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**J.G. Schoon was with Byrd, Tallamy, McDonald and Lewis when the concepts of micro- and macro-quality were being developed.*

A Systems Approach to Maintenance Station Location

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The California Department of Transportation (Caltrans) has developed a procedure for identifying appropriate locations for facilities needed to support the highway maintenance mission. The traditional approach has failed to answer the questions of whether the facility is really necessary and is in the best location, whether the adjoining stations are affected, and what the fiscal impacts of possible alternate locations are. The procedure developed by Caltrans considers the trade-offs between capital costs and operating costs over the project's life and emphasizes changes in expected travel costs as a function of maintenance station location. These costs can then be weighed against the social and administrative aspects of deciding what facilities are needed and where to build them. Computerized network simulation is used to estimate travel-time impacts, while capital costs are evaluated by using discounted cash flows. A field application of the procedure, as a portion of the siting-decision process for a new facility, Beckwourth, is discussed, along with results observed after a year's application.

Twenty-five percent of California's 325 maintenance stations are older than 30 years; almost 20 percent of its stations are 40 years old or older. Although age alone does not determine the obsolescence of a facility, it is a major consideration. The aggregate age of California's facilities gives a partial insight into the magnitude of the problem that the California Department of Transportation (Caltrans) must face. The present dollar cost of modernizing the system could easily approach $100 million. This total grows daily as more stations join the ranks of the obsolete and as inflation continues its upward march.

Historically Caltrans' practice has been to identify specific deficiencies in maintenance stations and to address these specifically through a project. Most commonly the correction proposed is either reconstruction of the facility or construction of a new one nearby. The notable exception has been in the larger metropolitan areas, where the emerging trend is to develop centrally located service centers.

Appreciating the magnitude of the problem, Caltrans' management took a second look at the task. Over the past 30-40 years the highway system has evolved and changed considerably from the system that the maintenance stations originally served. From this second look it became apparent that the older facilities are no longer in the best locations to effectively support the maintenance mission.

In early 1976 the California Highway Commission challenged a project to locate a new facility in the remote community of Covelo in northwestern California. Responding to this challenge required a comparison of the total system cost of supporting the highway from the proposed local operating base in the Covelo area against the cost of supporting the highway from the next proximate bases at Willits or Leggett.

It was necessary to estimate the total costs for the various siting decisions. The maintenance-facilities siting model, developed to satisfy this objective, contains two major elements: the operating cost element and the capital cost element. Changes in the costs of maintenance operations as they relate to the location of the maintenance stations are examined in the operating cost element. The impact of capital expenditures, both present and future, are considered in the capital cost element. The facility siting model brings these elements together in a format that permits management to make the critical trade-off (see Figure 1).

The method of analysis that was developed to meet this purpose is the topic of this paper.

MAINTENANCE OPERATING COST ELEMENT

This element is used to simulate the normal highway maintenance function. The work done in each highway section is studied and the existing crew travel patterns analyzed. From the information gained, we can estimate what our costs might be if we were to relocate.

By working with reasonably short, fairly uniform stretches of highway linked together into a network, the actual road system may be simulated. If the time consumed by crew travel, their travel speed, and the travel distances are known, then an estimate of travel frequency can be made. In turn, these calculated travel frequencies can be used to estimate the total travel time needed by crews to come from a new location.

Terms

Throughout the discussion of the operating cost element, certain terms are used repeatedly. These terms are defined as follows:

Figure 1. Facilities siting model.

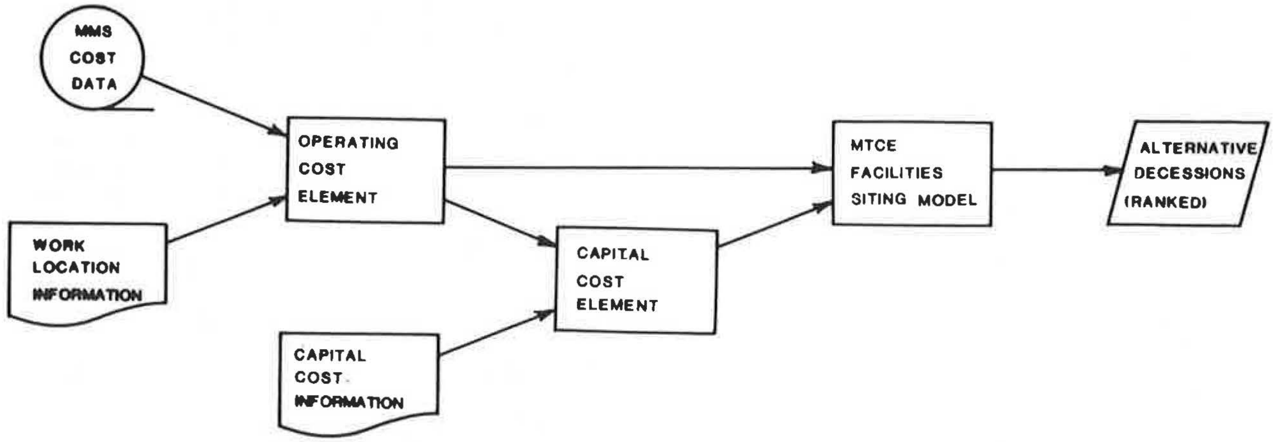
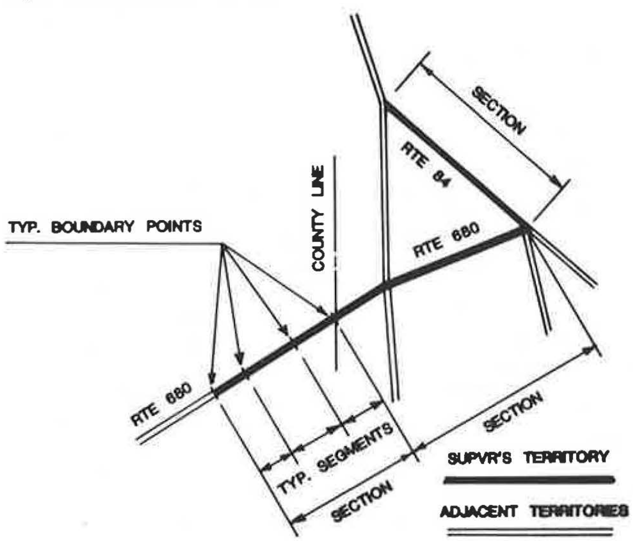


Figure 2. Network subdivisions.



1. Highway section: A highway section is the smallest cost-accounting unit within California's maintenance management systems (MMS).

2. Segment: A segment is an arbitrary but logical subdivision of a highway section and is characterized by its relatively high degree of uniformity of both the terrain and the required maintenance effort.

3. Boundary point: A boundary point is the end of any segment. Boundary points are identified by (a) a change in the character of the roadway terrain, (b) a change in the makeup of the roadway maintenance requirements, or (c) a maintenance station location.

Figure 2 illustrates these definitions.

Work Groups

Work groups are a convenient method of organizing similar work-related inputs in a meaningful manner. The structure and number of work groups may be varied to fit the different crew types. Some work group examples typical of a road maintenance crew are group 1, all of the flexible pavement maintenance activities except pothole repairs and similar labor intensive work; group 6, all snow- and ice-control activities; and group 9, hand repair of flexible pavements (the flexible pavement maintenance is excluded from group 1).

Weighting Factor

The weighting factor is a subjective measure of the maintenance effort expended within each segment of a highway section. Each work group is separately evaluated. Experienced local supervisors and managers estimate the relative effort per kilometer expended or expected to be expended in each segment relative to all other segments in a highway section. These estimates are used to allocate both the total maintenance effort and the travel effort between the segments of the section.

Work inputs are now being reported relative to post mile locations. (The customary term is retained throughout this paper.) As this post mile is accumulated over the coming years, these subjective weight factor estimates will be phased out and replaced by objectively derived data.

Maintenance Management System

The Caltrans MMS identifies and accumulates the work and support costs and assigns them to the highway section maintained by a single supervisor. It does not, however, subdivide the section. Commonly a supervisor's section will contain several different stretches of a road, each with its own maintenance needs. Each segment must be identified and a basis of work allocation established both by work type and quantity. Lacking recorded data between work and post mile, the section is subdivided and the work assigned in accordance with the supervisor or superintendent's judgment and knowledge. This is done in the field.

OPERATIONS ELEMENT

The operating cost element progresses through three distinct phases (exclusive of the field gathering of information). In phase 1 existing work and travel patterns are analyzed; in phase 2 the impacts of proposed changes on the systems elements are estimated; in phase 3 the network for each pattern of stations to be reviewed is reconstructed.

The output of this element becomes, in turn, the input for the facilities siting model. In addition, information about the total work load at each proposed location becomes input information for the capitalized cost element; that is, the derived data yield information about needed crew size. Crew size determination permits an accurate estimate of the facilities that will be required.

Three groups of input information are needed by the operating cost element. First, the station's location together with locations of alternatives are described, which establishes the critical relations between the station sites and the highway section. Second, information showing the subdivision of the section into segments and assigning work to the segments by type and quantity is given. The third input provided is the categorized work hours obtained from MMS records.

Phase 1: Analysis of Existing Work Patterns

The first phase of the element analyzes the established work patterns. In California, all maintenance costs are reported to the highway section (the portion of a state highway within the responsibility of a single supervisor) and must be allocated back to the segment level by subjective means. The person responsible for the day-to-day work planning reviews the highway and provides weighting factors for each type of work performed by the crew.

The work reported in MMS is allocated to the various segments in proportion to the weighting factors; travel support is allocated in proportion to both the weighting factor and the actual travel distance. The average travel speed for each work group is derived from the MMS recorded work hours and kilometers of travel. Travel frequencies are developed from the actual distances, time spent, and derived speed.

The analysis process provides five-year average values for production effort, travel support, and travel frequency for each segment. Travel frequencies are estimated in one-way trips.

Phase 2: Estimating Travel Time Impacts

By using the travel frequency estimates just developed for each segment together with the information describing each alternative location, the travel effort for a location of interest can be estimated. The combined travel and production estimates yield an estimate of the total maintenance effort required to support each segment of the highway from that location, whether it already exists or is being planned.

The travel and total effort estimates are also presented as five-year averages.

Phase 3: Network Simulation

The systemwide impacts of the various patterns of station location are tested by simulating highway operation by using sets of selected sites.

More complex networks are first simplified by deciding which station is responsible for each primary or backbone route. The maintenance responsibility for lateral routes is that assigned to the station found responsible for the primary route at the lateral's junction.

The cumulative production and travel-demand functions are graphically displayed by plotting the values for each successive segment. Separate plots are developed for each discrete set of station sites. The plots of cumulative total effort and travel effort suggest where service boundaries can be located. Under ideal conditions, the point of equal single-trip travel time and the points of equal travel and total effort would be the same spot. While we have yet to find that ideal highway, our experience to date has been that these three indicators will not differ widely. Taken together they establish the general location for the service boundary.

From a practical point of view, once the location has been established, the exact boundary will be determined by field consideration. We have found that most section boundaries are characterized by a well-defined landmark and a suitable place to turn the equipment around.

When the selection of service boundaries is completed for each station site under consideration, the maintenance force required at each station can be estimated. The station estimates of the maintenance effort in work hours per year are translated to dollar costs by applying appropriate hourly rates for labor and equipment. Likewise, staffing needs can be readily estimated from the estimates of annual work hours. The latter information is extremely helpful when establishing the type and size of facility needed to support the maintenance area.

MAINTENANCE STATION CAPITAL COST ELEMENT

Station- or plant-related costs are the subject of this element. Its objective is to present the cost data in a manner that will allow management to make trade-offs with the previously modeled operating costs. Consideration is also given to the facility's operating costs, even though these are not capital costs.

When the operating cost models were developed, discrete sets of station sites were examined, and costs were estimated for each of these patterns. In addition, estimates were made of the staffing and work load that would have to be supported from each site. For each condition examined in the operating cost model it is proper to develop a companion capital cost model.

The first, most critical step in developing the capital cost model is to write a schedule of the capital outlays required to implement each pattern. To do this one must estimate all of the cost factors expected to arise during the study period.

Each site being considered in the location study process requires a capital cost analysis. A few sites may require alternate studies that cover more than one possible development plan.

CAPITAL COST MODEL

In the capital cost model, all planned or anticipated expenditures over a 30-year study period are included, starting with the first expenditure. The time between the performance of the study and the beginning of the study period is treated as lead time. To properly evaluate each expenditure, an estimate of when each expense will occur is as critical to the analysis as the dollar cost itself.

The 30-year time span of the study was not chosen for its convenience. We have a significant number of stations that have been replaced or reconstructed. In reviewing the service lives of these stations, we found the median age to be 30.0 years (average 33.2 years, most common 27.0 years). The 30 years' expected life span is also used as a guide for estimating when existing buildings should be replaced.

One of the outputs of the operating cost model was a location-by-location estimate of the total maintenance effort needed to support the highway system. These estimates, when translated into work years, are used to select appropriately sized buildings and related improvements for each station.

The staffing estimates will indicate the basic building size needed at any given site. Once the building size has been estimated, it will be necessary to identify those supplemental facilities that will be required at each site—the number and size of storage bins, the absence or presence of storage areas, warehousing, and emulsion tanks—which are all determined by the character and quantity of the work to be supported by the facility.

To facilitate the trade-off analysis, the station-related costs need to be stated in terms compatible with the results of the operating cost analysis. The operating costs previously developed are expressed as annual expenditures. Therefore, the station costs are also annualized.

COST FACTORS

Five major categories of costs are treated in the capital cost element. At any given station, some of these costs may not be applicable. In some cases additional costs may be identified. Common and unusual costs are listed below.

Common Costs	Unusual Costs
Land	Employee housing
Value of existing facilities to proposed solution	Costs associated with personnel shifts
Investment in new facilities	Unique community costs
Value of any facilities replaced	
Remaining value of all land and improvements at end of study period	

Land Values

Land values include both the value of existing sites that will be used in the future and the costs of acquiring new sites. In developing the land costs, the costs of road improvements, utilities, and other undepreciable work such as land leveling or site clearing are included. The cost base for estimating land values is the expense of obtaining new sites or the estimated market value of existing sites that will be continued in service.

Existing Facilities Retained

The next major cost consideration is the value of any existing facilities that will be continued in service. This consideration concerns only the improvements on the land, not the value of the land, which has already been treated. There are three common methods of estimating the value of the facilities to be perpetuated: the fair market value, the alternate-use value, and the salvage value. Each of these methods of valuation should be reviewed and the appropriate method selected. The costs of upgrading, remodeling, or rearranging are not included in this category but are considered as new facilities investments.

New Facilities Investments

The investment required for new facilities is the most significant of the capital cost categories. Within this category are considered not only the costs of new improvements at new sites, but also the cost of additions, modifications, or extensions of existing facilities at existing sites. Planned future capital improvements are also included in this category.

Building costs are estimated by using standard industry techniques. Special features unique to maintenance stations are best estimated from historical costs of similar facilities or apparatus.

Costs that will not arise at the beginning of the study period but will have to be paid in succeeding years are estimated in base-year dollars. However, the year in which the improvement will be required must also be identified. The finished product of this schedule preparation should be a long-range capital improvement plan for the site that covers the entire 30-year study period. Because some of the capital outlays are deferred outlays that arise at some future time during the study, it is necessary to calculate the probable salvage value of each element of the site's master plan at the final year of the study.

Existing Facilities Replaced

When an existing facility will no longer be used as a maintenance station, the residual value of that station is considered in the analysis. This is normally treated as a credit or cash inflow. The credit to be taken for a facility to be replaced is the estimated market value of the improvements, the salvage value of the improvements, or the value represented by the improvements when they are converted to another use.

In some special cases, there may be no cash inflow. One case of this type would involve federal land occupied under withdrawal or special-use permit. This land cannot be sold. In some cases, the value may be negative if the improvements must be removed.

Residual Value of Investments

All the investments discussed up to this point will have a residual value at the end of the 30-year study period. Because plant investments lose value with age, their depreciated value must be estimated. These residual values are treated as credits or cash inflows occurring in the last year of the study period.

Maintenance stations are special-purpose developments and rarely can be sold, even when new, at a price equal to their cost. For this reason, Caltrans has avoided using straight-line depreciation as a method of estimating residual value. Depreciation methods that show more rapid loss of value in the earlier years of a station's life are considered more realistic.

Unusual Costs

In more remote areas of the state, housing frequently must be provided for the employees. These costs are generally similar to the stations' other costs but are handled separately. When presenting the results of the economic study, the costs of housing and any differences in housing costs between locations are pointed out.

The companion social-economic study, which goes along with the location study, may reveal cost impacts affecting either Caltrans employees or the communities in the study area. Significant impacts on the local tax base or school system, the costs of employee relocations, or any similar effects are considered in the study. If the personnel or community costs are one-time expenses related to the implementation of a proposed course of action, then these costs are estimated and capitalized. Costs of a continuing nature are combined with the annualized capital costs.

Station Maintenance and Upkeep

Station upkeep and operations are not capitalized costs, but, because of their relation to the maintenance stations rather than to the highways, they are included in the capital cost element. Costs included in this category are such items as utilities, repairs due to normal wear and tear, and custodial work.

The magnitude of these costs is estimated by past costs projected into the future or by regional norms. Regional norms have been established for each of the five geographical areas of the state as shown in Table 1. The operating and maintenance costs are added to the annualized capital costs.

ECONOMIC ELEMENT

When the master plan of capital development for a site has been completed, the net present worth of all investments and investment credits is calculated. This net present worth plus the net present worth of all future expenditures is then translated into an equivalent annualized capital cost so that it may be combined with other annual costs that have been developed.

Caltrans' current practice in the economic analysis is to use a discount rate of 10 percent, which was selected after consideration of a number of factors. The rate represents a compromise between the return that would be expected on a dollar invested in the highway system, a dollar of state highway funds invested in nonhighway improvements, the rate of return demanded by California public utilities, and current federal practice.

After capitalized cost estimates are developed for each station combination in the operating cost analysis, these annualized costs are combined with the estimated annual station operating and maintenance costs to develop the station's total specific cost. The station's specific costs are then in turn combined with the costs for other stations to develop the capital costs for the entire network. This process is repeated for each pattern of stations investigated in the operating cost analysis portion of the model.

The results of the capital cost model are now in a format that can be integrated with the results of the operating cost model to generate the total maintenance station location model.

MAINTENANCE FACILITIES SITING MODEL

In the previous elements a wealth of specific information relating to the costs of maintaining a state highway system and the capital requirements to support that maintenance effort have been developed. All of this information is now brought together to disclose how each alternate network arrangement will affect the total system.

California has chosen to preserve existing service locations and work assignments as its benchmark for the measurement of change. The cost base used is the total of the operating costs for the maintenance effort and the station-related costs. These costs represent the total variable costs associated with the system. The fixed costs of system support such as training, safety, and supervision are not developed because they are equal components of all solutions.

The potential solutions are placed into classes based on the number of service locations to be used. In this manner network configurations proposing the use of three service sites are separated from potential solutions proposing the use of two, or perhaps four, service locations.

Working in turn with each potential solution within a given class, the maintenance cost and station-related costs are tabulated and the change in cost from the benchmark is determined. The alternatives within the class may then be ranked by the effects of their total cost. This process is repeated for each class studied (see Table 2).

Unless the number of solutions is small, a doubled ranking system is very helpful in reaching a suggested solution. First, all the solutions in a single class are ranked by relative savings. Second, the most attractive solutions or alternatives are identified and ranked. The second ranking compares the preferred solutions of each class. This process highlights the most preferred or the most economical solution.

Up to this point any discussions of the noneconomic factors that always surround decisions of this type have been carefully avoided. These factors are treated in a separate socioeconomic report whose function is to carefully examine the superior alternatives. The report will examine, in considerable depth, the impacts each alternative will have on local communities and on the lives of the employees. Although the social effects of the decision are the subjects of a separate study, the economic study should be sensitive to the potential impacts of all solutions. If one of the solutions carries an obvious and severe social penalty, then the analysis should explore the economic aspects of that penalty. It should not make a social judgment but simply provide the information necessary for managment to make its decision.

THE DOYLE-BECKWOURTH CASE STUDY

By mid-1976 our limited model had advanced to the stage where field testing was indicated. The theory was apparently sound because we had used two very limited but real situations in its development. The long-delayed project to replace an obsolete station in the small community of Doyle offered us the opportunity we needed. The manager was approached and agreed to the trial.

The station at Doyle, a community of 175 people, was established in about 1945 by using buildings moved in from another location. The source and age of the main building are unknown, but its type of

Table 1. Regional norms for station costs.

Geographical Region	Operating and Maintenance Costs: Unit ($/year per square foot)	Operating and Maintenance Costs: Total ($/year)	Coefficient of Reliability (R)
Coastal	$591 \times (\text{area})^{0.723}$	$591 \times (\text{area})^{0.277}$	0.49
Valley[a]	$1678 \times (\text{area})^{0.864}$	$1678 \times (\text{area})^{0.136}$	0.80
	$846 \times (\text{area})^{0.664}$	$846 \times (\text{area})^{0.336}$	0.74
Foothills	$2096 \times (\text{area})^{0.900}$	$2096 \times (\text{area})^{0.100}$	0.79
Mountains	$85.78 \times (\text{area})^{0.472}$	$85.78 \times (\text{area})^{0.528}$	0.61
Desert	$67.27 \times (\text{area})^{0.456}$	$67.27 \times (\text{area})^{0.544}$	0.90

[a]The first line is crew costs, the second supervisor costs.

Table 2. Summary of changes in annual costs.

Alternative Number	Proposed Station: Pattern	Proposed Station: Location	Station Costs ($)	Highway Operating and Maintenance Costs ($)	Total Changes ($)	Intrapattern Ranking	Interpattern Ranking
0	Three stations	San Lucas, Soledad, and Priest Valley	Base	Base	Base	3	
1A		San Lucas, Soledad, and Priest Valley	-	-1 100	-1 100	2	
1B		San Lucas, Soledad, and Junction US-198 and US-25	-4 000	+1 000	-3 000	1	4
4A	Two stations	Kings City and Priest Valley	-42 900	+9 800	-33 100	3	
4B		Kings City and Junction US-198 and US-25	-46 900	+11 300	-35 600	2	2B
5B		Greenfield and Junction US-198 and US-25	-46 900	+11 200	-35 700	1	2A
3C	One station	San Lucas	-82 800	+28 700	-54 100	1	1
4C		Kings City	-89 300	+36 200	-53 100	2	
5C		Greenfield	-89 300	+45 400	-43 900	3	

construction would indicate that it was originally built in the late 1920s or early 1930s. It is obsolete.

The present Beckwourth station was built in 1932 and, although expanded in 1959, is also obsolete.

To keep both of these stations functional would require a capital expenditure of nearly $650 000 in the near future, which would continue the existence of both small crews. These four- and five-person crews were not really capable of economical production under current traffic and safety requirements. The need to take corrective action was identified as far back as 1972 when a budget request was first submitted.

The Location Study

With the cooperation of local and regional managers, a full-scale study of the Doyle-Beckwourth needs was undertaken in the second half of 1976.

The scope of this study was far broader than anything attempted during the earlier development stages. The study treated 178 centerline kilometers (110 miles) of state highways. Three maintenance crews became directly involved in the study, and the costs from seven separate highway sections divided into 31 separate segments had to be considered. During the course of the study a total of 10 solution strategies were investigated. Five of the strategies were

1. Reconstruction to preserve the status quo,
2. Relocation of the crews to a common plant,
3. Crew consolidation and relocation,
4. Joint use of a single yard with another state agency, and
5. Various boundary conditions coupled with other strategies listed above.

The preferred solution included the aspects of (a) joint facilities development with the Department of Water Resources, (b) crew consolidation, (c) boundary reassignment, and (d) relocation. Multiple considerations required very carefully prepared plans, but beyond that no special problems were encountered.

The solution recommended to management was combining the crews into a single, larger crew to construct joint operational facilities with the Department of Water Resources in Beckwourth and to sell both existing stations.

The economic implications of these decisions were that areawide travel costs would be increased by $11 000/year, that plant construction costs would be about $375 000 instead of the $650 000 needed to continue the existing pattern of stations, and that the combined operating and capital costs of the offered solution would be $14 000/year less than the combined costs of two stations and crews.

The local managers agreed to accept the offered solution, and early in 1977 the crews were combined and the necessary service area adjustments were made. Operations were temporarily set up in the existing plant at Beckwourth pending the construction of new facilities nearby.

Study Evaluation

After operation for a period of one year with the Beckwourth and Doyle crews combined into a single crew, the results were evaluated. The results were both surprising and gratifying.

During the trial period preliminary architectural plans were prepared, and project budget estimates were developed. The architect's estimate for the project was $380 000, within $5000 of the conceptual estimate. Some upward movement of the estimate is expected because of unusually high inflation and minor project additions.

The study had projected a rise of $11 000/year in the costs of providing highway services without any increase in the service level. The study had assumed little or no change in productivity. The first year's results showed that, although there was an increase in travel time, it was not as great as had been expected.

An unexpected finding was an extremely significant increase in productivity. The year's operating costs decreased by $20 000 despite the increase in travel costs. Local management's analysis attributes this decrease in costs to three factors: increased efficiency because of crew augmentation, modification of work methods made possible by a larger crew, and a reduction in the quantity of nonproductive effort.

Throughout the study area no reduction in service levels occurred, even though the total staff serving the area was reduced from 10 to 9 people by the elimination of one supervisor when crews were combined. In fact, winter snow- and ice-patrol activities have actually increased on more than 56 centerline kilometers (35 miles) of the system along US-395. Before the merger of the crews, patrols were provided 8 h/day, 5 days/week with night and weekend service provided on an on-call basis. With the larger service area, it became economical to provide patrol service 7 days/week, 20 h/day.

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Systematic Development of a Highway Maintenance Simulation Model

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The number of interactions involved in the operation of the common industrial or governmental organization of today makes effective management very difficult, especially when the system is constantly changing. One effective method of examining the various aspects of such a system is by means of simulation. This paper reports research required to perform the initial phase and several follow-up stages in the development of a highway maintenance simulation model. This model is expected to provide management personnel in a state highway maintenance program with the opportunity to consider realistic alternatives and to analyze results of various possible actions before physical changes or irrevocable policy decisions are made. The model uses information such as work activities, labor power, equipment, materials, work-crew alternatives, road network consideration, weather characteristics, and scheduling alternatives. The model should give administrative personnel a means of considering a wide variety of typical highway maintenance dilemmas. Situations that only experience and rule-of-thumb reasoning explained in the past can thus be examined through the eyes of statistical indicators.

The number of interactions required to operate an industrial or governmental organization complicates the job of effective management. This is especially true when the system at hand is constantly changing. Simulation provides an effective tool for considering the various aspects of such a system.

This paper deals primarily with the research needed in order to perform the initial and several follow-up stages in the development of a highway maintenance simulation model.

The simulation model being developed is expected to allow highway maintenance management personnel to consider realistic alternatives and to analyze the results of various possible actions before they make any physical changes or irrevocable policy decisions.

PREVIOUS WORK

In 1967 the office of research and development of the Bureau of Public Roads (BPR) sponsored a study on the application of systems analysis to highway maintenance. The study was conducted by the National Bureau of Standards in two phases. Phase 1 was essentially a broad examination of highway maintenance and the identification of problem areas where systems analysis techniques appeared to offer some promise. At the end of phase 1, it was recognized that, in order to realize the greatest benefit from the project, it would be necessary to channel the remaining study resources into a single problem area; the one selected was the development of a simulation model for highway maintenance.

The phase 2 effort (1), however, was not sufficient to develop a working simulation model to its full potential. The model was designed with extensive detail in certain areas and showed excellent potential in some ways, but the program had one significant shortcoming: The simulation model would not operate (run) to the extent that it was intended. The major error seems to have been including too much detail too soon, given the project's time restrictions.

A number of other studies have been conducted that deal with specific portions of the overall highway maintenance problem, such as weather conditions (2,3), road networks (4), job-scheduling techniques (5), maintenance station locations (6), and roadside mowing operations (7). However, none of these addresses the highway maintenance problem as a whole.

SCOPE AND LEVEL OF DETAIL

The purpose of the simulation model is to aid the users to better understand the response and behavior of the highway maintenance system under different conditions.

For example, suppose that highway maintenance management personnel are considering purchasing some maintenance equipment. Reports show that equipment types 5 and 7 are needed more than the other equipment types. The question then arises of whether management should allocate the money for purchasing equipment type 5 only, or equipment type 7 only, or a combination of both, and, if so, how many.

In such a situation the decision maker's goal is to purchase and use sufficient amounts of each equipment type that the total contribution to the system's performance will be as large as possible. In reality, there is only one sure way to know exactly what contribution the addition of three pieces of equipment type 5 will have on the overall maintenance system. That way is to buy them and observe how the system functions with these additional equipment units over a period of time. But the result may be negative or the improvement slight, which indicates that another course of action might have been better. Simulation allows the user to