline. It is an adjustment that will have to be made in virtually all of the public sector as programs are reduced. The age of rapid growth is giving way to the age of slowdown, as Kenneth Boulding has labeled it (1). The public sector, which has expanded enormously over the last four decades, can no longer presume increasing revenues and expenditures. However, almost all public management strategies are predicated on expansionist assumptions (2).

In transportation the peak of highway construction was in the 1950s, 1960s, and 1970s. The U.S. Interstate system was developed. The states built, expanded, realigned, and connected trunk highways and constructed bridges and bypasses. With this gigantic effort came an unparalleled expansion of the public work force.

Minnesota's construction peak came in 1967 to 1969. In 1973 the Arab oil embargo caused oil supplies to diminish and gasoline prices to rise throughout the rest of the decade. To economize, drivers bought small cars that got better gasoline mileage. The gasoline tax has been the principal source of Minnesota highway funds, but because the amount of revenue is a function of the amount of gasoline used, economizing has dealt a critical blow to the state's highway revenues.

Gasoline consumption in Minnesota is expected to decrease an average of 2.2 percent annually through the late 1980s. In the 6 years preceding the embargo, gasoline consumption in Minnesota increased an average of 5.8 percent annually. If that trend had continued, state gasoline revenues, including the three gasoline tax increases approved by the state legislature since 1972, would have totaled $2.68 billion between 1973 and 1982. Instead, gasoline revenues for the 10-year period totaled $2.04 billion. Economizing in Minnesota has resulted in $640 million less in highway revenue during the 10 years.

At the same time that gasoline consumption was dropping, construction, maintenance, and operating costs were increasing. Higher oil prices after the 1973 embargo meant rapidly rising building and maintenance costs because of the oil in materials such as asphalt and concrete and the fuel use of heavy equipment.

As a result Minnesota's highway construction cost index soared in the last decade and a half. From a base of 100 in 1967, it climbed to 292 in 1981. An additional index reflecting cost of maintenance and operations, based on a nationwide average, rose to 218 in 1978 from a base of 100 in 1967.

Inflated construction costs are reflected in the cost of completing the Interstate system. In Minnesota seven sections totaling 40 miles remain unfinished, and the cost is estimated to be $767 million. The cost of the 860 miles that have been built was $1.6 billion. In 1958 the estimate to complete the system statewide was $750 million.

The budgetary crisis in transportation is severe, and the situation will not improve in the near future. Efforts to significantly increase revenues have not been successful.

NEED FOR RETRENCHMENT

Initially measures such as a hiring freeze, deferred maintenance, and eliminating the so-called fat can be used to mitigate an imbalance of expenditures and revenues. If the imbalance is small or temporary, these measures might be effective enough to carry the organization over a rough period.

However, when the deficit is large and permanent, real retrenchment is necessary. This means that the organization must be turned into one that is smaller and consuming fewer resources while remaining functional and effective.

The decisions that must be made are extremely difficult. When should the move be made from interim solutions like a hiring freeze and deferring projects and maintenance to making cuts in staff and programs? Who will be laid off and when? What projects and programs will be scaled down or terminated?

As unpleasant as these questions are, avoiding them and relying on short-term expediencies can only exacerbate the problems of a large, permanent decline. Acknowledging the reality of the financial crisis and the necessity of making large reductions is a crucial stage in dealing with a deficit. To be sure, hurdling what Levine calls the Tooth Fairy Syndrome--the belief that the decline is temporary and the cuts will be restored soon by someone--is no small accomplishment (3).

MANAGING RETRENCHMENT AT MINNESOTA DEPARTMENT OF TRANSPORTATION

The change from an expanding to a contracting organization happened rapidly at the Minnesota Department of Transportation (Mn/DOT). In fall 1978 a comprehensive transportation plan was drafted based on historical funding and inflation trends. Six months later, because of a dramatic decrease in funding from declining gasoline consumption and an unexpectedly high inflation rate, 61 construction projects totaling $122 million had to be canceled. In May 1980 an additional 60 projects totaling $130 million were canceled. These events initiated the retrenchment process at Mn/DOT.

Managing a contracting organization is different from managing one that is growing. New kinds of decisions, choices, and strategies are necessary during retrenchment. At Mn/DOT managing retrenchment was separated into four stages: education, reduction of projects, reduction of number of employees, and improved decision making.

Each of these stages will be examined. Use of education to convince the public and the organization's employees and managers of the necessity for making large reductions will be described. The sections on reduction of projects and personnel explain how cutback decisions were made. Finally, for improved decision making some of the computer systems and packages that have been developed to aid decision making and meet informational needs are described.

EDUCATION

Education is aimed at three groups: the public, who are the users of the state's highway system; Mn/DOT employees; and Mn/DOT managers.

Educating the Public

Educating the public is an essential component of managing retrenchment. There are two major stages in this process. The first is for the manager to recognize the impending decline and the inevitability of large cutbacks. If he is unwilling or slow to do this and relies on short-term solutions such as deferring repairs or preventive maintenance, the organization's long-term physical plant and its workability may be endangered. It is in the manager's own interest, too, to begin the task of managing the decline, thereby establishing on his terms how the organizational contraction is to be directed. The effects of remaining in the short-term expediency phase can be disastrous (4).

In order to see that major cutbacks are needed, the public manager must understand the long-term trends and the sources of the organization's resources and analyze patterns and shifts that affect the funding. Preparing for the decline requires considerable data collection, analysis, and anticipation of legislative and congressional action and public desires.

Explaining to the public that major cuts are essential and that the slowdown is permanent is the second stage. This is a problem because the public believes that trimming inefficiencies and paring the work force are enough to meet the budgetary dilemma. The difficulty of the task is illustrated by the following observation (4, p. 12):

> In this political environment, it is in the interest of few leaders to accept the reality of retrenchment, let alone to state that reality publicly. The messenger who attempts to explain that a long-term decline is beginning may be first ridiculed and then shot. The elected leader who reports that resources will no longer continue to grow and that cutbacks must be made may be voted out of office. The appointed administrator who disrupts his agency with similar news may lose the support of his staff, his effectiveness as an organizational leader, the confidence of his superiors, and finally his position.

At least two obstacles impede convincing the public that a decline is long term. One obstacle is that generally the public is insulated from the legislative process. They do not understand the dynamics by which the transportation department obtains its revenues nor do they know how funding relates to programming. Retrenchment is an appropriate and necessary time to generate public awareness of the complexity of the processes and relationships.

Another obstacle is that the general public is often a special or even vested-interest group with a pet project. Consider that there are numerous groups that were at one time promised better roads, new bridges, or a bypass, only to see these projects canceled for two, three, or four construction seasons. It is important to realize that something is being taken away even though it was only a promise.

At Mn/DOT the course of action was to flood the public with the facts of retrenchment. Behn observes that this greatly improves the chances of successfully convincing the public (4, p. 16). Media exposure and public involvement were used to deliver messages about the cutback. Continuous, or at least frequent, media exposure is especially effective in the beginning stages of retrenchment. It can be accomplished through television spots, for example, within the nightly news programs, through radio, and especially through newspaper coverage. For example, the plight of the state's highways and the problems of financing repairs and new construction were examined in a six-part series in one of the major Twin Cities newspapers. Public involvement such as citizens' meetings and speeches to a variety of large and small groups offers direct and more personal opportunities to explain the state's financial straits and what is being done to meet the problems.

Convincing Employees

The public manager cannot lead his organization through a major retrenchment without the cooperation of at least some major components of the organization. That cooperation will not be gained until members of the organization are convinced that the decline is real and imminent. Hence an essential element of leadership at this time is convincing the members of the organization to accept the reality.

Public employees are no less ingrained with a growth ideology than the general public, and their acceptance of retrenchment likewise will be slow. In addition there are reasons why as employees they will tend to resist the changes that retrenchment will bring: a misunderstanding of the situation and its implications, a belief that the consequences will not be beneficial to employees, and a belief that the changes do not make sense for the organization (5,6).

One of the most common and effective ways to overcome resistance to change is to educate people about it beforehand. Early communication of the need for and the logic of cutbacks in the organization helps to prevent the suspicion, misunderstandings, and resentment that often result when information is held back.

The education process at Mn/DOT involved the use of in-house informational tools, group presentations or meetings, and audiovisual presentations. The Mn/DOT informational tools included the monthly departmental news-and-feature magazine, short and lengthy memos, and open letters to all employees. Presentations or meetings involved groups of all sizes; cutback meetings were held with assistant commissioners, office directors, and section managers, who in turn held informational sessions with their own, smaller units. Opportunities to speak before a large group are infrequent and perhaps not the ideal way to deliver a cutback message, but they were used when they did arise, as at the annual employees' meeting, which occurred early in the transition period. What proved effective was a half-hour audiovisual presentation that described historically how Mn/DOT found itself in a financial dilemma and where it was going from there. The presentation was seen by employees in small groups of 20 to 40.

Convincing employees is a matter of continually confronting them with the reality of retrenchment and the necessity of more modest expectations. Although there are many issues in the organization that are not of great interest to its members, this is not true of retrenchment because everyone is affected. Decisions are of immediate, personal interest to everyone. Employees will become involved more readily because of this interest.

Convincing Managers

The managers in an organization may be the most crucial element in accomplishing a smooth and efficient transition. This is because of their role in the planning process, in carrying out plans and policies, and in supervising and managing their own employees. They must be convinced early of the reality of retrenchment. However, among managers there is a hesitancy to slow down because of the need to provide lead time in planning activities and projects.

The most important aspect of convincing managers is lowering expectations. Development of highway projects has become an extremely lengthy process. Beginning preliminary design and engineering activities on a project implies a commitment of major state and federal resources for as long as 12 years. However, once the project has been started, money might be available for only a fraction of that time, if it is available at all. Unfortunately a number of highway projects one-fourth or one-half completed already exist. As a result, at the time that a project is being planned it is imperative to be confident that the funds needed to complete it will be available. It is a matter of realistic expectations and an awareness that planning too far in advance for something that may not be finished wastes public money.

Thus expectations must be lowered. Clearly plans for a project could no longer be drawn up today or next year under the assumption that funds for it would become available in 4 or 6 years. This illustrates the fundamental planning message that must be conveyed: be as certain as possible when planning a project that it will be possible to finish it. The alternative at the least is bad management. If this message is conveyed successfully, not only will staff plan intelligently because they understand and accept the need for cutbacks, but also there will be a core of leaders to help direct and manage the retrenchment.

EMPLOYEE REDUCTION

Allocating Cutbacks

In spite of attrition, hiring freezes, and elimination of vacant positions to achieve a reduction in force, Mn/DOT in the late 1970s was faced with effecting sizable employee layoffs. Decisions about who is to be laid off and what activities and projects are to be scaled down or terminated are at the heart of the retrenchment process. The answers to these questions will determine the new structure of the organization. It will be this structure and its workings that will reveal whether or not the retrenchment was successful. Is the organization doing things and doing them well despite being smaller and using fewer resources than before?

No packaged or standardized formula will determine what employees and services are more expendable than others. That answer as well as the decision-making process will differ in each organization. But the dilemma is the same: How can one cut services, decrease expenditures, and still maintain or even increase efficiency?

Across-the-board cuts are an appealing method of allocating reductions in an organization. Sharing the pain by distributing cuts in equal shares to all units has a superficial equity, and as a result it is popular among managers. It is readily justifiable, socially acceptable, and involves few decision-making costs. But it is in the final analysis a short-term strategy aimed at short-term economies. Its insensitivity to unit size, unit effectiveness, and the importance of each unit to the central mission of the organization is reason for not using it except in the early stages of retrenchment (although it is often suited to a minor or temporary decline).

It is tempting to rely on across-the-board cuts as a panacea. But they are likely to be an attempt to avoid targeting cuts and making hard choices. For this reason, they are seldom management's best response to financial pressures (7,3,4).

It has been said that targeting cuts is a difficult job that tends to be avoided by all but the most brave or foolhardy public officials (3, p. 182). Nevertheless, it is the only road to take in periods of major decline. The first order of business when the need to plan for retrenchment arrives is to review the organization's functions and objectives to determine whether they are still appropriate and whether new ones created by the new situation are also appropriate. It is also important to set priorities that will be used to target the cuts in the organization.

Activity Analysis

In one effort to allocate cutbacks, Mn/DOT in 1980 developed and carried out an activity self-analysis project that could be used specifically to earmark potential activity reduction that would achieve a like employee reduction. Envisioned as an in-house contingency plan, the project consisted of four study phases. Phase 1 involved project planning, orientation of peer facilitators, development of guidelines for activity definition, and orientation presentations. Phase 2 involved data collection by the facilitators of information from each office (in the central unit, called the central office) and district (transportation offices located throughout the state) on the activities performed, the outputs or products of each activity, the clientele, and the percentage of work done for other state agencies, counties, and municipalities. Especially important were questions about the source or reason for the activity (i.e., why do we do it?), the impact of stopping or greatly reducing the activity, and the personnel required to perform it (measured in full-time equivalents or person years).

Phase 3 provided the office directors and district engineers an opportunity to analyze the data collected on their own unit's activities to ensure that all major activities had been identified and that the data accurately reflected work accomplishments. Those activities from their unit that could, if future conditions warranted, be eliminated or scaled down were identified. In addition, they considered whether activities could be consolidated, whether some work should be shifted to other governmental units, whether any activities might be better or more logically performed by the private sector, and whether decentralized activities (those performed in the districts) should be centralized, or vice versa.

In phase 4, the assistant commissioners reviewed those activities ranked in the bottom 10 percent as prepared by their subordinate offices and districts. They then prepared their composite divisional recommendations for potential activity elimination and reduction, which were presented in separate meetings to the Deputy Commissioner for his final decisions.

The result was a set of recommendations for activity elimination and reduction for each Mn/DOT division. For each recommended activity reduction, a potential savings in employees was given.

Developing and carrying out the project was extremely time-consuming. Completion of phase 4 was roughly 9 months after the project began. For this reason, projects of this kind must be started long before the need to make large cutbacks occurs if the results are to be used effectively in the retrenchment process. Because of the unique project design, Mn/DOT has been able to use the results to allocate cuts to its units in order to achieve a reduction in the work force and to continue to carry out the important activities and functions of the units.

Consolidating Functions

In another effort to allocate cuts, Mn/DOT has been examining consolidation of functions where duplication and overlap exist. For example, the main function of the district offices has been highway and bridge construction, and each has a full complement of engineers, surveyors, and employees who specialize in design, rights-of-way, and contract administration. The reduction of construction projects has raised a number of questions. For example, is there a need for large right-of-way offices? Should all districts have full design capabilities? Should all districts have full engineering capabilities? Should some district functions be transferred to the central office? Preliminary conclusions indicate that the answer to the first three of these questions is no.

Mn/DOT's long-range plans are to consolidate divisions, offices, and other units wherever possible in order to reduce personnel at all levels and, secondarily, to produce a realistic organizational structure. In early 1982 the Planning and Public Transportation Divisions of Mn/DOT were consolidated, and additional divisional consolidations are being examined.

Employee Mobility

Retrenchment inevitably erodes morale. During a sharp decline, the employee questions the value of his contribution to the organization. He may also sense a loss of personal control over his future. Under these conditions it is difficult to counteract morale problems.

Attention to employee mobility is an effective way of helping to maintain interest. As vacancies occur in the organization, they may be filled through lateral transfers of employees from other divisions, offices, or units. At Mn/DOT the course of action was to make job postings conspicuous and to aggressively encourage employees to consider transfers. This course is beneficial to the organization and to the employees and still adheres to cutback guidelines (i.e., the hiring freeze).

PROJECT REDUCTION

Priority Ranking of Objectives

In the past the prime mission of the department was expanding the trunk highway system. Recent financing problems have forced the reshaping of this mission to that of protecting roads already built. In the main, Minnesota highways are not in good shape. Most were built to withstand up to 35 years of use, assuming that they received two resurfacings during that period. However, 20 percent of the trunk highways have had no major rehabilitation in 50 years, and 75 percent have had no major rehabilitation in 25 years. As a result, road repairs now have higher priority than new construction.

Preparing for retrenchment centers on the need to review objectives and set priorities. For example, with declining revenues should Mn/DOT's objectives include supporting information centers, rest areas, landscaping, noise walls, and long-range transportation planning? There need to be priorities between objectives. These are not linear priorities per se: First do A, then B, then C. Rather, one works on all of the adopted objectives, and when two objectives compete for the same resource, the objective with the higher priority comes first (work on all 50 projects in a program but when any two projects compete for the same funds, concentrate on maintenance projects first and allow system expansion projects to slip in the schedule). In other words, it means not putting all the resources on A until it is finished and then shifting the resources to B, and so on.

Funding Levels

In an example of ranking objectives by priority and emphasizing opportunity costs, Mn/DOT developed and presented to the 1981 state legislature four spending packages, or levels of work that could be accomplished with specified funding. Each option described what work the department could do and what it could not do given a certain amount of authorized spending. The levels represented priority-ranked objectives; for example, the objectives listed in level 1 (the bottom level of least spending) have higher priority than the objectives in the second, more expensive, level, and so on.

Briefly the four levels were as follows:

1. Deterioration: If the level of highway spending is not increased, Mn/DOT will have to reduce spending by $51 million by laying off employees and saving on material and will have to trim repair and maintenance efforts; some Interstate projects will not be funded, and no highway bypasses or four-lane trunk highways will be built.
2. Patch and repair: Given $223 million in new spending, Mn/DOT can continue its current maintenance effort, largely maintain the current level of resurfacing and reconditioning, greatly increase major rebuilding, and provide for repair and replacement of bridges; Interstate construction will receive much more money, but no new construction will be done on major trunk highways.
3. Preservation: If $327 million is authorized, more major roads will be rebuilt, 30 miles of new non-Interstate highways will be built each year, and Interstate construction will proceed rapidly; in addition, some of the $250 million worth of projects deferred in the last 2 years can be carried out.
4. Limited development: With $432 million Mn/DOT can accomplish many deferred projects, build more bypasses and 65 miles of new non-Interstate highways each year, and greatly increase major road repairing.

A distinct advantage of presenting a budget request as a set of alternatives is that it points out the opportunity costs of not authorizing a given amount of spending. For example, if the patch-and-repair option is not approved, the state's highways will not undergo adequate maintenance, resurfacing, and reconditioning; that is, the system will then decay even further. This will be the cost of not authorizing the required $223 million in new spending. At each level the costs are clearly stated in the spending options.

The legislature authorized $206 million in new highway spending, somewhat less than that for the patch-and-repair level.

IMPROVING DECISION MAKING

Although it is more difficult to develop and carry out improved analysis capabilities, control and information systems, and hardware and software systems during hard times, it is then that the need for them is also greatest. The loss of lead time, the inability to experiment, and most of all the need to minimize mistakes make efforts to aid decision making and to meet established information needs important. Toward these ends, Mn/DOT has made efforts in recent years to expand and accelerate the development and installation of new computer systems and packages. Primary among these are the transportation information system, FHWA's investment analysis packages, and the pavement management system.

Transportation Information System

The transportation information system (TIS) is a computer system that maintains, updates, retrieves, and reports a large number of transportation data items. Five subsystems of TIS are currently in operation: roadway, accident, traffic, bridge, and railroad. The data base is large, but access to the information is easy through dial-up terminals at off-site locations. A simple, user-oriented command language enables its use by nontechnical staff. Basic report formats allow numerous options.

At first TIS was used mainly by the traffic engineering unit and the districts for accident analysis. Currently the accident subsystem offers the most sophisticated analysis methods. TIS has been used increasingly for analysis not related to accidents. For example, it has been used heavily for analysis of federal-aid and functional-class mileage for route systems and geographic regions. In addition, TIS data are used to produce FHWA-required reports and special requested reports for various Mn/DOT units such as maintenance, government relations, and finance. Complex reports, which were once difficult or virtually impossible, are now frequently requested.

Investment Analysis

In order to develop budget requests and allocate available funds, the ability to assess and interpret large amounts of data relative to the physical condition and travel patterns of existing roads is crucial. A computer package was sought that would provide the ability to quickly and effectively assess the impact of various funding levels on the condition of the highway system; assess the funding levels required to attain or maintain a particular set of safety, condition, or performance standards; and summarize the results of these assessments with graphic displays.

The Performance Investment Analysis Process (PIAP) was acquired from FHWA for possible use at Mn/DOT. Testing revealed a number of problems with the package. Mn/DOT is currently working with FHWA to develop the Highway Performance Monitoring System (HPMS) investment package, which is similar to PIAP but incorporates improvements suggested by Mn/DOT. Mn/DOT is one of two states that will test the HPMS package in spring and summer 1982.

Pavement Management System

A pavement management system (PMS) is currently in the developmental stage at Mn/DOT. PMS, once implemented, will be a set of tools or methods that will assist in finding optimum strategies for providing and maintaining pavements in a serviceable condition over a given period of time. At the program level, PMS will provide information valuable in the development of a statewide program of maintenance or rehabilitation. It will be a tool to study making optimal use of available resources. By comparing the benefits and costs of several alternative programs, the program having the least total cost, or greatest benefit, can be identified. At the project level, alternative design, construction, maintenance, or rehabilitation activities for a particular section or project within the program are considered. When the benefits and costs of the alternative activities are compared, an optimum strategy providing the desired benefits or service levels at the least cost can be identified.

The need to institute a PMS is not as critical when an adequate budget for rehabilitation is available. Sections can be evaluated yearly and required rehabilitation can be scheduled whenever the need is observed. In retrenchment, however, proposed actions must be carefully evaluated with regard to current needs and costs and to the consequences of any action on future needs and costs.

CONCLUSION

Retrenchment means less of almost everything: less money, less construction, fewer services, fewer employees, fewer winners, fewer options, less time. It should therefore come as no surprise that retrenchment also brings less enjoyment of managing. It is difficult to tell people that there simply is no money to build them a safer road. It is difficult to tell 300 employees that they will be laid off.

The necessity of budgetary discipline and cutbacks is new to public organizations, but in the private sector retrenchment-type problems generally are commonplace. During hard times it is important to look at the tactics employed by others and to apply appropriate techniques and ideas. The skills required to manage a shrinking organization are not only different from but are likely greater than those required to manage growth (1). In the private sector some valuable lessons have been learned that can be applied in the public organization.

The foremost premise is to face up to the situation. Managers must put aside the idea that the era of fiscal constraints will go away and that if they hold out long enough, hard decisions will not be necessary. Decisive action should be taken as early as possible to minimize negative effects. Timing becomes critical during hard times; there is actually no time to lose.

Mistakes must be eliminated altogether. It is possible to be wrong once in a while when resources are plentiful, but it is not possible to make a mistake during austerity. This can be prevented by not committing too far ahead for something that may not get done but contingency plans should be ready if funds become available. Attention should be given to new techniques, tools, methods, and practices. The best answers to the decisions to cut back may be the result of using new analytical tools and computer software systems.

It is especially important to concentrate on

1. Convincing managers of the permanence of the decline and educating them about the hazards of mismanagement,
2. Convincing the public that cuts must be deep and widespread, and
3. Involving the organization's employees in the retrenchment process and preparing them for change.

The greatest, and most basic, need is to accept the challenge of managing decline. It is tougher than managing growth. The problems will not of themselves disappear. The era of growth and abundant resources is gone, but transportation is still as vital as ever. It must be managed regardless of the fiscal situation.

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Value Engineering in the Pennsylvania Department of Transportation

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The Pennsylvania Department of Transportation's value engineering (VE) program is presented. How the program started, how it is now administered, and the accomplishments are described. The program has achieved significant savings of more than $10 million per year. Recommendations are aimed at agencies beginning a VE program.

Although it is common knowledge, it bears repeating that transportation and highway agencies throughout the country are trapped between inflation and reduced revenues. Many avenues are being investigated to reduce costs. Many agencies are instituting cost-reduction programs. Some of these programs reduce standards, reduce the size of projects, or otherwise reduce the performance of highway and transportation projects. There is, however, another way to reduce costs, called value engineering (VE). For about 40 years, VE has been recognized as a way to reduce costs without reducing performance.

VE, value analysis (VA), and other similar terms describe (1, p. 9) "an organized action system, attuned to one specific need: accomplishing the function that the customer needs and wants." VE improves quality, but it is more than a quality control system. VE is, at its most basic level, an organized process that ensures that a product meets its necessary function without waste and without extras.

VE is defined by the Society of American Value Engineering as the systematic application of recognized techniques that identify the function of a product or service, establish a value for that function, and provide the necessary function reliably at lowest overall cost. VE is, above all else, systematic. By using a set, well-developed procedure, the VE practitioner can analyze the function of an activity or project and reduce the cost, improve the quality, or both.

HISTORY

VA was developed as a specific procedure after World War II. During the war, the General Electric Corporation discovered that wartime shortages required substitute designs and materials that often resulted in improved performance at a lower cost. In 1947 Lawrence Miles, a staff engineer with General Electric, was assigned to develop this observed phenomenon into an organized activity that could be applied throughout the company. The process became known as value analysis and was slowly accepted as a valuable tool.

VA was applied to many manufacturing activities and later to construction projects. The U.S. Department of Defense (DoD) was one of the first government agencies to apply VA to major construction projects; VA was applied to shipbuilding and renamed VE. VE has since been applied to many DoD activities.

FHWA has promoted VE for more than 5 years, in which time FHWA, through the National Highway Institute, has sponsored more than 70 VE workshops in some 40 states. Under the program the agency has trained more than 1,500 highway professionals and technicians in the discipline and techniques of VE. An indication of the support for and the worth of VE was evident in the Federal Highway Act of 1982, which requires VE on all projects with a construction cost of more than $2 million.

The Pennsylvania Department of Transportation (PennDOT) has been using VE since early 1979. At that time a single project, the relocation of US-30 near Everett, Pennsylvania, was chosen for a VE study.

This project was a 100 percent federally funded demonstration to show how fast a project could move from concept to completion. It was selected for the demonstration because of the adverse effects of another federal project (the Raystown Dam) on the local highway system.

At the time the estimated cost for the project was fast approaching a $25 million ceiling imposed by Congress. Almost in desperation, FHWA selected VE as the method of reducing the cost of the project. Although it was a back-door approach, this project made many realize that VE could save money without loss of performance.

A VE team was assembled made up of representatives of FHWA, the design consultant, and PennDOT. The team identified about $750,000 in savings. Although not all of the recommended changes were carried out, the results of that pilot study were favorable and a VE program was born.

Soon after the VE effort on the Everett Bypass, FHWA sponsored the first VE conference for state highway officials. The conference, held in New Orleans in 1980, was to begin the federal emphasis of VE in highway design and construction and launched many state efforts into VE. There are now at least eight states that have active VE highway programs; Pennsylvania, Florida, California, and Minnesota are among the most prominent.

PENNSYLVANIA'S VE PROGRAM

General Philosophies

Two general philosophies guided the VE program in PennDOT. The department has adopted a multidisciplinary approach to VE and has decentralized the program, relying heavily on the district offices. The multidisciplinary, or matrix-management, approach is vital to the success of a VE program. Varying backgrounds and expertise bring a variety of new ideas to bear on VE studies. VE teams have consisted of environmentalists, urban planners, and even lawyers as well as an assortment of highway designers and engineers. Those who have no direct involvement often bring a fresh viewpoint to the problem, asking the questions that highway specialists do not think to ask.

The other guiding philosophy is decentralization. PennDOT is divided into 11 engineering districts, each responsible for the highways in a geographic area. The districts are decentralized, in that each district is somewhat autonomous in design, maintenance, and construction. Therefore, the districts were given the responsibility of actually performing the VE studies under the guidance of a district VE coordinator. Not only is this in line with the general philosophy of decentralization, but it also eliminates the stumbling block that often exists when ideas and changes are directed from a central office. The districts originate the ideas and they have a stake in making them work.

Although the program is decentralized, there is a central office coordinator who is given the responsibility of ensuring that the program is successful, that the districts follow the general policies, and that the districts work at keeping the program vital. In Pennsylvania the coordinator is a staff position at a fairly high level, so that top management support is fully given to the program. It cannot be repeated often enough that top management support is essential to the success of VE.

Program Characteristics

The first administrative step in starting the program was the assignment of a VE coordinator in each engineering district. This is not a full-time position but an assignment to an engineer in an established position. The districts were permitted to assign their own VE coordinators, but they were encouraged to assign those who were known to be creative and who were not locked into traditional ways of thought.

The district VE coordinator is responsible for the successful VE program at the district level. The coordinator works with the design chief to select projects that are good candidates for VE studies, assigns the VE team, and schedules the study. The coordinator is responsible for training district staff in VE principles and practices. He is also responsible for following construction VE proposals to ensure their timely review.

To have a pool of those qualified to take part in VE studies and particularly to have qualified VE coordinators, it is necessary to have an aggressive training program. Three times PennDOT has taken advantage of the federally sponsored workshops to train about 50 people. The workshops are a 40-hr course taught by a certified value specialist (CVS). Anyone with VE responsibilities should attend at least one workshop.

Whenever possible, actual projects should be studied. In this way the students feel that they are contributing to the program and to the savings rather than just doing an exercise. In addition, the savings that result from a workshop can be from 10 to 100 times the payroll costs of the workshop. In Pennsylvania, more than $1 million has been saved in a single workshop.

The department has, through the workshops, built up a pool of about 50 who are qualified to lead VE efforts, and a larger pool has been established by introducing new people to VE through a VE study. Each VE team usually includes one person who has not been exposed to VE and who thus is in an on-the-job training program.

VE POLICY

Design

PennDOT policy is to submit all projects with an estimated construction cost of more than $1 million and 10 percent of all projects with a lesser value to the VE study. VE projects are chosen fairly systematically by using the principles of Pareto's distribution.

Pareto's law of distribution states that in any region, a small number of elements (20 percent) contain a greater percentage (80 percent) of the costs. VE takes advantage of this principle, not only for individual studies but for project selection as well.

Large projects with complex features, such as construction of new bridges and expressways, bridge rehabilitation, and major reconstruction, are studied first. The more complicated the project, the greater the chance for major savings. Likewise, the greater the cost of the project, the greater the chance for large savings.

VE is done in the engineering district by a multidisciplinary team. The team conducts an intensive study, usually for 3 or 4 days without interruption. It is important that the team members be totally committed to the study for its duration. Interruptions, other work activities, and so forth, can destroy the effectiveness of the team. An important element of a VE study for a highway project is a field view of the project site.

Team members are chosen carefully from various disciplines, including nonengineering staff, and should be creative thinkers who are not devoted to only traditional ways of thinking. The team must not include the original designer. The designer is used as a resource during the investigation, but the designer naturally wants to defend his design and seldom has a truly open mind with respect to his own project. The team selects a chairman and a recorder, who prepare a report at the end of the study. An oral presentation to decision makers is recommended.

VE studies are done by district staff in the district office. Although this may restrict creative thinking somewhat, because the department team members may have a natural inclination to defend a design developed in their district, this policy increases the acceptance of those changes proposed. The district decision makers do not feel that the changes are coming from an isolated central office and appear to feel less threatened by them.

Construction

The department also has a contractor VE program, modeled after the U.S. Corps of Engineers program. This is administered through a VE incentive clause in construction contracts.

Contractors are encouraged to submit VE proposals. If a proposal is determined to provide equal performance at lower cost, the savings that result are split equally between the contractor and the department. This results in savings for the department and an additional project for the contractor and often results in ideas that can be used on future projects where the department can get the total savings. There is no limit to the savings paid to the contractor.

An important element of a construction VE program is speed. Contractors' proposals must be reviewed quickly. Contractors are usually on tight schedules, and if a proposal is delayed, it may as well not be submitted.

This does not mean that the review should be compromised. Contractor proposals must meet all of the requirements for a change order. All prices and quantities must be justified, and the final savings depend on the final quantities.

A construction VE program offers a way for an agency to start a VE program quickly; the only effort required is writing a specification and evaluating the contractors' proposals that are received. The actual studies are then done by the contractor.

ACCOMPLISHMENTS

Table 1 shows the total savings for each year of the VE program since its beginning. The savings have been substantial, and yet the manpower cost is minimal. The estimated manpower cost since 1979 is less than $100,000. The figures shown for construction savings are the department's savings; they

Table 1. VE summary.

Item	Savings ($000s)		
	1979-1980	1980-1981	1981-1982
Estimated design savings	9,838	11,749	11,241
Construction savings	0	1,178	220
Total	9,838	12,927	11,461

Note: Number of VE studies is as follows: 1979-1980, 12; 1980-1981, 60; 1981-1982, 60.

should be doubled to show the construction cost reduction.

A VE program is not without its problems. There are the usual problems of acceptance of a new program, especially one the purpose of which is to question established ways of thinking and to question the work of designers. This can be overcome by good top management support of the program. Without top-level support a VE program will not succeed. With top-level support it has a fair chance of success. Pennsylvania has been fortunate, because Thomas Larson, Secretary of Transportation, is a strong supporter of VE and is committed to making the program work.

Another serious problem is acceptance of the program by contractors. Many delays have arisen in PennDOT's construction program because of arguments over prices and costs in a contractor's proposal. A contractor's education program is being planned that will describe the steps that a contractor must follow for the submission of a VE proposal. It will emphasize that a contractor's proposal must be complete and must contain justifiable prices. Proposals that are complete and accurate are evaluated quickly. An important point, to which all agencies adhere strictly, is that a VE proposal is not approved until the contract change order has been approved.

Contractors and others have questioned this policy of strict price justification. They claim that the department is saving money anyway, so why should their prices be questioned? The response is simple. We owe it to the taxpayer to save the maximum amount possible. Otherwise contractors could manipulate the prices so that they got a 60 percent or even 75 percent share of the savings.

RECOMMENDATIONS

PennDOT's experience can prove valuable to other agencies that would like to start a VE program. The following recommendations may be useful:

1. Obtain top management support. Without this support, creative ideas will be suppressed, and local staff may lack the incentive to continue with the program.
2. Adopt a multidisciplinary approach. Environmentalists, planners, right-of-way specialists, lawyers, and others will bring a fresh point of view on a problem, whereas designers and engineers may, through old traditions, be restricted in their thinking.
3. Let district or regional personnel perform the studies, but with a central guiding policy and support.

CONCLUSION

VE works. PennDOT has, over the past 2.5 years, saved more than $30 million without reducing performance. A statewide policy has been instituted within the framework of which VE is promoted at the district or regional level. Contractors have been encouraged to join the VE program by adding an incentive clause to construction contracts. VE has even been marketed by using training programs, posters, and pamphlets.

REFERENCE

1. J.J. O'Brien. Value Analysis in Design and Construction. McGraw-Hill, New York, 1976.

Publication of this paper sponsored by Committee on Manpower Management and Productivity.

Pennsylvania's Inventory Reduction Program

PARKER F. WILLIAMS

In October 1981 the Pennsylvania Department of Transportation (PennDOT) launched a statewide inventory reduction program. Results have been dramatic. In September 1982, 1 year after the start of the program, inventories have been reduced by more than $14 million (30 percent). A description of the underlying causes for excessive inventories at PennDOT, specific remedies that have developed to reduce inventories, the results to date, and actions planned for the future are presented. The methodology includes the use of fairly simple inventory management performance indicators such as turnover ratios, zero-use reports, and inventory values per lane mile to highlight excessive inventories and establish priorities for their reduction. PennDOT's program is especially relevant to other states that have computerized systems but can also be useful to those whose automated systems are in the design stage.

The purchase of materials and supplies is the largest cost element in a transportation department's highway and bridge maintenance program next to wages and contract maintenance. The private sector has long recognized that the major potential for controlling these costs lies in inventory management. Because of the astronomical costs of financing inventories at today's interest rates, programs to reduce inventories have been placed high on the priority list of private-sector materials management goals.

Consistent with the efforts in Pennsylvania to apply proven business practices to state government, the Pennsylvania Department of Transportation (PennDOT) has concentrated on applying basic inventory management techniques to reduce inventory costs. Clearly transportation agencies faced with dwindling funding levels that do not match even the most basic maintenance needs must recognize the large cost savings potential in reducing excessive inventories.

NEED FOR INVENTORY REDUCTION

Pennsylvania has the fourth largest state transportation system in the United States: 45,000 miles of highway and 27,000 bridges. Because the three states with larger systems have warm climates, Pennsylvania's system is the most difficult to maintain. Because of declining liquid fuels revenues, the General Assembly appropriated only $439.4 million for Pennsylvania's road and bridge maintenance program in FY 1980-1981, some $46 million less than in 1979-1980. An ambitious highway and bridge maintenance program coupled with this reduction in revenues made it clear that cost efficiencies and productivity improvements would be needed to carry out the program.

Inventory carrying costs are at least 20 to 25 percent per year (1). PennDOT's statewide inventories as of June 1981 totaled $48.1 million (see Figure 1). With a conservative carrying cost of 20 percent (includes storage and financing costs), every $1 million reduction in inventory could save $200,000.

Field visits by top management to county yards, stockpiles, and storerooms confirmed that inventories were excessive compared with operational needs. Clearly PennDOT's Automated Inventory Management System (AIMS), in place since 1975, was not serving its primary inventory management objective. Secretary of Transportation Thomas Larson, aware of the potential cost savings, charged the Bureau of Office Services with the task of determining the causes of high inventories and developing an inventory reduction program to reduce levels without impairing the achievement of maintenance goals.

AIMS

To gain a better understanding of how the PennDOT inventory reduction program was developed, it is first necessary to provide a brief description of the inventory management system. In the late 1960s, PennDOT made a long-term management commitment to automate inventory record keeping, procurement, and materials use functions and began phased institution of the system now known as AIMS. By mid-1975 the system was fully operational in all district offices; since 1975 all central warehouses have been incorporated into the system.

AIMS is an on-line, real-time, remote-data-entry computer system that automates routine clerical procedures for inventory accounting, purchase order preparation, and materials use accounting. AIMS provides managers with automated control mechanisms and ready access to the information needed for decision making.

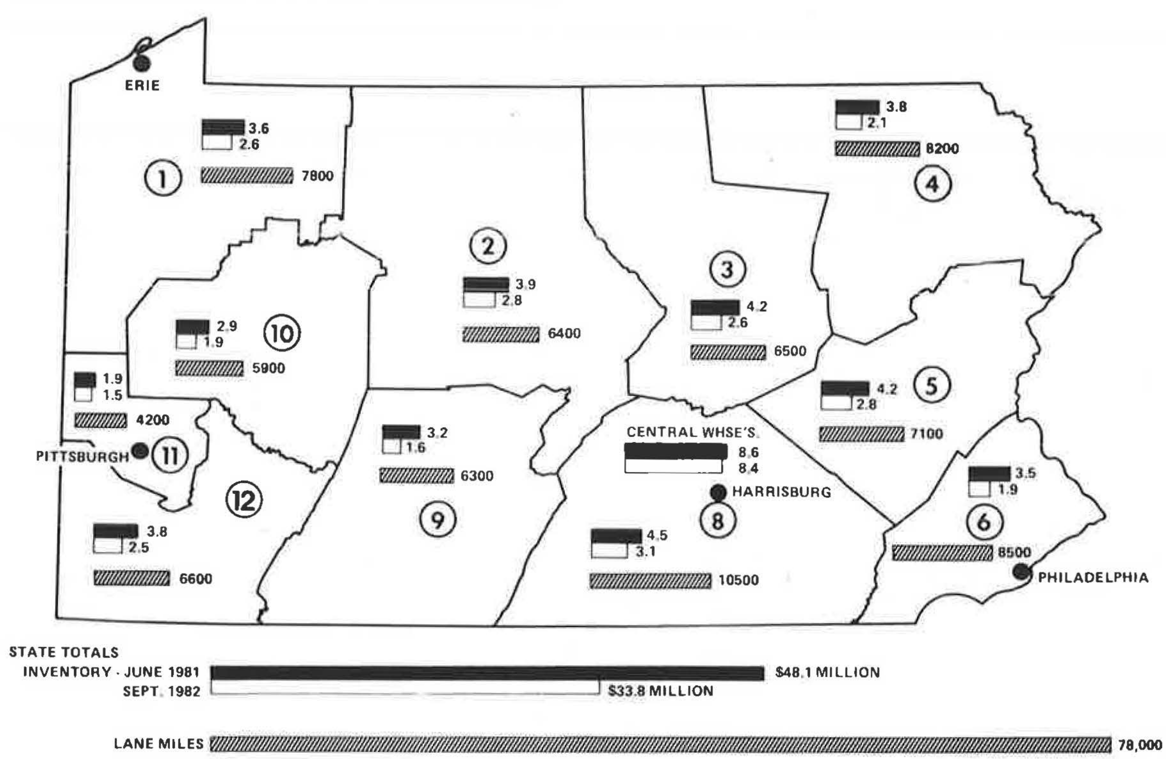
Operating-level managers establish reorder points and reorder quantities. By means of the remote-data-entry terminal located at all district offices and central warehouses, receipts and issues are posted to inventory records; low-stock notices are given; orders are placed; fiscal control over material budgets is maintained; and information on current inventories, open orders, physical inventory adjustments, and historical use is maintained. Summarized reporting is provided at all management levels and data are captured for reporting and analysis.

The director of the Bureau of Office Services as materials manager has overall responsibility for the AIMS system. The Bureau of Maintenance provides guidelines to district materials coordinators on the technical aspects of ordering and using materials.

Each of the engineering districts has an AIMS coordinator who approves or disapproves orders and monitors inventory records, controls, and system performance. Each county maintenance district has a materials coordinator and a storekeeper who oversee AIMS at the operating level.

During FY 1981-1982, AIMS was used to control 14,712 different commodities at 1,053 separate loca-

Figure 1. Inventory reduction and lane miles by engineering district.



tions. The system processed 17,168 orders and 513,409 issue transactions representing $121.6 million in materials charges to the accounting system.

CAUSES OF EXCESSIVE INVENTORIES

After numerous field visits and extensive discussions with responsible individuals, five primary causes of high inventories were identified.

Lack of Management Commitment

The best-designed inventory management system will not work effectively unless managers directly responsible for inventories are committed to, and insist on, accurate and timely input of the order, receipt, issue, transfer, and adjustment transactions critical to the effective operation of the system. Moreover, these managers must also be directly involved with, and take an active interest in, reviewing and analyzing the system's summary reports to be able to monitor and successfully control materials use and inventory levels.

There are three reasons that county-level managers were not motivated to adequately control inventories. First, the AIMS system was primarily designed and established by central office and engineering district staff with less involvement of the county maintenance staff who are responsible for entering transactions and overseeing the system at the operational level. As a result operating-level management did not totally understand the complexities of the system and even viewed it as a threat. Second, it was difficult to get county-level management interested in reducing inventory levels. Many managers did not see the cost savings that resulted from lower inventories, only the possible loss in production if critical materials were not in stock. This has resulted in the tendency to stockpile materials for unforeseeable future needs. Third, top-level management in previous administrations did not place a high priority on inventory management. This lack of management commitment at all levels was the key reason for excessive inventory.

Lack of Quantitative Methods

Quantitative methods were not being extensively used to answer the four questions common to any inventory management system: (a) Which items or group of items should be more closely controlled? (b) How much and which types of items would be needed to meet the production plan (demand)? (c) When must an item be ordered (reorder point)? (d) What quantity must be ordered (order quantity)? The first question can be answered by use of ABC analysis (discussed later), the second by systematic materials requirements planning (MRP), and the third and fourth by mathematical determination of the economic order quantity (EOQ). Although these quantitative techniques are commonly used in the private sector, they were not being used by PennDOT.

Surplus

Excessive inventory always leads to surplus. There is a natural tendency, even in an organization with a well-managed inventory program, to hold on to items even if they can be clearly identified as surplus. Several categories of surplus were identified at PennDOT: usable items overstocked in a particular county maintenance district or statewide, items obsolete in one county but usable in another, items obsolete statewide but having a salable value, salable scrap or wornout items, and junk with little or no value. Surplus was an especially difficult problem for several reasons.

First, without any AIMS exception reports to compare inventory levels and use or to determine whether an item had been used recently, the extent of the surplus problem could not be accurately determined. Second, there were no ongoing central efforts to identify and encourage the transfer of items excessive or obsolete in one county to another county where the items could be used. Third, there was a lack of knowledge of how to dispose of surplus. Fourth, inventory managers had a tendency to retain surplus even if it could be sold, because surplus revenues were not credited back to their budgets. Fifth, planning for the introduction of new materials was inadequate. The quantity, value, and location of material that would be made obsolete by the introduction of improved material were not identified nor were policy guidelines issued that required the use of existing material before new material was ordered. Sixth, not unique to PennDOT, is the obsolescence of equipment repair parts, which occurs as a result of the competitive bidding process. As equipment produced by one manufacturer ages and needs to be replaced, there is always the chance that the low bidder on the new equipment will be a different manufacturer.

Procurement Methods

PennDOT must operate its procurement functions within the policies of the Commonwealth as administered by the Department of General Services. Three basic procurement methods apply: contract purchasing, requisition purchasing, and local purchasing.

Contract Purchasing

Contracts are established by General Services for major material items regularly purchased by many organizations at locations throughout the state. Some examples of material contracts are those for tires and tubes, motor fuels and lubricants, winter materials, aggregates, bituminous materials, and pipe. Contracts include the free-on-board (FOB) delivered price for every purchasing location. The contracts are loaded into AIMS for automated preparation of a purchase order when a reorder point has been reached. Benefits include fixed prices, usually for 1 year, ease of ordering, and timely receipt of materials in the exact quantity needed. However, because of the extensive and time-consuming process involved in assembling each agency's requirements and bidding, awarding, preparing, and distributing the contract, it was not unusual for the existing contract to lapse before the new contract was available. In the absence of assurances that a new contract would be loaded into AIMS before the existing contract expired, stockpiling before the end of a contract was the rule, especially for critical maintenance materials. An added problem with contracts was the minimum order quantity, which could force excessive inventory if it exceeded immediate needs.

Requisition Purchasing

A purchase requisition must be prepared, either manually or through the AIMS system, for commodities not on contract when the order amount exceeds $1,500. The requisition is processed through the Transportation Procurement Section and goes to General Services for bidding and award, a process that takes an average of 90 days to complete. To gain a better price on noncontract commodities used by maintenance districts throughout the state, the Procurement Section solicits annual requirements from each maintenance district for a group purchase. The elapsed time between solicitation of needs and delivery of materials is 6 to 9 months. The long lead time coupled with the lack of AIMS reports correlating past use with inventory and the necessity of purchasing the estimated quantities results in excessive inventory levels.

Local Purchasing

Materials not available through contract may be purchased locally by the district office if the order does not exceed $1,500. Because materials purchased locally are readily available and usually used within a short period of time, this procurement method was not a cause of high inventories.

Lack of Inventory Management Performance Indicators

A critical element in any inventory management program is the measurement of the program's success. Without performance indicators, it is difficult to establish and monitor inventory goals and to identify problems that require management attention. With AIMS a variety of useful information was being reported to inventory managers on the system's operation, but the data were not being correlated into exception and performance reports. For example, AIMS reports the quantity and value of inventory by commodity and location and use of each commodity in units and dollars for the current month, year to date, last fiscal year to date, and last fiscal year. The system also provides aggregate totals for commodity groups and all commodities at a particular location, all locations in a county combined, and all counties in an engineering district, and statewide totals. However, a county manager responsible for inventory management could not readily determine through existing AIMS reports the value of county inventory compared with that of other counties, how many months' stock was on hand in relation to use, or which items reflected no use and should be transferred or sold as surplus.

PENNDOT'S INVENTORY REDUCTION PROGRAM

The primary causes of high inventory were identified and presented to top management in May 1981. In October 1981 the Inventory Reduction Program was launched by Secretary Larson. The following discussion describes the specific performance indicators developed to establish inventory reduction goals and what specific remedies were instituted to help achieve those goals. The key cause of high inventories, lack of management commitment, was resolved when the program received top management's endorsement.

Table 1. Zero-use report.

PROG 3584710 — ZERO USAGE REPORT — JULY, 1981 THRU JUNE, 1932 — RUN DATE 06/30/82 PAGE 15 & TIME 20:27

ORG 011

STKPL	COMMODITY CODE	QUANTITY ON HAND	UNIT PRICE	VALUE OF ON HAND	U/M	NOMENCLATURE	DESCIPTION
01	8010-2400-0201	4.0	10.00	$40.00	GAL	PAINT,#4	BLUE GLASS HISTORICAL SIGNS 1 GALLON CAN
01	8010-4000-0206	.0	10.00	$.00	GAL	PAINT,#6	BLACK SEMI-GLOSS SIGN POSTS 1 GALLON CAN
01	8010-4200-0200	80.0	9.50	$760.00	GAL	PAINT,#12	WHITE GLOSS WOOD 5 GALLON CAN
01	8010-5400-0102	21.0	10.00	$210.00	GAL	PAINT,#1ZY	YELLOW ZINC PRIMER STRUCTL TOUCH-UP 1 GALLON CAN
01	8010-5400-0204	5.0	10.00	$50.00	GAL	PAINT,#1ZY	YELLOW ZINC PRIMER STRUCTL TOUCH-UP 5 GALLON CAN
01	8010-5450-0402	3.0	10.00	$30.00	GAL	PAINT,PRIMER	ZINC-DUST ZINC OXIDE PRIMER 1 GALLON CAN
01	8010-6100-0200	.0	6.25	$.00	CAN	PAINT,MRL SP	MINERAL SPIRITS 5 GALLON CAN
01	8010-9900-1070	.0	8:58	$.00	GAL	PAINT, #3	YELLOW ENAMEL, 5 GAL CAN
01	8010-9900-1128	24.0	10.50	$252.00	GAL	PAINT #9	ANTIQ BRONZE MINERL SP ALK RESIN BRIDGE 1 GAL CN
01	5610-4500-0410	.0	4.20	$.00	BAG	CEMENT	OCTOCRETE FAST-SETTING, 50 LB. BAG
01	5350-6000-0500	256.0	2.93	$750.08	BAG	ABRASIVE	SAND BLASTING
01	9545-0100-0050	9.0	29.95	$269.55	EACH	WIRE	BLACK ANNEALED #8 GAUGE, SPEC. FED. QQ-W-461F
01	9545-0100-0104	7.0	30.00	$210.00	EACH	WIRE	BLACK ANNEALED #9 GAUGE, SPEC. FED. QQ-W-461F
01	9545-0100-0250	6.0	30.30	$181.80	EACH	WIRE	BLACK ANNEALED #12 GAUGE, SPEC. FED. QQ-W-461F
01	9545-0100-0352	.0	30.90	$.00	EACH	WIRE	BLACK ANNEALED #14 GAUGE, SPEC. FED. QQ-W-461F
01	9545-0200-0081	.0	32.00	$.00	BAG	TIES	8IN ANNEALED WIRE 14 GAGE 5000 PER BAG
01	9545-0200-0128	.0	21.00	$.00	BAG	TIES	12IN ANNEALED WIRE 14 GAGE 2500 PER BAG
01	9545-0200-0140	.0	23.25	$.00	BAG	TIES	14IN ANNEALED WIRE 14 GAGE 2500 PER BAG
01	7920-5310-0200	23.0	1.21	$27.85	EACH	BRUSH,HANDLE	TAPERED,HARDWOOD,60 IN.,FOR HWY ST. BROOMS
01	7920-5800-0300	1.0	88.80	$88.80	DOZEN	MOP DUST	DUST, SLIP-ON, W/HOLE, 22 IN.FRAME,30 IN.SURFACE
01	7920-5800-0605	1.0	39.96	$39.96	DOZEN	MOP, DUST	REPLACEMENT HEAD FOR 30 IN SURFACE #1130LTR
01	7920-6230-1303	.0	37.59	$.00	EACH	MOP EQUIP	WRINGER,BUCKET-TYPE I CLASS A,STYLE 1,SIZE 1
01	7930-2475-0907	55.0	3.72	$204.60	GAL	DETERGENT	ALKALINE LIQUID DETERGENT FOR BIG RIG STEAM CLNG
01	7930-3400-0400	.0	.18	$.00	EACH	POWDER	SCOURING W/O BLEACH (48/14 OZ CANS PER CASE)
01	8110-2000-0250	.0	11.82	$.00	EACH	COVER, DOME	HOT-DIPED,GALV.,SELF CLOSE DOME COVER,55 GAL CAN
01	8540-3001-0300	.0	21.65	$.00	CASE	TOWELS	PAPER, ROLL, GRADE A, CLASS II
01	2805-0199-0115	28.0	.17	$4.90	EACH	FILTER&COVER	R-10 DUST PRE-FILTER
01	2805-0199-0228	7.0	1.40	$9.80	EACH	FILTER&COVER	R-21 ORGANIC,VAPOR,PAINTING
01	2805-0199-0308	1.0	9.88	$9.88	EACH	RESPIRATOR	SPRAY PAINTING PROTECTION, COMPLETE
01	2805-0199-0330	10.0	2.16	$21.60	EACH	FILTER	R-15 PAINTING PRE-FILTER
01	2805-0199-0400	.0	9.58	$.00	EACH	RESPIRATOR	WELDING PROTECTION, COMPLETE
01	2805-0199-0443	8.0	1.64	$13.12	EACH	CARTRIDGE	R-12 DUST,FUMES,WELDING
01	6505-3758-0100	.0	9.38	$.00	UNIT	IMUNIVY	1CC VIALS 4 TO UNIT
01	6545-1015-0053	1.0	13.48	$13.48	EACH	KIT,FIRSTAID	W/STING-KILL DEPT.OF TRANS FIRST AID 10 UNIT
01	6545-1020-0204	.0	.96	$.00	UNIT	BANDAGE	PLASTIC ADHESIVE 2IN.X3-1/2 IN. 02-09-15
01	7240-4200-1002	9.0	39.15	$352.35	EACH	CAN,DSPNSER	SAFETY DISPENSER 5GAL. RE:EAGLE MODEL U2-51-S
01	8415-5500-1156	50.0	1.54	$77.00	EACH	SUSPENSIONS	ADJ 6 3/4-7 5/8 FOR HARD CAPS NYLON WEB VINYL BD
01	8415-5500-4100	.0	1.20	$.00	EACH	LINER,WINTER	FOR HARD CAPS,SIZE SMALL UP TO 7 1/8
01	8415-7000-0103	3.0	13.90	$41.70	PAIR	GUARD,FOOT	PROTECTIVE,SANKEY (MENDS)_200 ALUM.ALLOY, 5 IN.
01	8415-7000-0409	3.0	13.90	$41.70	PAIR	GUARD,FOOT	PROTECTIVE,SANKEY(MENDS)_200 ALUM.ALY,5-1/2 IN.
01	8340-1000-1508	.0	.38	$.00	SQ FT	TARPAULIN	CLASS 1 VARIOUS SIZES
01	8340-2000-1000	.0	76.00	$.00	EACH	TARPAULIN	STOCKPILE COVER, 24 FT. X 36 FT MT 26
01	8340-2000-2000	.0	101.00	$.00	EACH	TARPAULIN	STOCKPILE COVER, 24 FT. X 48 FT. MT 27
01	8405-6600-0102	6.0	11.46	$68.76	EACH	JACKET	RAIN, SMALL (36-38)
01	8405-6700-0104	1.0	10.00	$10.00	EACH	PANTS	OVERALL, SMALL
01	8405-6700-0308	7.0	10.00	$70.00	EACH	PANTS	OVERALL, LARGE
01	8405-6700-0400	2.0	10.00	$20.00	EACH	PANTS	OVERALL, X/LARGE
01	8405-6800-0106	6.0	2.00	$12.00	EACH	HOOD	RAIN, ONE SIZE FITS ALL

Inventory Management Performance Indicators

Three performance reports were designed: zero-use, inventory turnover, and inventory value versus lane miles.

Zero-Use Report

It was clear that eliminating surplus inventory and junk held the greatest immediate potential for inventory reduction. Thus the first performance report was developed to give inventory managers a tool to assist in identifying those items in inventory that had not been used recently. The report is prepared monthly from AIMS Inventory Master File records and reflects all inventory records for an organization (county maintenance district, engineering district, or central warehouse) against which there have been no issue transactions during the previous 12-month period (Table 1).

When the baseline report was run, the zero-use value totaled $13.9 million, or 29 percent, of the June 30, 1981, total inventory value. This was the first time that the magnitude of excessive and surplus inventories had been quantified. The Inventory Reduction Program set an initial goal to reduce the value of zero-use items 50 percent by June 30, 1982--a goal that would result in a more than $7 million inventory reduction.

Inventory Turnover Report

It was also clear that, for reasons already cited, storekeepers and materials coordinators were setting reorder points and quantities so that they would never be out of stock. As a result, quantities in inventory represented far more than immediate needs plus a safety stock. The problem was that the AIMS system was not reporting a performance measure that has been the most widely used inventory management indicator in the private sector--inventory turnover.

Inventory turnover is the quantitative measurement of the number of times each item in inventory turns over each year. When expressed a little differently, it tells an inventory manager, based on the past 12 months' use, the number of months that the on-hand quantity will last. The turnover rate is used to identify items that may be overstocked or understocked. The inventory turnover report is prepared monthly from AIMS Inventory Master File records and is calculated by comparing total use in units for the previous 12-month period with the average number of units held in inventory for the same period (see Table 2).

Table 2. Inventory turnover report.

PROG P3584710 — INVENTORY TURNOVER REPORT BY ORG — JULY, 1981 THRU JUNE, 1982 — RUN DATE 06/30/82 PAGE 7 & TIME 20:27

ORG 011 GROUP 12 SIGN ACCESSORIES

COMMODITY CODE	------AVERAGE INVENTORY-------- QTY	VALUE	TOTAL USAGE (UNITS)	INVENTORY TURNOVER (MONTHS)	NOMENCLATURE	DESCRIPTION
0210-2291-0000	272.0	$1,572.62	227.0	14.2	H 2 29 1	CHAN BAR ANCHORS 3FT 6IN 4.0 LB
0210-2300-0000	1,122.0	$1,279.17	810.0	16.5	H 2 30	CHAN BAR STRAP 2.0LB
0210-2320-0000	3.9	$36.36	14.0	3.2	H 2 31	CHANNEL DRIVE CAPS MAN 2.75LB
0210-2360-0000	9.3	$69.69	1.0	111.9	H 2 34	CHANNEL DRIVE CAP 6 FT.
0210-2390-0000	103.0	$1,004.25	222.0	5.5	H 2 38	CHAN BAR BRKWAY 8FT 2.25 LB
0210-4020-0000	3.5	$84.99	5.0	8.4	H 4 2	STEEL BANDIT BAND 3/4IN ROLL
0210-4030-0000	4.9	$75.08	2.0	29.4	H 4 3	BANDIT BUCKLES 3/4IN BOX
0210-6010-0000	10.0	$442.26	24.0	5.0	H 6 1	FRAME PORT SIGN SUPPORT 36IN
0210-9010-0000	85.1	$613.15	59.0	17.2	H 9 1	ORANGE TRAFFIC CONE (28 INCH)
0210-9020-0000	16.6	$26.15	25.0	7.9	H 9 2	REFLECTIVE BAND (28 INCH)
GROUP 12 TOTS	3,791.3	$18,918.40	4,067.0	11.1		
GROUP 13 SIGN RAW MATERIALS						
0210-1170-0000	2.2	$66.16	6.0	4.4	H 1 17	RIVITS CHERRY POP 1000 BOX
GROUP 13 TOTS	2.2	$66.16	6.0	4.4		
GROUP 16 LINE PAINT, BEADS & PROTECTORS						
8010-4320-0101	962.4	$7,158.69	3,026.0	3.7	PAINT,TRAFIC	WHITE TRAFFIC LOW HEAT,RAPID DRY, 55 GAL DRUM
GROUP 16 TOTS	962.4	$7,158.69	3,026.0	3.7		
GROUP 18 FASTENERS						
5305-1520-0012	0.2	$.33	1.0	3.0	SCREW,CAP	ALY STEEL,HEXGN HD,GRADE 5,DIA.1/4,L.1/2 N.C.T.
5305-1520-0056	0.5	$1.06	4.0	1.6	SCREW,CAP	ALY STEEL,HEXGN HD,GR.5,DIA.1/4 L.1 NC
5305-1520-0103	0.2	$.61	2.0	1.4	SCREW,CAP	ALY STEEL,HEXGN HD,GRADE 5,DIA.1/4,L.1/1/2N.C.T.
5305-1520-1104	0.2	$.81	3.0	0.9	SCREW,CAP	ALY STEEL,HEXGN HD,GRADE 5,DIA.5/16,L1-1/2N.C.T.
5305-1520-1206	0.5	$2.75	1.0	6.9	SCREW,CAP	ALY STEEL,HEXGN HD,GRADE 5,DIA.5/16,L.2-1/2N.C.T
5305-1520-1250	2.5	$15.78	1.0	30.9	SCREW,CAP	ALY STEEL,HEXGN HD,GRADE 5,DIA.5/16,L.3 N.C.T
5305-1520-2207	0.0	$.55	3.0	0.2	SCREW,CAP	ALY STEEL,HEXAGN HD,GRADE 5,DIA.3/8,L.2-1/2N.C.T
5305-1520-6109	1.0	$16.15	1.0	12.0	SCREW,CAP	ALY STEEL,HEXAGON HD,GRADE 5,DIA.5/8,L.1-1/2 NCT
5305-1520-6550	0.6	$31.21	1.0	7.9	SCREW,CAP	HEXAGN HD,HIGH CRBN,GRADE 5,DIA.5/8,L.6 NCT
5305-1525-0033	0.5	$1.11	2.0	3.4	SCREW,CAP	HEXAGN HD,HIGH CRBN,GR.5,DIA.1/4 L.1 NF
5305-1525-0204	0.4	$1.63	1.0	4.9	SCREW,CAP	ALY STEEL,HEXAGON HD,GRADE 5,DIA.1/4,L.2-1/2 NFT
5305-1525-1103	0.2	$.64	1.0	3.0	SCREW,CAP	ALY STEEL,HEXAGON HD,GRADE 5,DIA.5/16,L.1-1/2NFT
5305-1525-2057	0.3	$1.28	2.0	1.9	SCREW,CAP	ALY STEEL,HEXAGON HD,GRADE 5,DIA.3/8,L.1 NFT
5306-0510-3150	2.6	$301.77	1.0	31.9	BOLT,CARRAGE	W/O NUT,RND UNSLT HD,SQ NK,GR8,DIA 3/8 L 1-1/2NC
5308-1000-0254	3.3	$.89	1.0	39.9	ROD	THREADED,NC,3FT.LNGTH,CBN.STL,SIZE 1/4,ROD 20
5308-1000-0356	2.7	$1.54	5.0	6.6	ROD	THREADED,NC,3FT.LNGTH,CBN.STL,SIZE 3/8,ROD 16
5308-1000-0403	0.7	$.54	3.0	3.0	ROD	THREADED,NC,3FT.LNGTH,CBN.STL,SIZE 7/16 ROD 14

The formula is X = 12Y/Z, where X is the turnover in months, Y is the average annual inventory, and Z is annual use. For example, a tire that has an average annual inventory of 6 units and an annual use of 12 units has a turnover of 6 months [12(6)/12]. In other words, the normal inventory of this tire is sufficient to last 6 months under typical conditions.

Turnover ratios gain significance when turnover standards or goals are developed. When it is questioned whether an overstocked or understocked condition exists, the turnover rate must be considered in light of the goal and delivery times, minimum purchase requirements, storage capabilities, method of procurement, and actual and anticipated need for the item. When it is determined that there is an excess of an item, the reorder point and quantity should be adjusted and steps should be taken to record the excess quantity as surplus.

The baseline turnover report as of June 30, 1981, identified many commodity groups that had a turnover in excess of 12 months (see Table 3). The Bureaus of Office Services and Highway Maintenance, with the assistance of field inventory managers, developed inventory turnover goals for each major commodity group (except fuels and bulk materials) to be met by June 30, 1982. If these goals were achieved, inventory could be reduced by as much as $4 million. A combined inventory reduction goal of $11 million was set ($7 million zero-use reduction plus $4 million turnover reduction).

Inventory Value Versus Lane Miles

The AIMS system had no indicator by which to compare the relative value of the inventory in one county or engineering district with that in another. Lacking was a common denominator to compare organizations of different sizes. After the correlation coefficient had been tested by using regression analysis (see Figure 2), lane miles was chosen as the common denominator. The graph and tables showing inventory values per lane mile for all counties and districts were included with the Inventory Reduction Program. The indicator can be useful in determining the reasons why inventory value per lane mile is higher (or lower) in one county versus that in another and identifies locations that require a detailed analysis.

Table 3. Inventory turnover goals and results.

COMMODITY GROUP	INVENTORY TURNOVER (MONTHS) 6/30/81	INVENTORY TURNOVER GOAL 6/30/82	INVENTORY TURNOVER ACTUAL 6/30/82	INVENTORY TURNOVER ACTUAL 9/30/82
FIELD RELATED				
Signs & Accessories	13	10	14	12
Traffic Line Paint & Beads	15	12	7	7
Pipe	13	11	8	8
Tires & Tubes	8	6	6	5
Tire Chains & Accessories	35	6	16	15
Batteries	6	4	6	6
Automotive Parts	20	12	12	14
Other Equipment Repair Parts	15	6	12	12
Cutting Edges & Shoes	22	15	15	14
Guiderail	37	12	27	24
Lumber	19	12	21	19
Steel & Iron	44	24	26	26
Paint & Brushes	24	12	16	14
Tarpaulins	11	6	12	12
Fasteners	31	12	24	16
Bridge Decking & Inlets	12	10	25	20
Roadside & Landscaping	10	6	11	9
Electrical Supplies	12	6	8	7
Concrete & Cement	7	6	4	4
Safety Supplies	12	9	11	10
GENERAL OFFICE RELATED				
Forms, Publications, Office Supplies	12	10	12	13
Janitorial Supplies	9	6	7	7

Quantitative Methods

It is not enough to issue performance reports that show an inventory manager that a certain percentage of his inventory represents zero-use items or that the turnover ratio for several commodity groups exceeds the goal. Quantitative methods for determining where priorities should be placed, how reorder points and quantities should be set, and how to translate a maintenance program into material requirements are needed. The following three quantitative methods address these problems.

ABC Classification Analysis

ABC analysis is a quantitative technique used to focus attention on and apply effort to items that have the potential for yielding the greatest cost savings (2). ABC analysis stratifies commodities into three classifications based on their value relative to their numbers. Figure 3 is an ABC analysis of PennDOT's commodity groups.

The A items should be controlled the most closely because they are few in number (8 percent) but represent 57 percent of the total inventory value. The A items should be controlled by a computerized inventory system, and an economic order quantity (EOQ) model (discussed later) should be applied to systematically determine optimum reorder points and quantities. The B items represent 39 percent of the total and 31 percent of the value. These items should also be controlled by an automated system but

Figure 2. Lane miles versus inventory value for county maintenance districts.

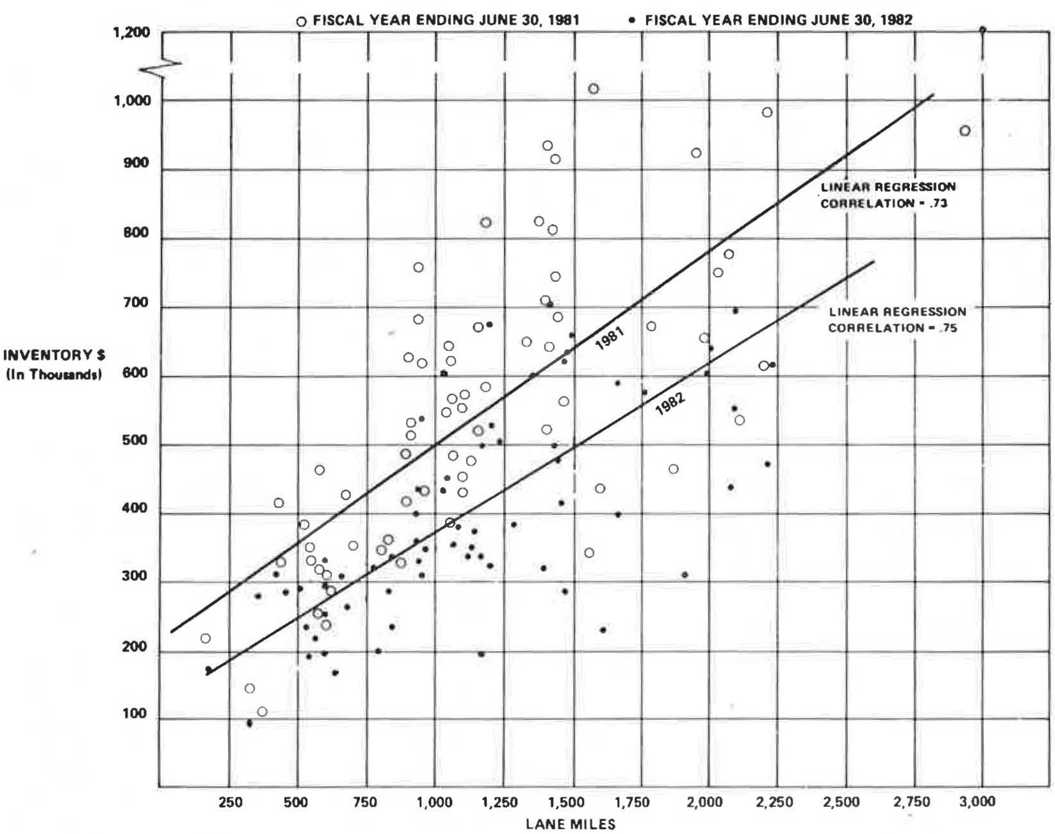
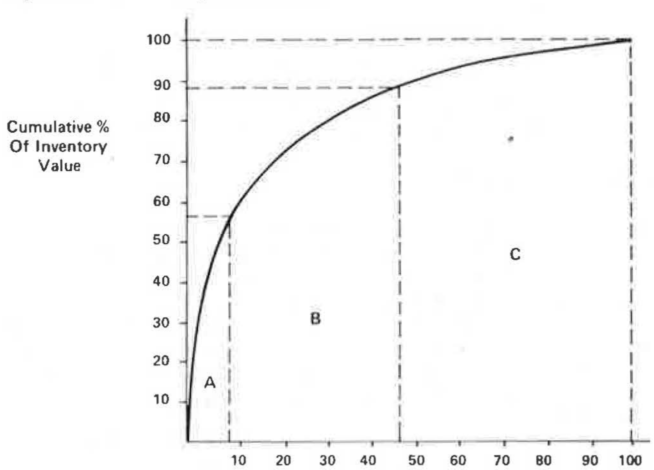


Figure 3. ABC inventory classification.



Cumulative % of Items in Inventory

CLASS	GROUP	Percentage of Total Commodities	Percentage of Total Inventory Value
A	Traffic Paint/Beads; Pipe; Bituminous Mat's; Aggregates; Winter Mat's; Petroleum Products; Cutting Edges; Engines; Guiderail; Tarpaulins; Bridge Decking; Roadside/Landscaping Mat's.	8%	57%
B	Signs/Accessories; Tires/Tubes/Chains; Batteries; Hand Tools; Lumber Steel/Iron; Paint/Brushes; Misc. Mat's.	39%	31%
C	Equipment Repair Parts; Office/Janitorial/Safety Supplies; Forms/Pubs/Maps; Fasteners	53%	12%
		100%	100%

less closely than the A items through use of the optimum order quantity portion of the model alone. The C items represent 53 percent of the total but only 12 percent of the dollar value. These items need to be further classified into two groups: (a) items to be controlled on an automated system because of operational problems in the event that the items are out of stock (e.g., equipment parts) and (b) items requiring no automated controls (e.g., office supplies and forms). C items should be controlled by subjectively determined order quantities.

Inventory managers at PennDOT have been encouraged to prepare an ABC analysis on the inventory they control. The primary usefulness of this technique thus far has been to focus attention on A items, which should be first-priority items when the zero-use and inventory turnover reports are used to identify and reduce inventory.

EOQ Model

All inventory reorder points and quantities on the AIMS system are currently set subjectively. Subjective determination does not assure minimum inventory costs. Private-sector enterprises, particularly manufacturers, have successfully used the EOQ model as an inventory device for some time. Basically the EOQ model, given annual demand, cost of placing an order, cost of carrying a unit in inventory 1 year, cost of being out of stock 1 unit, lead time between the date on which the order is placed and the date on which the order is received, and average demand over the lead time, will first determine the optimal order quantity and then determine the optimal order point to balance inventory costs against the risk that the item will be out of stock to minimize inventory costs.

In a report prepared by an Office Services business intern in summer 1981, many of the problems in applying the EOQ model were described. For example, one of the biggest problems in applying the model, particularly to a department of transportation in a cold-weather state, is determining the effect of seasonality of maintenance activities and the unpredictability of winter activity on demand for materials. Simplified EOQ models are currently being investigated (3).

Materials Requirements Planning

Materials requirements planning (MRP) is another quantitative method that has been extensively used by the private sector to manage inventories but has not been so used by PennDOT. MRP is the process of translating a maintenance plan into detailed materials requirements. MRP is a relatively new (late 1960s) solution to an old problem: availability of the material needed for production without excess inventories (1).

The computerized Highway Maintenance Management System (HMMS) used by PennDOT to define, among other things, the effort and resources required to perform a maintenance activity is scheduled for redesign. One of the goals of the redesign will be to integrate the maintenance programming on HMMS with materials use and inventory on AIMS, a step toward MRP.

Surplus

Armed with the new zero-use report, inventory managers made efforts to reduce surplus-dominated inventory reduction activities in the initial phases of the program. Office Services released a procedure memorandum that brought inventory managers up to date on the various methods available to dispose of surplus. They were made aware of the Department of General Services' surplus contracts for tire casings, batteries, steel drums, waste motor oil, and scrap material and how to use them. Office Services also negotiated with local authorities for advertising and selling surplus or damaged snow fence, posts, and guiderail wire. Transfer procedures were explained and AIMS coordinators were encouraged to advertise surplus items statewide over the department's computer network. A new inquiry through AIMS was developed so that any division could determine for any commodity its quantity and location anywhere in the state. Procedures for transferring surplus to the Surplus Property Division of General Services for public advertising and sale were also explained. Due to the sheer volume of surplus identified at inventory locations throughout the state, the Surplus Property Division did not have sufficient storage facilities or staff to handle it efficiently. The lead time between identification of surplus and approval for transportation to Harrisburg and sale of the surplus quickly became unacceptably long. The alternative of holding regional auctions with General Services was investigated. Two public auctions were held in the central and southwestern parts of the state. More than $1.5 million in surplus (book value on AIMS) was sold or transferred to other state agencies from these auctions. Because proceeds from the public auctions were low, the department developed another alternative by offering surplus to local government at 50 percent of the book value.

Four local sales open only to municipalities have been held thus far; more are being scheduled. As an incentive to dispose of surplus, revenues from the sales are credited back to the organization declaring the surplus.

Other efforts made to help remedy the causes of surplus are better planning for the introduction of new materials so that existing materials are used up before new materials are ordered and the introduction of life-cycle cost analysis to determine the low bidder on equipment purchases.

Procurement Methods

PennDOT has worked closely with the Department of General Services in eliminating material contract lapses. An extension clause has been added to contracts that should eliminate any future problems with lapses. Stockpiling before the end of a contract has been eliminated. Authority to purchase contract items locally when contract minimums exceed immediate needs has been granted. Now that contract problems have been resolved, commodities that have statewide use but have been purchased through the requisition process are being placed on contract. Even though there is a long lead time between submission of requirements and issuance of the contract, the terms of the contract do not require a county to purchase the estimated quantity. Moreover a county can order from the contract as needed rather than receiving a year's supply at one time.

Management Commitment

In addition to the top management commitment given to the development and institution of the inventory reduction program, managers at all levels are held accountable for achieving the reduction goals. The deputy secretary for administration, who has top management responsibility for the program, conducts periodic inventory control visits to determine progress and identify necessary improvements. As an incentive to achieve the inventory reduction goals, inventory management has been added as a new category to the annual Maintenance Awards Program.

INVENTORY REDUCTION PROGRAM RESULTS

By June 1982, 9 months after the program had been launched, statewide inventories had been reduced $11.9 million (25 percent), from a level of $48.1 million in June 1981 to $36.2 million in June 1982 (see Figure 4). The overall reduction goal of $11 million had been exceeded. By September 1982, further reductions of $2.4 million had been achieved, bringing the total reduction to $14.3 million (30 percent). Inventory reduction by engineering district was shown in Figure 1, and the reduction by commodity group is shown in Table 4.

Figure 4. Inventory reduction: June 1981 versus September 1982.

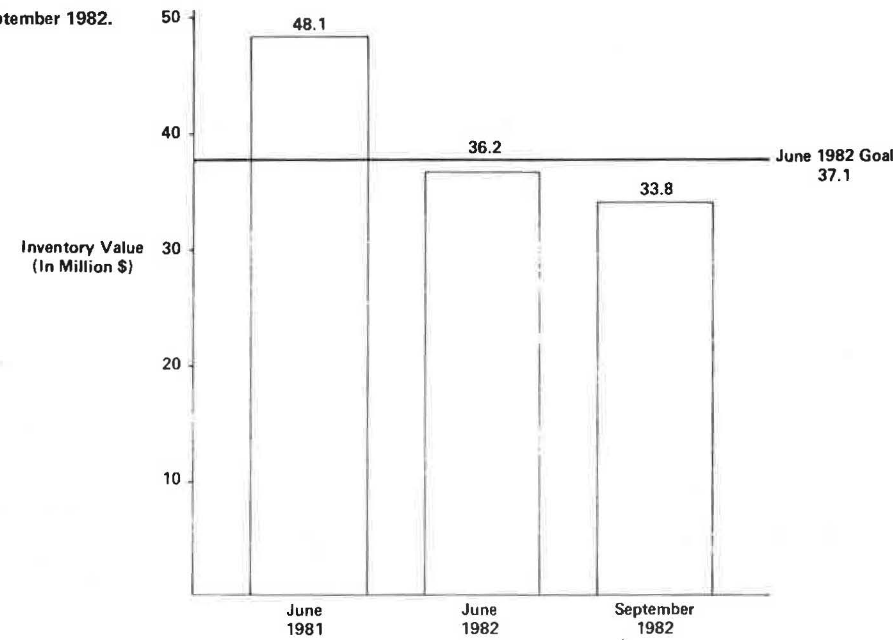
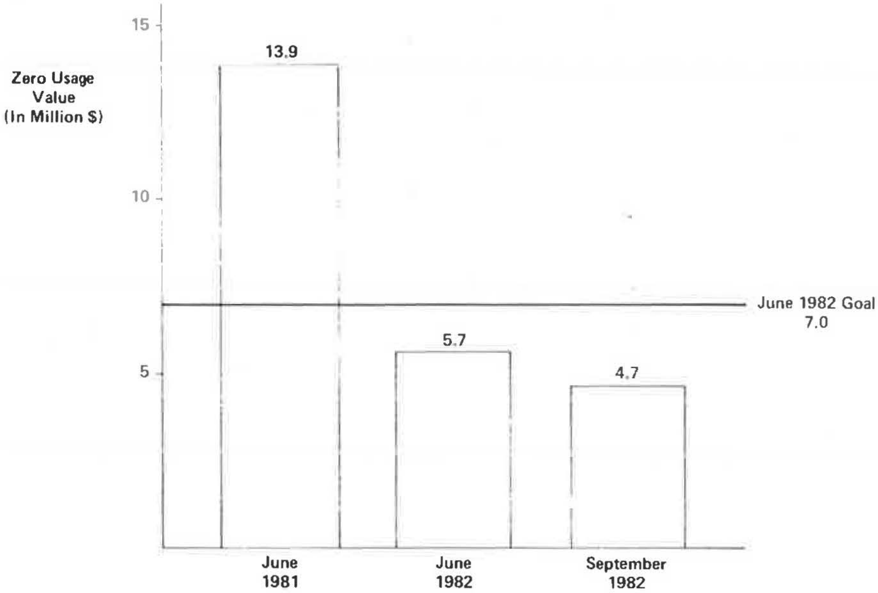


Table 4. Inventory reduction by commodity group: June 1981 versus September 1982.

Group	Inventory Value In Millions			Change	
	June 1981	June 1982	Sept. 1982	$	%
Signs & Accessories	$ 9.3	$ 6.8	$ 6.6	– 2.7	–29
Traffic Paint & Beads	4.2	4.2	3.7	– .5	–12
Pipe	2.4	2.2	1.3	– 1.1	–46
Bituminous Materials	2.0	1.7	1.7	– .3	–15
Aggregates	3.9	3.5	2.5	– 1.4	–36
Winter Materials	5.7	2.5	3.3	– 2.4	–42
Motor Fuels	1.0	1.0	1.0	–	–
Other Fuels, Anti-Freeze, Detergents	.4	.4	.4	–	–
Motor Oils & Lubricants	.5	.4	.4	– .1	–20
Tires, Tubes, Tire Chains	1.9	1.3	1.3	– .6	–32
Batteries	.2	.2	.2	–	–
Engine and Engine Parts	.6	.3	.3	– .3	–50
Automotive & Equipment Parts	.8	.7	.7	– .1	–13
Hand Tools	1.3	.5	.4	– .9	–69
Cutting Edges & Shoes	2.6	1.5	1.4	– 1.2	–46
Lumber	.3	.2	.2	– .1	–33
Guiderail	3.1	2.3	2.2	– .9	–29
Steel & Iron	.9	.4	.4	– .5	–56
Paints & Brushes	.8	.5	.4	– .4	–50
Tarpaulins	.2	.1	.1	– .1	–50
Fasteners	.7	.5	.3	– .4	–57
Bridge Decking & Inlets	.3	.3	.3	–	–
Roadside & Landscaping Materials	.8	.8	.4	– .4	–50
Forms, Pubs, Maps	2.4	2.6	3.1	+ .7	+29
Office, Janitorial, Safety Supplies	1.2	.9	.8	– .4	–33
Other Materials	.6	.4	.4	– .2	–33
	$48.1	$36.2	$33.8	$–14.3	–30%

Figure 5. Reduction of zero-use value: June 1981 versus September 1982.



The value of zero-use items was reduced 59 percent ($8.2 million), from a level of $13.9 million in June 1981 to $5.7 million in June 1982 (see Figure 5). The reduction goal of 50 percent ($7 million) had been exceeded. By September 1982, further reductions had brought the zero-use value down to $4.7 million.

By June 1982, the inventory turnover rate on 17 of 22 commodity groups had improved from the 1981 level. However, only five of the established turnover goals had been met (see Table 3). The turnover rate on several A commodities (e.g., cutting edges, pipe, and guiderail) and B commodities (e.g., steel and iron and tires and tubes) improved dramatically, whereas the turnover rate on several C commodities (e.g., equipment parts and forms, publications, and office supplies) showed less improvement or increased slightly. The turnover calculation reflects only quantities and not value. If the higher relative value of A and B items compared with that of C items (see Figure 3) and the dramatic reduction in several A and B commodities is considered, this may explain why total inventory was reduced by $3.7 million due to turnover rate improvements, an amount that almost met the $4 million goal.

APPLICATION TO OTHER DEPARTMENTS OF TRANSPORTATION

A survey conducted by the Texas State Department of Highways and Public Transportation in fall 1981 revealed that of the 39 state departments of transportation that responded, 22 have state-of-the-art computerized inventory management systems, 3 have old or outdated systems, and 14 have no system at all (unpublished survey). It is suggested that many aspects of Pennsylvania's inventory reduction program can be applied to those states with computerized systems and that those states in the process of designing automated systems can benefit from the quantitative methods and performance indicators adapted by PennDOT.

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