

A FRAMEWORK FOR A MAINTENANCE MANAGEMENT
SYSTEM FOR MASSACHUSETTS

by

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ABSTRACT

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Highway maintenance represents a major portion of the expenditure for transportation. The old methods for managing this costly function are no longer adequate. It is necessary that all of the appropriate management tools and techniques, developed by private industry, be adopted for use in highway maintenance.

The purpose of this study is the development of the framework of a maintenance management system which would be appropriate for Massachusetts.

The approach used was to study maintenance management systems already implemented in 17 states, while making first-hand investigations of five of them. Based upon that research, a composite model is presented which represents the current "state of the art." Massachusetts' present approach is described, and implicit weaknesses of that approach discussed.

A system framework was devised, based upon the literature and the research into existing management systems. This framework includes the following basic elements: highway features inventory; maintenance standards; performance budget; scheduling, reporting, control, and evaluation procedures. These elements, when incorporated into a formal system, should provide Massachusetts with the tools necessary in order to properly address the two important questions relative to maintenance of existing facilities: (1) How much maintenance should be done? (2) How can that maintenance be done efficiently?

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

No longer is maintenance playing a supporting role to construction in the overall highway transportation picture. Maintenance is requiring an increasingly larger share of the total transportation budget and has an important effect on the operation and service life of a facility.

Highway administrators are now keenly aware of the fact that more objective methods for selecting maintenance policies are needed in order to protect the investment that the systems represent and to fulfill the general objectives of the maintenance functions. At the same time, they are conscious of the need for adapting management techniques to the maintenance operations in order to increase overall efficiency thus reducing costs.

1.1.1 Historical Setting

The program for highway maintenance in most states has more or less just grown, without much formal planning or analysis. The maintenance of the earliest roads was largely the responsibility of the individual property owners abutting the roadway. As highway travel increased more maintenance

work was required. The abutters then logically asked the local unit of government, usually the township, to hire men to do the maintenance work, and the land owners paid taxes to cover costs. (1)

The advent of the motor vehicle marked the beginning of rapidly increasing demands for highway facilities and services. Around the turn of the century states began to feel the need for state financial aid in the highway program. The first state-aid law was enacted by New Jersey in 1881, and by 1900 six other states had implemented similar legislation. By 1917 every state was participating in the highway program in some way. By this time most states had established some sort of highway agency and had charged that agency with the responsibility for the construction and maintenance of the principal state routes. (2)

Every level of government, including the federal government, has participated in providing the United States with the most extensive highway system in the world. Total road and street mileage in the United States from the years 1904 to 1965 increased from 2,351,000 miles to 3,690,000 miles, but during that same period the total surfaced miles of roads and streets increased from 204,000 miles to 2,776,000 miles.

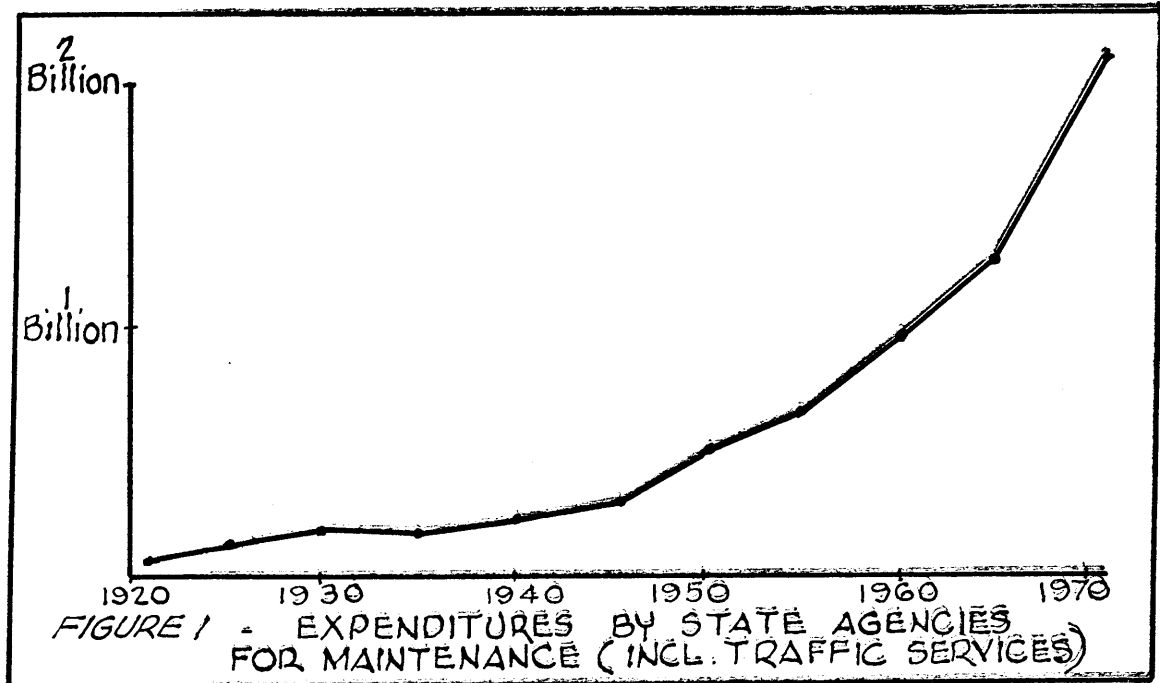
In 1971, total surfaced mileage was 2,983,072 and unsurfaced mileage was 775,870. Total travel in 1963 amounted to 252.2 billion vehicle miles. In 1971 total travel had risen to over 1,186 billion vehicle miles.

Working in combination with the above trends to increase demands for additional efforts in highway maintenance was the trend apparent in vehicle speed. Average passenger car speed in the United States on main rural highways had steadily increased from a war time low in 1941 of 37 miles per hour to an average of 62 miles per hour in 1971. During the same period the percentage of cars travelling at speeds exceeding 50 miles per hour had increased steadily from 6% to 89%. (3,4)

1.1.2 Present Needs

In the 1971 total maintenance and traffic services expenditures for all units of government amounted to over \$5.1 billion, of which \$2.14 billion was expended by state agencies. This might be compared with the total capital outlay expenditures for highways by state agencies in 1971 of \$9.9 billion. (4)

In the light of this brief presentation of statistical evidence, it is apparent that the existing demands placed on highway maintenance organizations necessitate that those



organizations be administered and operate efficiently and the maintenance policies be established with full economic consideration given to all reasonable alternatives, if the best interest of the taxpayer is to be serviced. The highway maintenance objective could be summarized as being to provide the most economical method for preserving the capital investments made in the highway facilities, and to assist in approving safe, convenient and economical highway transportation, with appropriate consideration being given to development of aesthetic features.

The old methods of carrying out the maintenance requirements are no longer good enough. The states were faced with

that realization over the last ten to fifteen years. Now, in order to meet current objectives, new approaches must be adopted for establishing policies; setting priorities; budgeting; planning and scheduling work; and controlling and monitoring work. All of these functions fall in the general category of maintenance management. Much has been done in these areas, especially at the state highway department level, and much more is yet to be done.

The Highway Research Board's Maintenance Management Workshop of 1968 listed the following management problems besetting most highway maintenance organizations:

- a. inadequate factual data concerning field activities
- b. nonuniform standards or lack of standards.
- c. ineffective procedures for planning and scheduling work
- d. widely varying quality, productivity and unit costs for field activities
- e. ineffectual means of comparing actual and desired quality, service level and unit cost for maintenance activities
- f. lack of a reliable means to forecast long-range maintenance requirements
- g. lack of a means to evaluate alternative policies
- h. shortage of trained personnel (5)

1.1.3 Maintenance Research Trends

Until the fifties, the traditional approach to maintenance management was adequate for several reasons. Increased revenues for highway purposes kept pace with the increased demands. Highway departments were able to meet increased maintenance demands by increases in staff and improved technology. Most maintenance organizations were satisfied with the status of their management and so they felt no need to develop more sophisticated procedures. During that period, maintenance management research was of little consequence, limited in scope and uncoordinated. Most studies were carried out informally, making it difficult to document their existence.

Organized, formal maintenance management research began in 1950. The purpose of the early research was "to obtain basic data on maintenance operations with particular emphasis on time utilization and production rates of labor and equipment. Such data are one portion of the total body of needed factual information that has not hitherto been available from any other source." (6)

Over the next eight years about 20 small-scale studies were conducted on the field operations of state maintenance

organizations. Results were not extensive enough to fully delineate management problems. In the early sixties the scope of research expanded to examine time utilization, productivity, methods and management. Later in the sixties studies were aimed at procedures for estimating costs. (5,7)

In 1965, the Virginia Maintenance Study was undertaken for the purpose of developing "better ways to manage the function." The Virginia Study signalled the beginning of the current era in which 33 states either have or are in the process of developing their own maintenance management systems. (8,9,10)

1.1.4 Fundamental Questions for Maintenance

Ultimately, three fundamental questions must be answered if maintenance is to play its proper role in providing the most useful highway system for the cost:

1. WHAT IS THE BEST BALANCE BETWEEN INITIAL SYSTEM COST AND FUTURE MAINTENANCE COST?
2. HOW MUCH MAINTENANCE SHOULD BE DONE ON THE EXISTING SYSTEM?
3. HOW CAN MAINTENANCE OPERATIONS BE ACCOMPLISHED MOST EFFICIENTLY? (11)

Many studies have limited their attention largely to the third question. Often there has been an implicit

assumption that there is a given quantity of maintenance work to be done each year.

Question #1 must be considered during the highway design phase. Questions #2 and #3 are discussed in Chapter #4.

1.2 OBJECTIVE AND SCOPE

The objective of this thesis is to develop a framework for a maintenance management system which would be appropriate for application in the Massachusetts Department of Public Works. Such a system should provide Massachusetts with the ability to explicitly address the policy question of how much maintenance should be done and the administrative question of how that maintenance can be accomplished most efficiently.

This study, in Chapter #2, looks at what has been developed and implemented in 17 state highway agencies in the area of maintenance management. A summary of existing inadequacies in those systems is presented.

Chapter #3 describes how Massachusetts now manages its highway maintenance, citing some of the weaknesses associated with that approach.

Chapter #4 considers the two basic questions which must be answered relative to existing highway systems: how much maintenance should be done, and how can it be done most efficiently? With these questions in mind, the framework for a maintenance management system for Massachusetts is presented.

CHAPTER 2

THE MAINTENANCE MANAGEMENT SYSTEM APPROACH

Most state highway departments have perceived the maintenance management system as the solution to the problem of providing adequate highway maintenance for an expanding highway system, faced with a limited budget and rising costs. A maintenance management system is a formal procedure which is used to plan, organize, direct, control, and evaluate maintenance programs and administration.

The purpose of this chapter is to present a composite model system which will reflect what is currently being done by the state highway departments in the United States which have implemented their own systems.

2.1 A COMPOSITE MAINTENANCE MANAGEMENT SYSTEM

There exists no universal system which would be appropriate for adoption by all states, therefore, each state has designed and implemented their own system, often with consultant assistance. Individual state systems may possess from only a few to almost all of the system features described below.

The following are the basic elements which comprise complete maintenance management systems:

- (1) Highway Features Inventory
- (2) Maintenance Standards
- (3) Performance Budget
- (4) Scheduling Procedures
- (5) Reporting Procedures
- (6) Control Procedures
- (7) Evaluation Procedures

All of the above elements, as they presently exist in several state highway agencies, will be discussed below.

2.1.1 Highway Features Inventory

Most systems include an inventory of the highway elements being maintained. State systems vary greatly as to thoroughness of their initial data collection efforts and the attention given to periodic updating of the inventory data. There are systems which, in the beginning, developed thorough inventories but never explicitly provided for their use in their system designs. As a result, those inventories are not used in the planning and budgeting phase except as guides to field supervisors in their determination of their annual work loads.

Most systems summarize the inventoried elements as to various road classifications and maintenance districts. The

following is a list of the typical elements included in the inventories:

Pavements (type; number of lanes; width)
Shoulders (type; width)
Slopes (how maintained: mowing; spraying; grading)
Medians (type; width)
Slope Protection (retaining wall; rip-rap; cribbing; etc.)
Interchange (type; ramp length)
Pavement Markings
Mowable Areas
Fencing (type)
Ditches (width; depth; type)
Guardrail (type)
Guide Posts
Bridge Structures (full description)
Culverts (size; type)
Drainage Structures (type)
Curbs and Gutters (type)
Signs (type)
Rest Areas (type; description)

Certain other elements found in some inventories are: litter barrels; impact attenuation devices; snow fences; light poles; electrical devices.

The following six paragraphs are one state's description of how they approached the task of gathering their inventory data. The task was to assemble a record of the quantities of maintainable elements of each highway by route and locations. Portions of data were gathered in headquarters but the major effort was in each individual district and carried out in the field by inventory teams. The inventory teams were composed of three members: a driver, an observer and a recorder.

Two members of the inventory team were assigned to serve for the complete inventory of a district, while the third member was the foreman of the highway section being inventoried. The assignments of driver, observer and recorder were rotated between team members in order to reduce fatigue while performing tasks.

Prior to beginning the field surveys each inventory team was given instructions at a training session at which a manual of inventory instructions was issued. The methods adopted for performing the field survey provided assurance that reasonable statewide uniformity would exist in the

resulting inventory data file.

Extreme precision was not required in determining dimensions for the inventory. It was believed that an inventory team could proceed between 5 and 10 miles per hour in recording data, stopping only when required to obtain information that cannot be seen or measured from the car, such as widths of drainage channels. The cars were equipped with odometers reading to a hundredth of a mile. Experience of the team quickly determined the most appropriate measuring method. For distances that could not be measured by odometers, such as drainage channels, distance was measured by pacing.

Practical considerations concerning the ultimate use of the data and the labor costs involved in collecting it led to the establishment of very modest precision requirements for most highway elements.

In addition to the physical quantities included by route and location, significant data about climate; terrain; contiguous land use (i.e. urban, rural); traffic volumes; road age; and other characteristics that could have an effect on maintenance requirements were listed in the inventory file. This latter part of the inventory was compiled in the headquarters office. (15b)

In Pennsylvania, the state with the greatest number of lane miles of maintenance responsibility (94,790 lane miles), a statistical approach to gathering their inventory data was used. The roads were each assigned a functional use category and complete inventories of element quantities existing for each category of road was performed in two districts. Using these data, regression analysis was performed in order to determine the sample size necessary in order to achieve a confidence level of 95% in the remaining districts. This approach enabled the highway department to reduce the cost of performing their highway features inventory by approximately 75% while achieving the levels of accuracy and thoroughness desired by them. (14)

2.1.2 Maintenance Standards

Maintenance standards are formally established criteria for establishing the need for work, required quality of work, resources necessary to achieve that quality, procedures to be followed to achieve that quality, and expected productivity rates. The purpose of this section is to describe the most prevalent way in which the states define and apply maintenance standards. Maintenance standards which differ from the popular approach will be described only if they are

considered of particular value to the ultimate objective of this study which is the development of a maintenance management approach for Massachusetts.

Consistent with the majority of state systems and the definitions adopted in 1971 by the Highway Research Board (30), three types of maintenance standards can be identified: quality, quantity and performance standards. Not all states use these categorizations but, because of their widespread use, they are considered appropriate for purposes of this discussion.

Maintenance standards are developed for each of several maintenance activities. The activities are identified during the system design phase and are intended to cover that maintenance work which accounts for at least 95% of the maintenance expenditure. Most states have identified from forty to eighty activities, however, some have over 100 while one state lists approximately 500 activities. An example of some typical activities is listed in Appendix 1.

2.1.2.1 Quality Standards

The purpose of quality standards is to define the thresholds at which certain maintenance activities should be carried out. They define an optimization of output taking into account the general aims of the maintenance policy defined.

They help to determine when to take action and may specify what type of action should be taken. Many states during the system design phase have developed department policy statements which formally define the maintenance objectives.

It is in the area of quality standards that one of the greatest weaknesses is found in the existing systems. Most of the more recently developed systems have seen fit not to develop quality standards as part of their systems. The resulting foregone opportunities for more analytic determination of needs and establishing of priorities will be discussed in greater detail in Chapter 4. Avoidance of quality standards, which formally establish a minimum level above which certain highway features should be maintained, may partially result from a fear of possible legal implications. In the case of an accident which occurs as a result of a substandard condition, liability may ensue where it previously did not exist before a quality standard was adopted. However, there is no body of precedents to confirm this fear. (31)

Ohio, which has not developed a maintenance management system, has employed consultant services in producing extensive studies into maintenance quality levels (32). Apparently Ohio considers the accurate, objective measurement

of maintenance quality levels to be the most important management tool available to the highway maintenance organization.

A review of the literature on this subject would indicate that not more than five or six states have explicitly included quality standards in their systems in such a way that they are adaptable to future developments of state, federal and international research efforts relative to quality levels. The following is a presentation of one of the more definitive approaches to quality standards, as seen in Pennsylvania's system literature:

The quality standards define the way a highway including all of its elements should appear if (1) it is to be preserved and kept up in as nearly as practicable its original as constructed or its subsequently improved condition; and (2) it is to provide safe, convenient and economical highway transportation. Quality standards define the desired level of service to be provided by the maintenance effort. These standards are meant to provide guidance to a supervisor and to establish a consistent level of service throughout the state.

The level of service is a measure of how well the highway, including all of its elements, meets the needs of the user. In this context, a highway meets the needs of the user when the established quality standards are met.

The level of service to be provided on the State Highway System, shall be determined by the Department with the objective of providing "obstruction free" travel in accordance with the State Highway Law. Levels of service are established as the basis of the following factors:

- . Safety
- . Preservation of the highway facility
- . Public Comfort and Convenience
- . Aesthetics

In addition, the level of service to be provided may vary depending on the character of service it is intended to provide.

Continuing with Pennsylvania's treatment of quality standards:

Quality Standards Subcommittees composed of Central Office, Engineering District and Maintenance District personnel are established to formulate, quantify and document the Quality Standards. In fulfilling this function it will be essential

that each standard establish a level of service which provides safe, convenient and economical highway transportation.

After management approval the Quality Standards will be issued for departmental use. Thereafter, standards will be reviewed and revised as necessary.

The Quality Standards are published solely for the information and guidance of the employees of the (department).
.....(14b).

Evidently the last statement was added in order to eliminate the possible legal implications previously pointed out. Examples of the quality standards which resulted from the above approach were not available at the time of this research.

The following excerpts indicate California's approach to the subject of quality standards:

Maintenance Levels The level of effort required for maintenance activities has been defined. An example of the quality standard for joint separation ...is:

Joint Separation Joint separation in PCC (Portland Cement Concrete) pavement allows water to reach underlying structural layers. This often results in a rocking slab with subsequent pumping of underlying materials through the joint and ultimate

slab failure.

Joint separation between PCC pavement and adjacent AC (Asphalt Concrete) shoulders is detrimental as it allows surface runoff to penetrate the structural section and often causes shoulder failure. In addition it provides space for growth of objectionable vegetation.

Joints in PCC pavement should be sealed upon visual evidence of pumping.

When shoulder joint separation between PCC pavement and AC shoulders exceeds $\frac{1}{4}$ inch, the joint should be filled (26f).

Contained in California's standard for hand patching of pavement is the following:

Desired Maintenance Level: Patch when wheel depressions exceed 1"; drip tracks or the vertical differential in any direction is greater than $\frac{1}{2}$ " on the T/W (travelled way); the vertical differential between the T/W and surfaced shoulder is greater than $\frac{3}{4}$ "; and when surface failure is visually evident and is not correctable by sealing and does not require base repair. (26 f)

Part of the rationale which influenced the above can be traced in the following:

Levels of maintenance provide a definite criteria for maintenance work and resultant maintenance dollar expenditure. We define and describe them ... as follows:

(1) Quality standards or levels of maintenance define the way a road and its appurtenances should look, serve, and be preserved as a result of the maintenance effort.

(2) The maintenance level is affected by many variables such as climatic conditions, traffic density, terrain, pavement types, geographical location, and the age of the facility. In addition, the maintenance level or quality is also influenced by the type or class of road: freeway, expressway or conventional; its surrounding environment, characteristic, and density of traffic.

(3) Levels of maintenance take many forms. They may be a written description or a numerical value. A level may be set by the frequency of a maintenance effort or a predetermined number of inspections in a specified time. A level may be the replacement of the missing, the repair of the damaged, or the elimination of the undesirable.

(4) It is recognized that any defined level or quality of maintenance must be tempered by the judgment and experience of those responsible for maintaining the state highway system.

It is imperative that these factors be considered, commensurate with the function of the facility maintained. (33)

From the literature it may be inferred that California is one of possibly three states which appreciate the full potential which explicit treatment of quality standards provides a system. They see quality levels as the one basic management tool which can be manipulated in order to operate within budget constraints. The inventory of maintainable features is fixed at any point in time. The resources necessary to achieve selected quality levels should always be minimized through the other management tools to be discussed below. Realizing the need to manipulate quality standards, California has established guidelines stating that, when considering reductions in service levels necessary to meet budget reductions, appearance can be sacrificed first, investment in the facility second, and safety can not be sacrificed. To further analyze the effects of reducing quality levels the department prepared an impact tableau which displayed the probable impacts which would result in areas where 10% reduction in cost could be realized due to reduced quality levels, Table I shows examples of some of the results of early analyses. (33)

TABLE I
TEN PERCENT REDUCTION - WORKLOAD PRIORITY LISTING

MAINTENANCE PROGRAM	ACTIVITY	REDUCTION 1970-1971	IMPACT
04 - roadway litter	Reduce street sweeping and pickup.	122 Man Years \$1,600,000	Adverse public reaction to environment pollution, possible potential liability from decreased street sweeping, and increased frequency of plugged drainage facilities.
05 - vegetation control	Reduce mechanical vegetation control	95 Man Years \$1,450,000	Criticism from general public, local agencies, and adjoining property owners. Increased fire hazard and loss in progress of certain grass and other undesirable weed-control program.

Continued

TABLE 1 (continued)

MAINTENANCE PROGRAM	ACTIVITY	REDUCTION 1970-1971	IMPACT
03 - roadside	Reduce inspection and cleaning frequency of culverts and drainage ditches. Reduce frequency of removal of stuff from roadsides and benches.	90 Man Years \$1,310,000	Increased frequency of flooding with resultant damage to highway and traffic delay. Increased potential for traffic accidents and liability for damage.
01 - flexible roadbed	Reduce pavement and shoulder repairs.	39 Man Years \$540,000	Accelerated surface deterioration and base failure with resultant rough ride and added reconstruction costs.

Although these estimations of impacts are not quantified and are subjective in nature, the framework exists through which objective approaches to these analyses may be included when the necessary data are developed within the system.

Although the individual state systems which have been developed to date do not reflect a general awareness of the importance of quality standards, such an awareness certainly does exist. In October, 1974, the Transportation Research Board Task Forces A3T52 Advisory Committee met in Colorado to study maintenance research needs. That committee has been charged with establishing 5-year maintenance research needs. Presented at that meeting was a summary discussion of two previous meetings held in Homewood, Illinois and Atlant , Georgia. The following is quoted from that summary:

It was felt that research may be needed to determine priorities for maintenance on a cost-benefit basis and to consider expenditures to correct one defect in competition with another. These efforts must be coupled with parallel efforts to develop objective maintenance quality standards. When models have become available an optimum strategy for allocating funds can be developed and expenditures on many alternative maintenance operations will be compared.

This long term program offers high potential savings but it should be coupled with short term studies that can produce useful results in a shorter time period. (34)

Another paper was presented at this workshop by G. L. Ray, of the Louisiana Department of Highways, a state which does have quality standards included as an important part of their system. The paper discusses the need for designing quality of service in the system standards; some techniques for establishing quality levels; the need to establish quality standards in terms of physical measurements rather than judgmental criteria for as many maintenance activities as possible. (35)

2.1.2.2 Quantity Standards

Quantity standards, sometimes called frequency standards or workload rates, are meant to reflect annual resource requirements for each of the established maintenance activities in order to attain the desired level of service. Even in systems which have not explicitly defined quality standards, the quantity standards reflect the resource requirements necessary to maintain the highway at or above implicitly assumed minimum quality levels. The quantity standards do not express the maintenance needs of the highways at a given moment. They represent annual averages usually for particular

categories of roads, different road conditions, pavement age, geographic location, etc.

Quantity standards are established in three different ways, or in combinations thereof:

(1) Extrapolation of historical data relative to resource requirements for certain activities.

(2) Engineer's judgment.

(3) Direct quantifications of quality standards. (36)

An example of the third method would be in the case of an established quality standard for mowing which specifies that vegetation will be mowed to a height of 5 inches when the overall growth reaches 12 inches in height. It is possible, using average values for rate of growth of this vegetation in a given geographical area, to determine a quantity standard specifying 3 mowings per mowable swath mile per year. This translation of quality standards into resource requirements is a necessary step in the budgeting process and for the planning and scheduling of the work. Only certain activities are adaptable to this approach with the majority being established based upon experience and judgment.

The important point is (in a system having quality standards) that the quantity standards be realistic. Optimality

is sought through the quality standards. Many systems which do not have explicit quality standards use the quantity standards as a means of manipulating service levels. The supervisor determines in his annual visual inspection whether the resulting quality level for each activity is too low or too high. If for example, for a certain activity the quality level is too low then the quantity standard for that activity is increased. This method of adjusting service levels through the quantity standards is purely subjective and judgmental. Actually, it does not differ greatly from the method used prior to implementation of a maintenance management system, although it does have the advantage of directing attention to the question of actual quality levels. Some typical examples of quantity standards are shown in Appendix 2.

2.1.2.3 Performance Standards

A performance standard is a formally established criteria for a specific activity which (a) outlines the work involved; (b) describes work methods and composition of efficient crews; and (c) lists the expected accomplishment or productivity rate. This is the standard which is established for the purpose of controlling, directing and monitoring the operational end of the maintenance effort. It is through performance standards

that guidance is offered to the lower management levels for attaining an acceptable level of efficiency. It is not the goal of performance standards to define an optimum level of accomplishment. Rather the performance standard should reflect an expected level.

All states have included performance standards in their systems. Some have placed the major emphasis upon this one aspect of the system. In Chapter 1, it is pointed out that all early research efforts were directed toward establishing uniform and efficient performance of maintenance activities. The result is that this is the area in which there was the most widespread awareness of inadequacy. Also, since this is the standard which has received the greatest attention, the performance standards of all systems reviewed have been the most uniformly well refined component of any system.

Since there was very little information available at the time, many of the early systems utilized time-motion studies in order to develop performance standards. These studies, using industrial engineering techniques, were necessary but costly. Most of the more recent systems have been able to develop performance standards based upon previous studies coupled with the engineer's judgment and experience.

This is certainly an acceptable approach, provided those states follow the dictates of their own manuals, which say that the performance standards will be reviewed and updated at least annually.

The major variation between approaches to performance standards has been in the level of detail in which the standard describes how an activity should be carried out. There is a wide variation in levels of detail in different systems and examples of both extremes are shown in Appendix 3 .

Performance standards provide the following information for each maintenance activity:

- (a) the most appropriate crew size
- (b) the type and amount of equipment best suited for the work.
- (c) The amount and description of materials needed per production unit (e.g., ton of mix; sq. yds. of surface treatment; etc.).
- (d) a description of the methods and procedures to be followed in carrying out an activity. (It is in this part of the standard that wide variations in level of detail are found in various state systems.)

(e) a realistic estimate of the average daily production in terms of man-hours per unit of production. This figure is also displayed in terms of expected production units per crew hour. Often, expected daily production is also specified. (21a).

All systems emphasize the need for both annual and continuing review of performance standards. Changes become necessary due to improved technology or changed safety requirements. Given the control and monitoring capabilities which the reporting system gives to management, it is possible to perceive inadequacies in the standards. Possible improvements are tried and then may be evaluated against the existing performance standard.

Although performance standards are similar in structure and content in all state systems, an important refinement has been included in at least one set of performance standards. (14) One state has removed what they call "support activities" from inclusion in the performance standards. Four categories of support activities are defined: (1) travel time to and from the work site: (2) haul time spent performing the function of transferring materials from one point to another, disposing of load and

return trip to source of supply, except when specifically stated to be part of the performance standard; (3) safety work related to traffic control and warning devices, flagmen or sign truck with operator; and (4) other support activities, which would include all other types of delays amounting to over 30 crew minutes. This refinement does create additional reporting requirements but it provides the system with increased capability of assessing work methods and crew performance. Discussion of the advantages of this approach will be taken up further in Chapter 4.

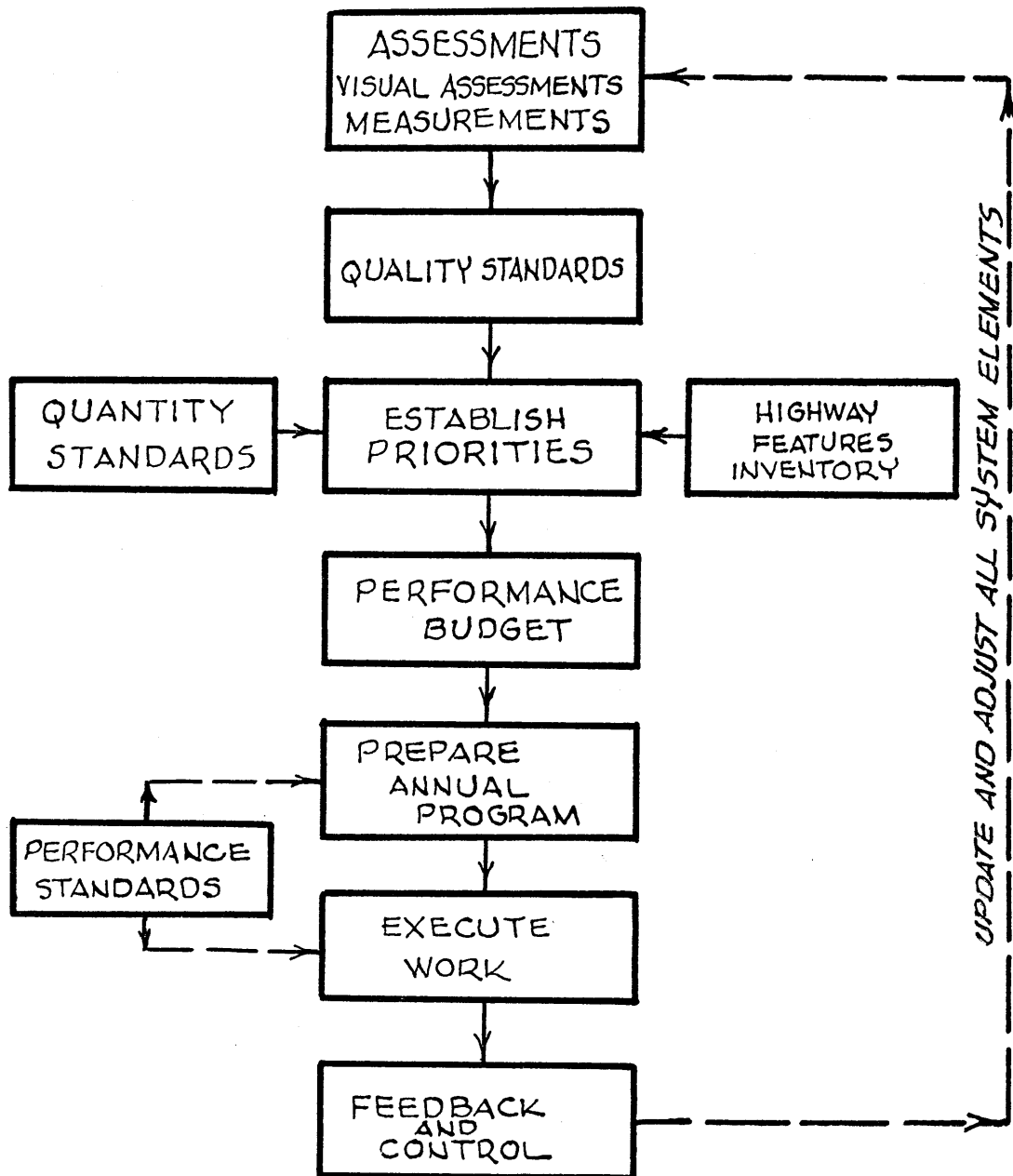
2.1.3 System Operation

A simplified diagram which shows schematically how a typical maintenance management system operates is shown in Figure 2. The system provides the context within which the highway department can efficiently carry out three categories of responsibility: (a) determine the maintenance program; (b) budget resources in order to meet that program; and (c) administer the accomplishment of the selected program by planning, control and assessment of the component activities.

2.1.3.1. Determining Priorities

It is in the methods used for determination of

FIGURE 2
 MAINTENANCE MANAGEMENT SYSTEMS
 FLOW CHART



priorities that the greatest need for research and sophistication presently exists. Before the quality standards may be applied in order to select a program, existing highway conditions must be assessed. The states continue to use the same methods for assessing sub-standard conditions which they used prior to system development. The periodic (annual or semi-annual) visual inspections are made at the supervisor or foreman level. It is based on the foremen's judgment, with varying degrees of guidance provided by the quality standards, that priorities are established.

One system has attempted to minimize the variations in this subjective assessment by including photographs of desired and unacceptable conditions for the more costly activities in the foreman's maintenance manual. (38) Another method used in an attempt to standardize the results of visual assessments is through continuing training programs which are provided for in most systems. The greatest refinement of the visual assessment method was found in Ohio's evaluation system. (32,35). Specially trained crews were formed and given the full-time task of

assessing the road features quality levels. This method is more costly than using the lower levels of management to perform the assessments but it has several advantages. The biases inherent in assessing one's own work are removed. Although this method is still judgmental, variations in the results are minimized, therefore it is possible to make meaningful decisions based upon the results. This method should result in the most consistent, statewide quality levels.

2.1.3.2 Budgeting

The budgeting process is a management tool basic to all maintenance management systems. With few exceptions, it is the performance budget which is used.

A certain amount of confusion of terms exists in that, although performance budgeting is merely one element in a maintenance management system, the term is sometimes used to mean the total system. (4) Performance budgeting is a budget development procedure which converts programs into resource requirements through the application of established maintenance standards. Those resource requirements are then converted to monetary requirements through the application of the appropriate cost data. The calculations are normally carried out in data processing using computer programs

developed during the design phase of the system.

The most definitive work to date relative to performance budgeting was sponsored by the National Cooperative Highway Research Program with the research results published in the Report Number 131, dated 1972. In that report the following distinction is made between performance budgeting and the PPBS:

The Planning - Programming - Budgeting - System (PPBS) recently has been advanced as a revolutionary method for making allocative expenditure decisions within the governmental sphere. Although performance budgeting possesses some of the features of PPBS, and can serve as one of the elements of PPBS, there are significant differences that should be understood.

Characteristics common to both systems are the establishment of program objectives in the form of work programs defining specific accomplishment to be performed according to standards of performance. Resource requirements for programs also are identified.

Perhaps the most significant differentiating factor is the element of measuring cost effectiveness. The capability of preparing and evaluating cost-benefit analyses of alternative programs or alternatives within a program is essential to

PPBS. Experience thus far has shown development of this capacity - in ways realistic, practical, and iniversally acceptable - to be extremely difficult.

Performance budgeting for maintenance, as discussed in this report, avoids confronting the issue of cost effectiveness by stopping one step short of the goals of PPBS. Instead of proposing sophisticated cost-benefit determinations of alternative maintenance operations within the program, the model system will provide detailed comprehensive cost data and permit highway administrators to make judgments as to the most effective allocation of resources. These judgments may be guided by additional specific research and evaluation but the model system makes no attempt to define such steps at this time.

In most instances where PPBS has been used or considered, it has been related to alternative programs within a private industry, a governmental unit, or a governmental agency. In the proposed model system, the scope is limited not only to a single agency but also to a single function within that agency. (42)

All, except two of the least sophisticated maintenance management systems, use performance budgeting in order to

determine resource requirements. Several systems use the performance budget only within the maintenance division. After resource requirements for the proposed program have been determined through the system and summarized in the performance budget, an additional step is taken in order to translate the performance budget, to conform with the existing state agency budget request format. This is a reasonable requirement considering that the maintenance budget request is merely one portion of the highway department's budget request, and legislative and executive review and approval is necessary for all of the many state departments and agencies. A different format being used for the submission of approximately one percent of the total state budget request would be confusing.

After the performance budget is converted into the format required by fiscal management, it is still the performance budget which is used by the maintenance division for scheduling; fiscal control; justification, in terms of quality levels and required workload, of any part of the submitted request; and adjustment of the annual program when approved appropriations differ from the budget requests.

2.1.3.3 Operational Management

This section deals with the operational end of the maintenance management systems. The goal is to efficiently organize, direct, control and evaluate the performance of the maintenance program as approved in the budget. The first step in achieving this goal is effective scheduling.

2.1.3.3.1 Scheduling

In all systems, the principal guide used in scheduling is the annual work plan developed during the planning phase and adjusted to conform to budget approval. Using the adjusted annual work plan the first step is to develop the annual work schedule. This schedule is relatively rough but consideration is given to seasonal constraints. All activities cannot be carried out during all periods of the year. Several states use a computer program in order to accomplish this workload levelling, thus reducing fluctuations in labor and resource requirements. Another method used as an approach to workload levelling is the issuance of a seasonal schedule for maintenance activities to all levels of management responsible for scheduling. The seasonal schedule is a guideline providing the framework within which managers develop various sub-annual schedules. The schedule lists graphically the

months during which each of the defined activities are normally performed. Some systems distinguish between periods of expected performance and periods of possible performance. Times when certain activities are not normally scheduled are also depicted. The sub-annual scheduling, for which these scheduling guides and the annual schedules serve as a framework, varies from system to system as to frequency. Various combinations of quarterly, monthly, biweekly, weekly, and daily schedules are used. A typical system uses the following breakdown of the annual schedule: quarterly schedule made up by district supervisors and district maintenance engineers; bi-weekly schedule devised at bi-weekly meetings of district level supervisors and area supervisors and crew foremen; daily scheduling done by the crew foremen.

2.1.3.3.2 Work Authorization

Several systems, all of which have been designed by the same consultant firm, utilize a formalized method of authorizing the work to be done by maintenance crews within the approved program. After budget approval, the annual program is determined whereupon crew schedule cards are issued to all of the field foremen. Each card represents one day's work by a standard sized crew performing a specific work activity. A

color coding system is employed in order to control the performance of the activities. Typically, the following four categories of cards are used:

(1) Routine Unlimited Activities - (Green Card).

These activities must be performed when needed, and in the amounts required to correct the deficiency. There are no quantity limitations for these activities since they are to be performed as required to maintain safe highways. The planned work quantity is an estimate of average conditions. In any particular year the number of crew day cards may be somewhat more or less than indicated. The Maintenance Management System recognizes this condition and provides for crew day card overruns and underruns by adjustments; to other activities. Some activities included in the ROUTINE UNLIMITED category are Spot Premix Patching, Snow and Ice Control, and Emergency Maintenance.

(2) Routine Limited Activities - (Red Cards)

This category includes activities for which quantities of work can be established and firmly adhered to. For example, mowing can be set at five times yearly, Bridge Cleaning twice a year, and so on. For these activities, control of work quantities normally will be exercised on the basis of

planned work units and the number of crew day cards issued.

(3) Special Authority Activities - (Yellow Cards)

These work activities are not urgently needed. The planned work is desirable, but it is not critical that all of the planned work be completed during any one year. The planned quantity represents an average value designed to provide the desired level of maintenance service. Activities such as Joint Filling, Shovel Ditching, and Brush and Tree Cutting are in this category. Also included in this category are special maintenance activities that require approval from the Division of Maintenance Engineer. Some activities included are Major Repairs of Bridges and Minor Maintenance Improvements. These types of activities need to be coordinated with the total highway improvement program.

This group of activities provides flexibility -- the amount of work may be expanded by other routine activities, particularly the ROUTINE UNLIMITED activities. The crew day cards for these special maintenance activities are controlled at the division level and issued to the District Engineers at the discretion of the Division Maintenance Engineer.

(4) Overhead Activities - (Orange Cards)

Included in this category are those service and overhead

activities such as Structure Attendant, Weigh Station Operations, Standby Time, Training, and Materials Handling. This work is required but is not related to the maintenance of specific roadway or structure elements. Crew day cards are used principally to record work rather than to control work quantities. (17)

2.1.3.3.3 Control and Evaluation

Vital to proper operational management of the system are the feedback reports produced by the system and made available to the appropriate levels of management. The system must yield the sorts of information required by the various management levels in order that they may control and evaluate: work performance; planned versus actual performance; productivity; needs for standards revisions; and conformance with the approved program and fiscal constraints. The types and degree of detail of feedback reports are practically limitless. One state system has written 37 different computer programs in order to generate the reports which they consider necessary to their system. The breakdown as to the program function is as follows:

- A. Eleven programs list inventory information, control files and edit errors.
- B. Four budget - related programs.
- C. Three programs on organization and performance.
- D. One control program.
- E. Three informational summary programs.
- F. One exception report program.
- G. Two analysis detail programs.
- H. Five file creation programs.
- I. Seven support or housekeeping programs.

The 19 distinct reports produced within this system fall into six general categories; budget; performance; control; summary; exception; and analysis reports. Of these, six reports have been designed to monitor the performance of the maintenance organization. These reports reveal the productivity and unit costs being achieved monthly at the division and district levels and make a comparison between budgeted work and actual work accomplished. The reports also flag production and unit cost values which are either exceptionally high or low relative to the district and statewide averages. Of these reports, four are routine monthly printouts, six are annual and the remaining reports are available upon request (38).

Most reporting and information subsystems are basically the same, varying mainly in degree of detail. One refinement found in many systems is the explicit assignment of system responsibilities to the various levels of management. In the systems manuals, one section is devoted to defining responsibilities for planning, control and evaluation as to scope and frequency for each management level function.

A common point made by most states in the description of their systems is the need that the system be dynamic. Constant review and refinement of all system components is necessary if full value is ever to be achieved from the system. Initial implementation is agreed to be only the starting point.

2.2 SUMMARY

Presented in this chapter was a composite maintenance management system which reflects those features which are present in the systems of various state highway agencies in the United States at the present time. This might be considered a state of the art discussion in which all of the basic system elements were considered. Those basic elements are:

Highway Features Inventory

Maintenance Standards (Quality, Quantity & Performance)

Performance Budget

Scheduling Procedures

Reporting Procedures

Control Procedures

Evaluations Procedures

CHAPTER 3

MASSACHUSETTS' APPROACH

3.1 RESPONSIBILITY

There are currently more than 350 different highway agencies that share the responsibility for the administration of approximately 30,000 miles of public roads in Massachusetts. Approximately 9% of this mileage is under the jurisdiction of the Massachusetts Department of Public Works. About 23% of the highway network is the responsibility of the 39 cities, while the 312 towns of Massachusetts are responsible for about 65% of the road mileage. Other agencies having responsibility for the remaining public roads are the Metropolitan District Commission, the Massachusetts Turnpike Authority and Port Authority. (39)

The Massachusetts General Laws (Chapter 81, Section 13) define the duties of the Department of Public Works as follows: "State highways shall be maintained and kept in good repair and condition by the department at the expense of the commonwealth. The department shall keep all state highways reasonably clear of brush and shall cause suitable shade trees to be planted thereon if practicable."

The following definitions from the Maintenance Manual

of the Massachusetts Department of Public Works indicate the departments' view of the maintenance objective.

Physical Maintenance - The preservation and upkeep of a highway, including all of its elements, in as nearly as practicable its original (as constructed) condition or subsequently improved condition.

Traffic Services - The operation of a highway facility and services incidental thereto, to provide safe, convenient and economical highway transportation.

Betterment - The improvements, adjustments or additions to a highway which more than restore it to its former good condition and which result in better traffic serviceability without major changes in its original construction. (40)

(See Appendix 4 for a list of some typical activities under each of the above categories.)

The Maintenance Division of the Department of Public Works is responsible for 2,774 miles of state highway, comprised of 11,438 highway lane-miles.

The Division maintains 2,590 bridges, with a total of 24.5 million square feet of deck, and a total of 5,339 overhead lights, signals and flashers.

For the fiscal year ending June 30, 1974, maintenance

accounted for 19% of the total Department expenditure. Of the \$35.7 million fiscal 1973-1974 maintenance expenditure, the breakdown is as follows: personnel 62%; materials - 16%; equipment - 12%; contracts - 10%. There are currently 2,074 people assigned to maintenance out of a total department force of 5,424 people.

3.2 DESCRIPTION OF THE MASSACHUSETTS SYSTEM

The following is a general description of the methods used by the Massachusetts Department of Public Works for carrying out their highway maintenance function. Their approach is the traditional one used in all other states before the introduction of maintenance management system techniques.

It is not intended that this be a very detailed presentation of existing practices. Those interested in further details can find them in the referenced sources. Practices presented as being typical of a district or a crew level may vary somewhat between districts or between crews, and what is presented here is the result of interviews conducted with only one unit of management at each organizational level. (See organizational charts in Appendix 5)

3.2.1 Technical Data

3.2.1.1 Data Processing

The department's Data Processing Section stores all department expenditures on magnetic tape or disc files. This information is taken from employees' weekly time reports, invoices, state owned equipment expenditure reports, etc. These data are coded by activity and cost account numbers in such a way that, knowing the account numbers, one can retrieve upon request certain data of interest.

There are no routine maintenance management feedback reports extracted from the data files. Usually such a request is submitted only in connection with a specific study, such as maintenance staffing requirements or annual snow and ice control costs.

Certainly there are data in those files which could assist managers at various organizational levels in monitoring performance and planning future requirements. The fact is that many supervisors, especially at the field level, are not aware of what information is available nor exactly what data would be of value to them.

3.2.1.2 Maps and Statistics Unit

The Maps and Statistics Unit is a management unit of the Boston Maintenance Section. (See Appendix 5)

The staff is responsible for all statistical records pertinent to state highways, development of maintenance costs and production of the Official Highway Map, Detour Bulletin and other maps required by the Department.

The following sets of State Highway atlases are kept and updated by this unit:

a. The first set shows by means of color codes the number, location and limits of the Federal Aid System and also those portions of State Highway not on the Federal Aid System.

b. A set which shows locations and limits of all state highways. The route is delineated in red and alongside is shown the year of the layout or major alteration and the stations at the beginning and end of each layout or alteration. Also shown are stations at town lines and any station equations of major significance.

c. A set which shows the locations of all numbered auto routes.

In addition to the Highway Route Atlases, straight line diagrams of each Highway Route are kept. These diagrams, plotted on a scale of two thousand feet to the inch, show the local road name (if any); the year of the layout; the

year the latest surface was laid; type, width and depth of surface, base and foundation courses; type, width and depth of shoulders. Also the intersections of side streets and the locations of bridges and large culverts are shown.

Surface treatment books are maintained showing the treatment each section of State highway has received since the last construction, reconstruction or resurfacing.

There is an inventory of State highway features kept on cards maintained and updated in the Maps and Statistics Unit. These same data are also stored in the data processing computer file. These inventory files list: route; town; district; county; rural or urban classification; type of access control; length; number of lanes; year existing surface laid; width, type and depth of surface; type and depth of shoulders; and plowing status.

The existence of such a detailed highway inventory will be a great advantage to the Department should it decide to design and implement a maintenance management system. As shown in the previous chapter, the highway inventory is one of the required components of a maintenance management system. Development of their road inventories was one of the major tasks facing most states in the design phase of

their systems. Massachusetts' inventory should merely require updating and also the inclusion of some additional categories of data.

From the atlases and files previously described and from data supplies by other agencies, the Maps and Statistics Unit generates the following annual reports:

Mileage of State Highway by Types;

Lineal and lane mileage of state highway by Repair Sections;

Mileage of the Interstate System;

Analysis of Maintenance Costs (Department Report);

Analysis of State Highway Maintenance Costs (Selected Sections for the Federal Highway Administration);

Analysis of Maintenance Costs (Transportation Research Board)

3.2.1.3 Office Files

An enormous amount of information is stored in the office files of the district maintenance offices and also the Boston Maintenance Sections offices. Examples of some of the reports contained in those files are: inspection reports; reports of necessary repairs; equipment use reports; equipment status and accountability reports; traffic signal reports; traffic sign erection reports; pavement marking

reports; priority lists; road inventory books.

It is those office files which yield the majority of data used in the day-to-day management of the departments' maintenance effort.

3.2.2 Maintenance Planning

3.2.2.1 Long Range Planning

Long range programs, usually for five year periods, have been developed by the Boston Maintenance Section from time to time for certain activities. This type of long range planning has not been adopted in maintenance on a regular and continuing basis because it was found that, due to the realities of budget constraints, it was impossible to conform to the long range plan. After the first year, the unplanned needs would begin to outnumber the jobs programmed in the long range plan. Only with sizeable increases in budget allotments would it be possible to perform both the current needs and the long range programs. Since maintenance allotments remained much the same from year to year, it was not long before long range plans could not be followed.

Although formal long range planning has been found not to be feasible, the organizational unit heads in the Boston

Maintenance Section do informally conceptualize long range priorities which they consider when establishing annual programs.

3.2.2.2 Middle Range Planning

Most of the long and middle term planning discussed here applies only to that maintenance work which is let out to contract. The maintenance work done by department forces is almost entirely remedial or 'brush fire' maintenance. This type of work is not appropriate for planning, except in the short term.

There are two types of annual planning for department maintenance. First is the planning which is necessary in order to develop the annual budget request. That planning must be done during the fall of the year prior to July, in which the fiscal year begins. The second type is the planning required in order to carry out the programs during the fiscal year.

The annual budget requires planning for two types of expenditures; contract work and work by department forces (force account). Budget development planning for force account work simply requires projections of materials needed to perform that work. These projections are made based on historical data from the office files.

Budget development planning for contract work is based upon priority lists submitted semi-annually to the Boston Maintenance Office. The supervisors of the organizational sections (See Appendix 5), based upon the submitted district priority lists, their own experience, and their field assessments, establish state wide priorities. This process establishes the order in which contract work is to be done during the year. This order may later be altered upon the specific request of the district concerned.

The planning required in order to carry out annual programs is the responsibility of each of the district highway engineers acting through their district maintenance engineers. The Boston Maintenance Office offers guidance for this planning through two important methods. The first is the issuance of the Calendar for Annual Programs updated annually. This calendar, developed for the fiscal year, looks at the necessary timing of certain milestones related to contract work and to the purchase of materials needed in force account work. For certain activities this calendar displays the District Maintenance Section's responsibility; the dates contracts should be worked up by the District, sent to Boston, and advertised; the dates work should start and be completed.

The second method used by the Boston Maintenance Office in assisting the districts in carrying out its annual program is through annual maintenance conferences. For fiscal year 1975 there are nine of these conferences scheduled, each dealing with a different maintenance activity, e.g. snow and ice; permits; structures; highways; etc. These meetings are attended by the district maintenance engineers and their staff engineers and foremen responsible for the subject areas of maintenance, and are conducted by the Boston Maintenance Office staff. These meetings are seen as an important means of disseminating department maintenance policies. They also provide an opportunity for the districts to compare experiences, review program objectives and adjust existing plans. These conferences also provide those involved in the planning of maintenance an opportunity to get feedback on their planning efforts in order to make the necessary adjustments in future planning.

3.2.2.3 Short Range Planning

Short range planning is the responsibility of the district maintenance engineers. At the district level this planning is done at all levels, right down to the crew repair foremen. It is this planning which guides the performance

of force account work. It is through the constant contact and discussions between the different levels of management within the District maintenance organization, with guidance from the Boston Maintenance Section, that the force account work is planned. Flexibility must be incorporated in this planning because emergency work, which needs immediate attention, constantly interrupts the planned activities.

Experience has given all those responsible for the force account work an awareness of when certain activities are best scheduled. One season is better suited to performing some activities than others. It is through an exchange of these judgements that the short term program is established.

Another means of adjusting the short range plan is through constant visual assessment of conditions by all levels of management at the district level. Relative needs are established and priorities for force account work altered informally as a result of these visual assessments and discussion between management levels. In cases of conflicting assessments of needs, it is the district maintenance engineer who determines priorities.

The day-to-day planning of force account activities is

done at the foreman level. This is done through constant contact between the highway maintenance foreman and his highway repair foremen. Most of this day-to-day planning is based upon the judgement and experience of the engineers, and the foremen assigned to the various maintenance functions in the district, coupled with an awareness of the existing highway conditions.

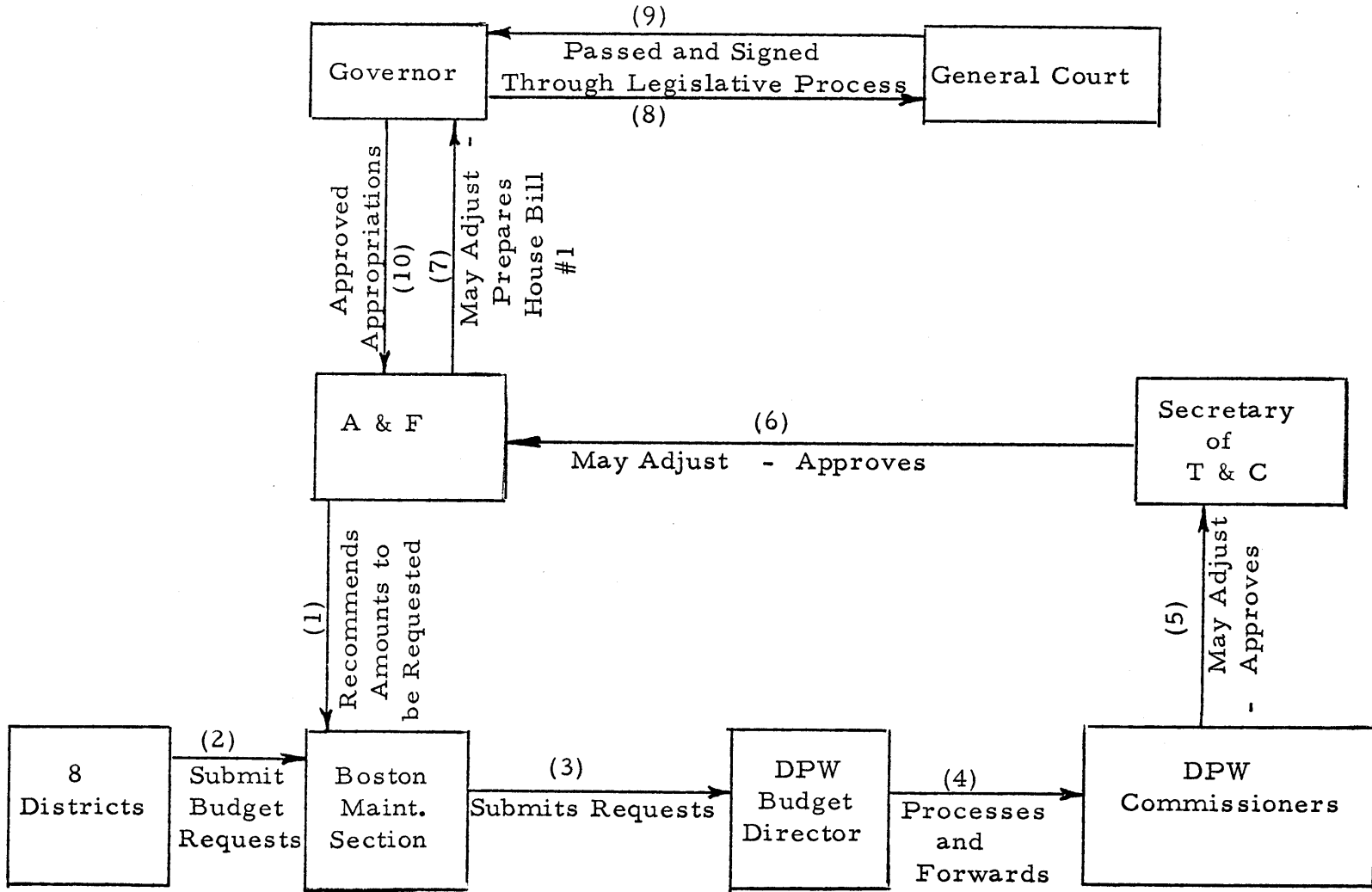
3.2.3 Budget Development

The budget development process for all spending agencies of state government in Massachusetts could not be precisely described as a smooth flow process. However, in order to present that level of detail necessary to portray the process as it relates to highway maintenance, a continuous flow chart is presented for reasons of clarity at the risk of oversimplification. An important part of the process which the chart does not present is the interchange between the various levels of management during the process. During the budget request adjustment stages, there is frequent backtracking to lower levels for purposes of questioning, justifying, defending and modifying.

(See Figure 3 for the budget development flow chart).

FIGURE 3

BUDGET DEVELOPMENT FLOW CHART



The budget development process begins in approximately July of the year prior to the fiscal year under consideration, when the Executive Office for Administration and Finance develops recommendations for amounts to be requested by all organizations and divisions. These estimates are made based on a study of the highway fund revenues and an estimate of amounts which will be available. Recommended request amounts are specified for each organizational unit and broken down as to expenditure accounts and subsidiary accounts.

The Boston Maintenance Section considers the recommended limitations, the district budget requests and their own state wide priorities in order to develop the initial maintenance budget request. This stage of the budget development is accomplished by the Boston Maintenance Section through consultations with the Deputy Chief Engineer for Maintenance and the Department Budget Director. In conjunction with the budget request, the section must complete forms which show explicit justification for each subsidiary account request. Budget requests for personnel accounts are not prepared by the Maintenance Division, except when additional positions are considered necessary by the Maintenance Engineer, and even then only upon the prior approval of the Chief Engineer and the Commissioner.

If there should be certain subsidiary accounts for which justified requests are greater than those recommended by Administration and Finance, the section must attempt to keep the total request for maintenance within the recommended limits by reducing amounts requested in other subsidiary accounts, preferably within the same expenditure account. If it should be necessary for maintenance to forward a budget request which totals in excess of the recommended amount for maintenance, then the Budget Director has the problem of balancing the requests of the entire department so that they fall within the recommended total. In such a case the first step would be a meeting between maintenance personnel, the Budget Director and representatives of the Commissioner's Office. At this meeting, the Deputy Chief Engineer for Maintenance and the Maintenance Engineer must present convincing justification to the Commissioner that overrunning the recommended total for maintenance is necessary.

When the maintenance budget request has been submitted to the Department Budget Director and found acceptable he combines it with the total department request and forwards it to the department Commissioner. The Commissioner reviews the total request, having the authority to make deletions,

additions or modifications. He then approves it and forwards it to the Secretary of Transportation and Construction. The Secretary reviews the entire department budget request. He may alter it as he deems necessary. Upon his approval he forwards the budget request of all agencies within the Department of Transportation to the Budget Bureau.

The Budget Bureau, under the authority of the Secretary of Administration and Finance reviews the budget request of all state agencies. After making what are considered necessary alterations and adjustments, the total budget request is framed into House Bill #1 and forwarded to the Governor. The Governor reviews the bill and presents it to the Legislature. After legislative process, which will not be described here, the budget is passed by the Legislature and signed into law by the Governor.

At this point, approved appropriations exist. These appropriations are administered by the Executive Office for Administration and Finance.

A distinction exists between appropriations and allotments. Appropriations are defined as amounts authorized by the Legislature for a determinable period of time from which expenditures may be made and obligations incurred for specific

purposes. To appropriate has been defined as "to set apart from the public revenue a certain sum of money for a specified object in such a manner that the executive officers of the government are authorized to use that money and no more, for that object and no other".(41) At this point in the description the budget development process is completed. The allotment process will be briefly described because allotted funds can differ from appropriated funds at the discretion of the Governor or the Commissioner of Administration when designated.

An allotment is defined in the General Laws as that portion of the appropriation made available to the specific purposes. The Governor may designate in writing to the Commissioner of Administration the authority to allot appropriated funds.(41)

Certain office and administrative and personnel appropriations are allotted automatically by the Commissioner of Administration. Some examples of such appropriations are: office supplies, travel expense, office equipment repair, and payroll. Every four months one third of the total appropriations for these accounts is released. However, the majority of

accounts are allotted funds only upon requests initiated by the spending unit. In the case of the Maintenance Division, requests for allotments must originate from the Boston Maintenance Section. The processing of this request follows the same procedures as the original budget request from the Boston Maintenance Section to the Executive Office for Administration and Finance. All of the approvals required in the budget request flow are required in the allotment request flow.

Chapter 29, section 9B of the General Laws states that the Governor shall from time to time divide each fiscal year into allotment periods of not less than one month nor more than four months. As funds are needed within various accounts, the maintenance section must submit a request for the allotment of those funds. The maximum period of time to be covered in these requests is four months. If, due to unforeseen circumstances, it should become necessary to expend more money than had been allotted to a subsidiary account, such an expenditure would require an act of the Legislature.

This has been a simplified version of the existing maintenance budgeting process which reflects the level of detail necessary for the purpose of developing a framework

for a maintenance management system suitable for application in the Massachusetts Department of Public Works.

3.2.4 Control of the Maintenance Operation

The purpose of this section is to describe how the department exercises control over the maintenance work actually performed. The word 'control' is intended to mean both the assignment of work and the evaluation of performance. Within the context of a maintenance management system, the control phase of the system can be clearly delineated because it has been explicitly designed into the system. However, without a maintenance management system, the department's maintenance control phase is difficult to discern because it is largely informal and is usually carried out at the field level of supervision.

3.2.4.1 Lines of Authority

The organizational structure of the maintenance division is shown in Appendix 5. The control of maintenance is carried out through the direct lines of authority from the Chief Engineer down to the repair foreman level, with the preponderance of day-to-day control being done at the foreman and repair foreman levels. Due to the fact that the Boston Maintenance Section has no direct line of authority to the Districts, it follows that it has very little involvement in the control of the work.

The Boston Section staff exercises fiscal controls over the work and also controls experimental or research projects in which data are gathered and assessed regarding new techniques, materials or equipment used in maintenance work.

Within the district maintenance organization, the line of authority is direct from the district maintenance engineer and his assistant to the foremen in charge of the various activities. The district maintenance engineer's engineering staff assigned to these various activities has no line of authority to the field supervisors, unless such authority has been specifically delegated to them by the district maintenance engineer.

On the district organizational chart it is stated that general work assignments to foremen will originate from the district maintenance engineer or his assistant, and that work priorities for the crews assigned to the foreman will be established by the foreman, based on advice from the engineers assigned to that foreman's activity. The district maintenance activities being referred to are structures maintenance, highway maintenance, traffic maintenance, roadside maintenance, and snow and ice control.

3.2.4.2 Job Duties

Massachusetts Department of Public Works personnel are under a civil service system. Within this system, every job has a description, including a listing of duties. Based upon the various job descriptions it should be possible to convey policy as to how the department intends to control maintenance activities. The following descriptions of duties have been excerpted from job descriptions.

Repair foremen are responsible for directing and supervising the work of maintenance crews. They are also responsible for the inspection of certain contract work. They work under the direct supervision of maintenance foremen.

A maintenance foreman supervises one or more repair sections engaged in his assigned activity. He plans and assigns work, and reviews performance for efficiency and conformance with instructions. He supervises the keeping of time, costs and reports on work accomplished. He exercises general supervision over contract maintenance work. He instructs others in proper supervisory, management and work techniques including preventive maintenance of tools and equipment. He makes work and cost reports.

The district maintenance engineer has the responsibility and authority to properly maintain all state highways in the district under the direction of the district highway engineer and in accordance with established policies, advice and instructions from the Maintenance Engineer for the department. He assigns work to the highway maintenance foremen, bridge maintenance foremen, supervising tree surgeons, highway traffic maintenance foremen, and equipment foremen, and coordinates work between the various crews.

The district maintenance engineer has a staff of engineers assigned to specific activities. Their duties are outlined in the Maintenance Manual and the following are those related to the control of maintenance: they give technical advice to the maintenance foremen in charge of their specific activity; they inspect the work to insure that established policies and instructions from the district highway engineer are being followed.

In summary, different types of control exist at different levels of management. Performance by department maintenance field forces is evaluated as to efficiency and conformance to plan at the maintenance foreman level. Control as to conformance to policies, plans and instructions, as well as fiscal controls,

are primarily handled at district maintenance engineer's staff level.

3.3 APPRAISAL OF EXISTING APPROACH

It should be emphasized that the above description of the existing approach by the Massachusetts Department of Public Works to managing their maintenance does not consider every aspect of the maintenance operation. Only those phases which seem appropriate for comparison with the maintenance management system approach have been discussed.

This section will present an appraisal of the department's existing methods for handling maintenance which will simply highlight some of the major apparent weaknesses inherent in the existing approach. The shortcomings are similar to those which existed in every state highway department before some states began to attempt to correct the problems through development and implementation of their own maintenance management systems.

The proposed solutions to these weaknesses will be presented in Chapter 4. The nature of all of the existing weaknesses can be summarized as certain foregone management capabilities, which could be possible through the application of current management techniques.

3.3.1 Technical Data

The mere existence of data is not enough, regardless of the quantities. In order to get full value of data, they must be integrated into a total system through a thoughtful design process. It must be determined just what data are necessary, how they should be gathered and disseminated in order to achieve full management capabilities from the data.

The data should provide management with the information necessary to determine the real maintenance needs, so that programs may be established based on real needs when weighed through economic analysis, wherever possible. Assessment of road conditions should be as objective as possible. In order to approach objectivity, increasing use must be made of measuring equipment. Visual assessments must always be used to complement measured assessments but an attempt should be made to standardize the visual assessment process so as to minimize its subjective nature.

3.3.2 Maintenance Planning

There is a need to develop quality standards in order that there will exist statewide uniformity in the establishment of priorities. An attempt should be made to set these standards at the economic optimum. The decision makers should know

specifically, in terms of level of service provided, what the planned program represents.

Since the planned program reflects top management's policies and decisions, it should be used constantly throughout the year to guide and control planning at all levels. Periodic feedback reports should reflect how various management units are meeting the annual planned program. Planning at all levels should be an overt and explicit part of the system in order that necessary periodic adjustments may be made by all levels of management so that statewide goals can be met. This type of planning is also necessary in order to perform the work more efficiently because it enables the maintenance foreman to make the most efficient use of available resources.

The existing system does not provide management with the capability of making meaningful analyses of the cost-effectiveness of performing work with department forces as compared to contracting that work.

3.3.3 The Budget Development Process

The budget should be developed so as to reflect the financial needs for accomplishing specific work programs based on established standards for level of service to be provided and resources necessary to accomplish that work. The line

item budget is developed based largely upon historical precedence and subjective judgment.(42) The requested budget should reflect needs based upon policy decisions of top management.

3.3.4 Control of the Maintenance Operation

There is a need for operational control which guides the day-to-day field operations efficiently and economically toward the objectives. At various management levels it is necessary to make evaluations of performance and productivity, and to take corrective action where necessary. Within the system there should exist mechanisms which enable management to make comparisons between planned and actual performance and also between actual and desired quality levels and unit costs.

CHAPTER 4

PROPOSED FRAMEWORK FOR MASSACHUSETTS SYSTEM

The purpose of this chapter is to present a framework for a maintenance management system which would be beneficial and appropriate for implementation within the Maintenance Division of the Massachusetts Department of Public Works.

Before presenting the basic system elements considered vital to a complete maintenance management system, it will be necessary to first address some basic questions relative to highway maintenance. To be considered are: why highway maintenance is done; how much highway maintenance should be done; and what are the supply-demand considerations which influence how much highway maintenance should be done. When these questions have been treated, the proposed framework will be presented and each recommended system element will be discussed in terms of how it provides capabilities for fulfilling those basic highway maintenance requirements.

4.1 DISCUSSION OF HIGHWAY MAINTENANCE

It is intended that this discussion be general in nature and universally applicable to highway maintenance. Specific maintenance policies in Massachusetts will not be considered here because they are subject to change and a system which is designed to fulfill the very basic highway maintenance

objectives would be capable of adapting to local policy shifts.

4.1.1 What is the Purpose of Highway Maintenance

Maintenance can be broadly defined as the work performed on a system, after initial construction, to defer the progress of deterioration, or to restore the partially deteriorated system to a condition closer to its initial state. This does not include reconstruction work which typically results in a system superior to the original or involves the complete destruction and rebuilding of a substantial part of the system.

A maintenance operation should be done only if it has a positive effect on the performance level or service life of the system, and if these effects are worth the cost of the operation. Performance is used here to include all aspects of the system's capabilities to accomplish its goals. (11)

An international road research group (OECD) states in a 1973 maintenance report: "Clearly, the preservation of the road network as a national asset justifies the considerable (maintenance) expenditure involved. However, this in itself does not provide a proper basis on which to establish a road maintenance policy. In effect, it would be necessary to determine the "level of service" offered to road users, by

means of an overall economic study that would balance costs with community benefits." (36)

Report 9 of the National Cooperative Highway Research Program opens with the following statements: "The primary purpose of a highway system is to provide safe, comfortable, convenient, and economical method of transporting goods and people. The role of the engineer is to design, construct and maintain the system in an efficient and economical manner."(43)

Most state highway organizations perceive their maintenance responsibility as being the optimum utilization of available resources in the operation and maintenance of the highway system in order to (1) provide safe, convenient, and economical highway transportation, and (2) preserve and protect the investment which the highway system represents. A basic goal of all organizations is that the maintenance operation be carried out in the most efficient possible manner.

4.1.2 Maintenance Policy

A basic distinction must be made between two types of maintenance:

Remedial maintenance - to correct deficiencies after the occurrence of serious damage or failure. Pothole patching

is one example of such maintenance activities;

Preventive Maintenance - to perform certain planned maintenance activities at times such that the level of service of the maintained feature does not fall below a previously determined acceptable level. (36)

Opportunity for tradeoff exists between the minimum service level to be provided and economic considerations. For every maintainable highway feature there exists a cost - efficient minimum service level. In searching for this optimum, total costs must be estimated, including highway user costs. In order to provide efficient transportation at the lowest cost, all of the possible tradeoffs must be analyzed during the design stage. Construction cost, maintenance cost and service level should all be considered design variables. Some of the tradeoffs to be examined during design are: (1) the relationship between the system's initial characteristics and future maintenance needs, that is, the balance between initial cost and the maintenance costs for the life of the system; (2) the effect that prescribed maintenance policy and construction cost have upon how long the system will last before reconstruction is required; (3) the tradeoff between maintenance costs and user benefits, where user

benefits may be reduced operating costs, increased safety, greater comfort, or whatever benefits the system is designed to produce. If the goal of economical transportation is to be achieved, rigorous analysis of these variables is necessary. At present, the data necessary to perform this analysis does not exist.

For existing systems we must consider the tradeoffs of maintenance costs vs. reconstruction costs and maintenance costs vs. user benefits. Maintenance policy on existing systems should be adjusted to obtain the most efficient operation considering the balance of maintenance costs, user benefits and reconstructions costs. (11)

At present, maintenance policy is decided on a largely subjective basis because the sort of data necessary to perform the analyses described above is not available. The highway agency must have the sorts of data which will provide the capability of predicting both the need for maintenance and the related resource requirements associated with various design options. Maintenance policy establishes minimum service levels for the various activities and selects the timing strategy for performing preventive maintenance for each activity. Optimum policy, in the process of minimizing

total transportation costs, would minimize the need for the more costly remedial maintenance tasks.

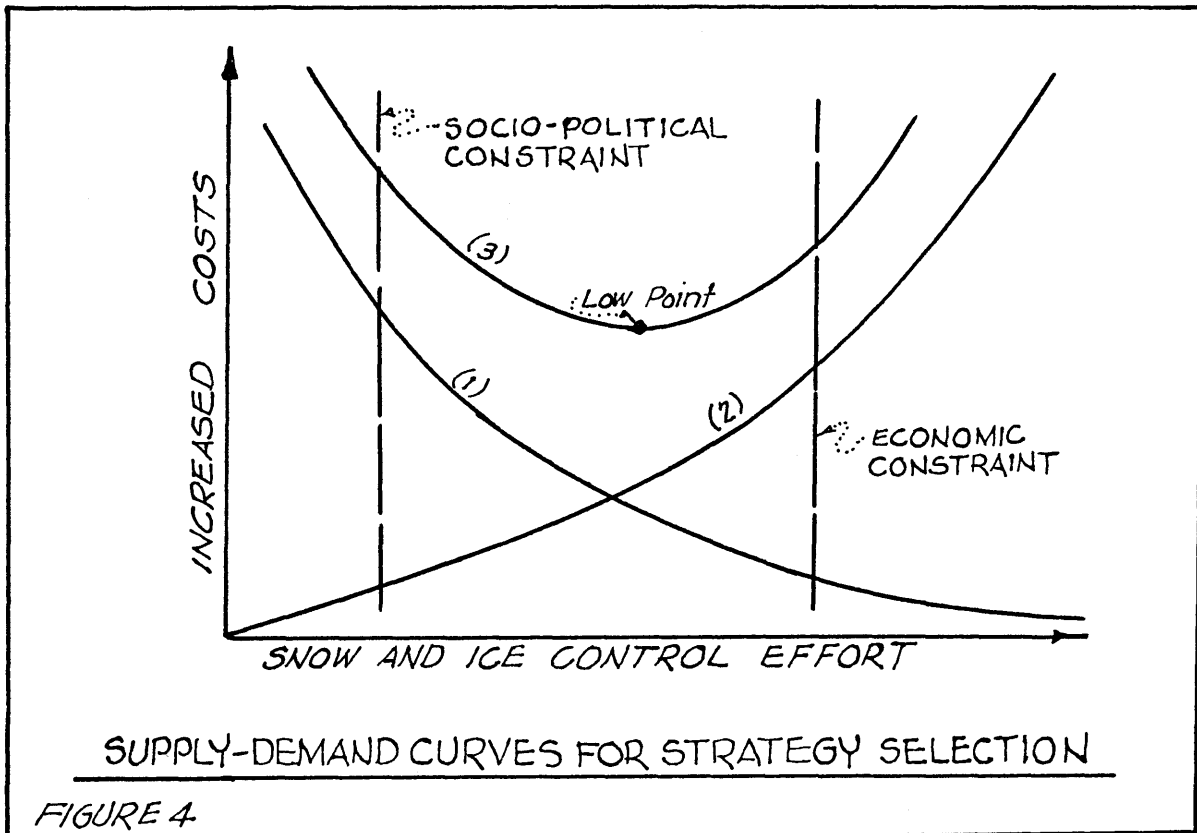
4.1.3 Maintenance Strategies

Consideration of maintenance policy during the design stage is beyond the scope of this discussion. Establishment of maintenance policy for existing systems is a matter of selecting the best maintenance strategies. A strategy may be considered to be a particular combination of techniques and resources. There are generally several strategies that can be considered for any situation, i.e., there are many solutions to a particular problem. Analysis and selection of the proper maintenance strategy, similar to analysis and selection of investment opportunity, will require a knowledge of both the supply and demand functions.

The supply function can be considered to consist of possible techniques for combining available resources (labor, equipment and supplies) to produce a maintained highway system. The demand function is expressed in terms of what is required of the system as influenced by factors such as physical inventory, environment, existing and projected traffic characteristics and axle loads.

The design problem is to select the best strategy which meets the demand requirements subject to certain constraints. These constraints are imposed based on policy decisions previously discussed. These constraints may be economical or otherwise. For example, the constraint may be to choose the alternative which meets the demand with a minimum total cost, or the one which meets demand with the highest degree of reliability or one with minimum maintenance requirements.(44)

A simplified graphical solution of the selection of the optimum strategy for snow and ice control activities is shown in Figure 4. The example is appropriate for the New England



environment. Curve #1 traces additional road user costs, due to increased operating costs and delays, associated with the various snow and ice control strategies. The ordinate axis represents strategies ranging from zero effort and increasing to the right. Curve #2 traces the increased department expenditures associated with the various possible degrees of effort.

Curve #3 is the combination of curves #1. & #2, added vertically, which represents total costs (maintenance cost and additional user cost) for the range of snow and ice control efforts.

The entire range of alternate strategies is not available to the decisionmaker because two constraints have been introduced. The socio-political constraint is the effort level selection below which public reaction and the resulting political ramifications will not allow. The economic constraint is that level above which operation is impossible because of budget constraints upon the highway agency.

At present it is those two constrain lines which determine strategy. The agency operates somewhere between those two constraints, but is not sure where in relation to optimality. In fact, the optimum strategy would be that level of effort

occurring at the low point of curve #3 if the goal is to be minimum total transportation cost. Regardless of what are determined to be the goals and constraints, they may be incorporated in the analysis in the search for the optimum strategy.

In this example no attempt was made to assign values to the change in cost or the snow and ice control effort axes. The information needed for this type of analysis is not available. One of the goals of a maintenance management system is the collection of data necessary for objective analysis and selection of the optimum maintenance strategies.

4.2 SYSTEM FRAMEWORK FOR MASSACHUSETTS

It is the purpose of this section to present a framework which will incorporate all of the elements from which a total maintenance management system may later be developed. It would be unrealistic to attempt to present the model of a complete system which would be appropriate for implementation in Massachusetts, because research has shown that system design is a task requiring approximately one year of effort by a staff of from eight to twelve people.

The basic elements to be described here will be the same as those presented in Chapter 2, namely: inventory;

maintenance standards; performance budget; scheduling, reporting, control, and evaluation procedures. Additionally, explicit consideration will be given to the methods of assessment of existing highway conditions and determination of priorities.

4.2.1 Highway Features Inventory

The basic purpose of establishing a roadway inventory as a basic element within the maintenance management system is to identify the physical items which are to be maintained. Massachusetts already has a thorough road inventory which simply has to be expanded and modified for use within the system.

The primary use of inventory data is for budgeting planning and scheduling of work. It helps to identify how much work must be accomplished. For example, management may establish, through previously described analysis, that the best strategy is to clean culverts smaller than 36" once a year. If it is determined that it requires one man - hour per culvert, it is possible to establish budgets, plans, and schedules if we have an inventory count of the total number of culverts smaller than 36", by districts.

The major modification to the existing inventory which will be necessary is the conversion of the units of measurement into units relatable to the various work activities. For example, if the unit of work for mowing is "acre", determining the lineal miles of right of way is not sufficient. The existing inventory will have to be expanded to include those items which represent maintenance effort. Drainage items are the major category which will have to be added to the existing inventory.

It will not be necessary to develop a sampling approach to inventory gathering because with only 3,000 miles of road responsibility and since most of the necessary inventory data already exist, such a technique is not warranted.

The discussion of highway features inventory presented in Chapter 2 will service as an appropriate guide to the development of the inventory for Massachusetts' maintenance management system. To ensure the proper levels of precision, accuracy and consistency, detailed instructions should be prepared and those involved in inventory gathering and updating should be given training sessions on the understanding of those instructions and the standard inventory forms.

4.2.2 Maintenance Standards

Research of existing maintenance management systems shows that the development of maintenance standards was the most difficult design task facing the highway department. The standards are the greatest single determinant of the success of a system. Even the best management system will not operate usefully unless the existing road conditions and the completed work can be compared to relevant reference standards.

A Massachusetts maintenance management system should include maintenance standards as described in Chapter 2 and summarized below:

(1) Quality Standards - defining the thresholds at which certain maintenance activities should be carried out. A major effort should be made in establishing these levels as objectively as possible, especially for those activities which represent sizable maintenance expenditures. For those activities which cannot be objectively analyzed because of insufficient data, the system should be designed to yield the data necessary for future analysis and updating of this part of the standard.

An impact tableau similar to that shown in Table I should be developed in order to test the sensitivity of changes in the quality standards with respect to resource requirements

and other expected results.

The ultimate objective is that after the system has been in operation for several years it is possible to determine optimum quality standards for each activity based upon cost - benefit analyses, considering maintenance costs and user benefits.

(2) Quantity Standards - estimating the resource requirements necessary to meet the quality standards for each activity. These standards may be considered to be a function of the quality standards. They must be specified because of their utility in budgeting and planning.

(3) Performance Standards - describing the work methods and crew composition, and defining the expected rate of productivity.

It is through the application of the quality standards, which reflect top management policy decisions, that the determination is made as to how much maintenance should be done. It is through the performance standards that guidance and control is applied in order to assure that the established program is carried out efficiently.

4.2.3 Periodic Assessment

Within the annual program, actual work to be done is

scheduled based upon periodic assessments. There exists a need for research and development of more objective methods of assessing the existing quality levels of the various highway features, especially the more costly ones, such as pavement. Specifically, there exists the need to develop reliable measurement techniques which need not be sophisticated, but rather that they be consistent in order that parameters may be derived which will enable management to objectively establish priorities. (36)

There are two methods by which road conditions may be assessed: visual assessment (direct or photographic) and special measuring equipment. For many activities the first method is sufficient for establishing needs and priorities, while for others, especially activities connected with the pavement and roadbed, a combination of both methods is required.

Since economic considerations suggest that pavement be given the most thorough assessment, the following is a description of the scheduling and methods of the pavement assessment process: routine inspection; systematic inspection; and detailed assessment.

(1) Routine Inspection - by direct visual assessment. These are daily inspections such as those presently being done by the maintenance staff in order to detect damage requiring immediate attention or conditions warranting more detailed assessment.

(2) Systematic Inspection - by visual (direct or photographic) assessment. These inspections are programmed annually (or more frequently if budget allows) and results used both for future program development and for monitoring of past program accomplishment. These inspections also flag those locations which require more detailed assessment.

It is during the design of this system feature that consideration should be given to Ohio's approach to the measuring of the quality of highway maintenance (45), as described in Chapter 2. Another design problem will be to include the "Photolog" system, currently underway in Massachusetts, in the systematic inspection phase to whatever extent is useful. The "photolog" team is now in the process of driving the highways under department jurisdiction in a van equipped with a 35 mm. camera. Photographs are taken every 53 feet along the highway. Every photograph can be referenced as to location. The photographs are perpendicular to

the road surface and can be used to provide both quantitative and qualitative information on the conditions of the surface. Future potential of this system both as a means for updating the highway features inventory and as a method by which to perform systematic inspections should be considered during system design.

(3) Detailed Assessment - by special measuring equipment. These measurements are scheduled when the need for them is signalled as a result of either of the two previous types of inspection. When evidence of pavement distress appears through visual inspection it is then possible by use of one of the many types of measuring equipment to relate measured parameters to certain types of failures, thus establishing the necessary corrective measures.

Two general categories of measuring techniques are widely used for pavement evaluation. The first type is roughness measurement devices, many of which are relatively simple and inexpensive. These measurements are usually done on a continuing basis in order to monitor the service level of the pavement. Extensive research has been done in order to correlate roughness measurements with pavement serviceability. Sections found to have low service levels would then be

further investigated by the second measuring technique.

The equipment normally used in the second type of measurement is deflection measuring equipment. Since this is relatively expensive apparatus, these measurements are not done on a monitoring basis, but only when called for as a result of the roughness measurements. The purpose of these tests is to predict the remaining life of the pavement or its structural capacity.

During Massachusetts' system design phase, consideration should be given to the assessment methods by measurement techniques being used by the State of California. (46) Only through increased use of measuring devices in pavement assessment can the department be able to make more objective decisions relative to pavement rehabilitation expenditures. The parameters developed during a continuing measuring program will also be useful in the establishment of priorities, that is the relative urgency of the corrective action. The data gathered through these pavement measuring techniques will also be fed back into the quality standards in order to update them based upon this sort of objective data.

4.2.4 Establishment of Priorities

Establishment of priorities consistent with all the constraints previously discussed is the major objective of the "top - level" end of the system, that is the part of the system concerned with preliminary planning; inspection and assessment of needs; and determination of priorities and allocation of funds. All of the remaining elements exist in order to assure that the program is carried out efficiently.

Studies have shown that total transportation costs are more sensitive to maintenance program selection than they are to operational efficiency. (11) This would indicate that, unlike all maintenance management systems researched to date, the greater design emphasis and effort should be directed toward that end of the system which can yield the greater total benefits: Program development.

All of the system framework elements which must interact in order to establish program priorities have already been described. However, the calculations necessary in order to make a thorough analysis of the almost infinite combinations of options would be impossible without the aid of a cost - model and data processing capabilities.

A cost - model is needed which is capable of establishing priorities. This model must look at inventory; quality standards; quantity standards; predict level of service over time; and test various combinations of remedies. Although the model will not be as sophisticated initially as it will be later through system refinement, it is important that it be capable of handling the more refined data as the system makes them available.

4.2.5 Performance Budgeting

The performance budget should be used within any maintenance management system for the reasons discussed in Chapter 2. Any type of budget can be produced from a performance budget by a simple conversion step within data processing. This may be necessary in Massachusetts in order to conform to statewide procedures. However, the performance budget must still be a part of the maintenance management system. The resulting duplication is insignificant when weighed against the advantages a performance budget gives management in terms of fiscal planning and control capabilities.

4.2.6 Scheduling Procedures

Scheduling procedures have been well developed in the existing systems in the United States. Current practice is

appropriate for adoption by Massachusetts.

4.2.7 Reporting Procedures

Design of all of the elements associated with the operational aspect of maintenance (performance standards; performance budgeting; scheduling; control and evaluation) will rely heavily on what has been developed to date by other states. The one operational element requiring special and distinct attention is reporting. Although reporting is carried out at the operational level, it has a direct effect on all phases of the system.

The reporting procedures should be the last part of the system to be designed. Only after the rest of the system has been designed can the question of what information is necessary from the field in order to make the system work be addressed. The reporting system must provide the needed data while minimizing reporting demands upon personnel, avoiding duplication of reporting effort, and providing clear and simple reporting forms. This is no simple task and research has shown that much of the relative success of the system operation depends upon how well those requirements are met during system design.

That is a description of the basic design problem. Enormous pieces of additional data will be of value in developing objective analysis procedures for refining quality standards and establishing priorities, as previously described. The tradeoffs existing between availability of valuable data and additional reporting requirements must be carefully weighed.

Since the purpose of this thesis is not system design but rather presentation of a system framework, it will suffice to emphasize the need for clear insight and foresight during the effort to design system reporting procedures.

4.2.8 Control and Evaluation Procedures

Feedback reports are the tools providing management with control and evaluation capabilities. Excellent guides exist in other systems, especially those of Pennsylvania and Nevada. (14,15) Participation of the various levels of management should be sought during the design of the reporting procedures. The reports must be relevant to those individuals who will use them. An unread feedback report is of no value to the system.

4.3 SUMMARY

This chapter has presented the framework for a maintenance management system which would be appropriate for the Massachusetts Department of Public Works. This system should provide Massachusetts with improved capability for addressing the two important questions of: "How much maintenance should we do?" and "How can we do that maintenance most efficiently?"

The elements to be included in the system are:

Highway Features Inventory

Maintenance Standards

Assessment Techniquet

Prioritization Techniques

Performance Budget

Scheduling Procedures

Reporting Procedures

Control Procedures

System design should assure that the system remain dynamic. Explicit and periodic attention should be given to updating and refining the system over time.

CHAPTER 5

SUMMARY, CONCLUSIONS & RECOMMENDATIONS

5.1 SUMMARY

The objective of this thesis is the development of the framework of a maintenance management system appropriate for the Massachusetts Department of Public Works.

The enormous demands for maintenance and the heavy financial burden they represent, clearly indicate the need for a more objective approach to the problem of managing the highway maintenance function than has traditionally been used. Chapter 2 presents a composite of 17 existing maintenance management systems in the United States, illustrating the current "state of the art". Chapter 3 illustrates how maintenance is currently being managed in Massachusetts, with a summary of some of the weaknesses inherent to that approach.

Chapter 4 presents the basic system elements which should be incorporated in a maintenance management system for Massachusetts. These elements have been selected for the purpose of providing to the department an objective approach to the basic maintenance questions of how much maintenance to do and how then to do it most efficiently. These basic maintenance considerations were also discussed.

5.2 CONCLUSIONS

In the light of present demands it is impossible to manage highway maintenance efficiently on the basis of good engineering judgment and historical data alone. There must also be objective analysis and reference standards within the context of a formalized system.

The Massachusetts Department of Public Works is in need of a formal maintenance management system. The Massachusetts highway user would be the ultimate beneficiary of such a system through increased highway quality levels, decreased user costs, decreased maintenance expenditures, or combinations of those benefits.

5.3 RECOMMENDATIONS

The Massachusetts Department of Public Works should immediately take the steps required to design and implement a maintenance management system. The current economic trends make this course of action more imperative because, although there are costs associated with the system design and implementation, public agencies must be able to analyze carefully alternative programs competing for limited funds. Further, after these programs have been objectively evaluated and selected on the basis of maximum overall public good,

the agency must carry them out in the most efficient manner possible in the light of modern technology.

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APPENDIX 1

MAINTENANCE WORK ACTIVITY LIST
(State of Alabama)

Roadway and Shoulder Maintenance

- 601 Spot Premix Patching
- 602 Major Premix Patching
- 603 Skin Patching
- 604 Strip Patching
- 605 Joint Filling
- 606 Blading Unpaved Roads
- 607 Major Patching Unpaved Roads
- 608 Blading Unpaved Shoulders
- 609 Spot Patching Unpaved Shoulders
- 610 Clipping Unpaved Shoulders
- 614 Other Roadway and Shoulder Maintenance

Drainage Maintenance

- 615 Patrol Ditching
- 616 Shovel Ditching
- 617 Cleaning Minor Drainage Structures
- 618 Repairing Minor Drainage Structures
- 624 Other Drainage Maintenance

Roadside Maintenance

- 625 Mowing
- 626 Herbicide Treatment
- 627 Brush and Tree Cutting
- 628 Erosion Control
- 629 Spot Litter Pickup
- 630 Full Width Litter Pickup
- 634 Other Roadside Maintenance

Traffic Operations Maintenance

- 635 Sign Maintenance
- 636 Centerline and Edgeline Painting
- 637 Pavement Message Painting
- 638 Guardrail Maintenance
- 639 Traffic Signal/Street Light Maintenance
- 644 Other Traffic Operations

(continued)

APPENDIX 1 (continued)

Structure Maintenance

- 645 Bridge Cleaning
- 646 Bridge Painting
- 647 Minor Repairs of Bridges
- 648 Major Repairs of Bridges
- 649 Movable Span Maintenance
- 650 Tunnel Maintenance
- 654 Other Structure Maintenance

Minor Maintenance Improvements

- 656 Other Roadway/Should Improvements
- 657 Roadside Improvements
- 658 Drainage Improvements
- 659 Traffic Operations Improvements
- 664 Other Improvements

Winter and Emergency Maintenance

- 665 Snow and Ice Control
- 666 Emergency Maintenance
- 667 Road Patrol

Service Activities

- 670 Installing Driveway Pipes
- 671 Work for Other S.H.D. Units
- 672 State Institution Work
- 673 Weigh Station Operations
- 674 Rest Area Maintenance
- 675 Bridge Inspection
- 676 Structure Attendant
- 677 Tunnel Operations
- 679 Other Service Activities

Overhead and Support Activities

- 680 Materials Handling and Storage
- 681 Equipment Transfer
- 682 Equipment Service and Repair
- 683 Standby Time
- 684 Training
- 689 Other Overhead/Support Activities

(continued)

APPENDIX 1 (continued)

Captive County Betterments

695 Captive County Betterments

Special Maintenance

696 Resurfacing

697 Structure Improvements

698 Other Maintenance Bureau Projects

WORK ACTIVITY	INVENTORY UNIT	WORK UNIT	ANNUAL QUANTITY BY ROAD CLASS				
			01	02	03	04	05
Spot Premix Patching	Paved Lane Mile	Ton Mix	0.10	0.80	0.00	2.00	0.00
Major Premix Patch	Paved Lane Mile	Ton Mix	0.70	1.00	0.00	1.00	0.00
Skin Patching	Bit. & Bit/PCC LM	Gallon	0.00	25.0	0.0	0.0	0.0
Strip Patching	Bit. & Bit/PCC LM	Gallon	0.0	25.0	0.0	25.0	0.0
Joint Filling	PCC Lane Mile	Gallon	12.0	16.5	0.0	0.0	0.0
Blading Unpaved Rds.	Unpaved Rd Mi	Road Mile	0.0	0.0	0.0	12.0	0.0
Major Patch Unpvd. Rd.	Unpaved Rd Mi	Cubic Yard	0	0	0	100	0
Blading Unpaved Shld	Unpvd. Shld Mi	Shldr Mi	0.00	0.15	0.00	0.15	0.00
Spot Patch Unpvd. Shl.	Unpvd. Shld Mi	Cubic Yard	0.00	4.00	0.00	2.00	0.00
Clipping Unpvd. Shldr.	Unpvd. Shld Mi	Shldr Mi	0.00	0.10	0.00	0.50	0.00
Patrol Ditching	Unpvd. Ditch Mi	Ditch Mi	0.01	0.05	0.00	0.25	0.00
Shovel Ditching	Unpvd. Ditch Mi	Lin. Ft.Ditch	26.4	52.8	0.0	25.0	0.0
Clean Minor Drn. Str	Minor Drn. Str.	Str. Cld.	0.43	0.43	0.00	0.20	0.00

EXAMPLES OF QUANTITY STANDARDS (Alabama)

APPENDIX 2

APPENDIX 3

MAINTENANCE PERFORMANCE STANDARD
(State of Connecticut)

ACTIVITY: JOINT AND CRACK SEALING ACTIVITY CODE 216
EFFECTIVE DATE: 4/1/72
WORK UNIT: Gallons

DESCRIPTION:

Cleaning and sealing of transverse and longitudinal joints reflective cracking in both concrete and bituminous pavement.

CRITERIA:

Loss of seal which allows infiltration of water and foreign material.

CREW SIZE (INCLUDING FLAGMEN)
7 MEN

WORK METHOD

- 2 Truck Drivers
- 1 Distributor Operator
- 1 Compressor Operator
- 3 Laborers

- 1. Place signs and safety devices
- 2. Clean with compressor
- 3. Pre-pack wide or deep joint with appropriate material
- 4. Pour joints
- 5. Light dusting
- 6. Pick up signs and safety devices

EQUIPMENT

<u>NO.</u>	<u>DESCRIPTION</u>	<u>CLASS</u>
1	Compressor	10
2	Dump Trucks	2
1	Distributor	3

MATERIALS

Liquid Bituminous Material
 Sand or Sawdust
 Signs and Safety Devices

PRODUCTIVITY

AVE. DAILY PRODUCTION: 200 Gal.
MAN-HOURS PER WORK UNIT: 0.24

APPENDIX 3 (continued)

OPERATIONAL GUIDELINE

(New York State)

<u>TASK CODE:</u> C41	<u>ACTIVITY:</u> C4	<u>PROGRAM:</u> B-C
<u>DESCRIPTION:</u> Pouring Cracks and Joints	Pouring Cracks and Joints	Pavement Maintenance
<u>METHOD:</u> Portable Heating Kettle		

MAINTENANCE DESCRIPTION

Pouring Cracks and Joints is the sealing of cracks and joints in a paved road surface with heated liquid bituminous material to prevent water from seeping through to the subgrade. All openings over 1/4" wide are to be sealed, preferably with a rubber-asphalt compound, to a level 1/4/" below the surface of concrete pavement and to the surface of flexible pavement. This task is to be performed according to Quality Guidelines, section 1.360.

BASIC CREW

- 1 - Highway Light Maintenance Foreman
- 3 - Laborer

MATERIAL

- Asphalt Crack And Joint Compound
- Rubber Additive
- Kerosene for heater fuel

(continued)

EQUIPMENT

- 1 - Small Dump Truck
- 1 - Portable Bituminous Heating Kettle
- 3 - Pouring Pots
- 1 - Axe
- 2 - Brooms
- 1 - Large Wooden Stirring Paddle
- 1 - Dry Chemical Fire Extinguisher

METHOD AND JOB DUTIES

1. The truck is loaded at the Residency with a full day's requirement of crack and joint material, rubber additive, kerosene and small tools.
2. One laborer is assigned to tending the heating kettle. He checks it at the Residency to insure that it is half full at that point and, if not, fills it to that level. The heating kettle is towed to the work site with the burner turned off while towing. The burner is lit at the work site. This one laborer stays with the kettle, stirring the material with the wooden paddle to maintain an even mix of rubber additive and asphalt and recharging the kettle. Barrels are split open and the asphalt broken into chunks with the axe. Material is added at the back of the kettle to avoid plugging the outlet.

(continued)

APPENDIX 3 (continued)

3. Two laborers fill the cracks and joints with the hand pouring pots.
4. All cracks and joints in Portland cement concrete pavement are to be filled to 1/4" below level with the road surface, so that when the slabs are fully extended in summer, material does not reach the road surface. All cracks and joints in flexible pavements should be filled flush with the pavement surface.
5. Direction of pouring is constant. Pour to the end of the road that is to be sealed then turn around and start back. When making the first pass on 2 lane highways, all transverse cracks and joints on the right lane are poured as well as the centerline and edge joint. The return trip in the adjacent lane necessitates that only the transverse cracks and joints be filled. On multilane highways, the longitudinal joint and transvers joints in the lane occupied by the vehicle should be poured in the first pass and other lanes poured in subsequent passes.
6. At quitting time, the kettle is shut off at the worksite and left 1/2 full with crack and joint material in preparation for the next work day. The kerosene tank is also filled. The crew then travels back to Residency towing the heating kettle.

(continued)

APPENDIX 3 (continued)

Note:

Use safety procedures as prescribed in the N.Y.S.H.M.S. Safety Manual. Crew size does not include safety men.

OPERATING RATE

316 gal. per 8 hr. day

39.5 gal. per hr.

APPENDIX 4

TYPICAL M.D.P.W. MAINTENANCE ACTIVITIES

PHYSICAL MAINTENANCE

The following routine maintenance operations, replacements and minor additions although not all-inclusive, are types of work which are considered to be physical maintenance.

Roadway Surfaces

Scarifying, reshaping and restoring material losses

Applying dust palliatives

On bituminous or concrete surfaces, patching, repairing, surface treating, joint filling and mudjacking

Replacement of traveled way and shoulder in kind for less than 500 continuous feet

Resurfacing of concrete, brick or bituminous pavements with bituminous materials of less than 3/4 inch thickness

Replacement of unsuitable base materials in patching operations

Shoulders and Side Road Approaches

Scarifying, reshaping and restoring material losses

Applying dust palliatives

Patching and repairing all bituminous types, including base

Resealing bituminous types

Reseeding and resodding

(continued)

APPENDIX 4 (continued)

Roadside and Drainage

Reshaping of drainage channels and side slopes

Restoration of erosion controls

Cleaning and repairing culverts

Removing slides

Mowing and tree trimming

Replacing topsoil, sod, shrubs, etc.

Replacement with essentially the same design of curb, gutter, riprap, underdrain and culverts

Structures

Cleaning, painting and repairing

Replacements with essentially the same design, of rails, floors, stringer and/or beams

Replacement of walls in kind

Repair of drawbridges and ferries

TRAFFIC SERVICES

The following operations performed by maintenance personnel, although not all-inclusive, are considered to be traffic services to the public.

Snow

All operations resulting from snow, such as erection of snow fences to minimize snowdrifts and the actual removal of snow from the traveled way.

(continued)

Ice

All operations to reduce hazard due to icing of the road way surface such as sanding, the application of chemicals, opening of inlets and waterways, actual removal of ice as by scraping, and in some instances the supplying of heat.

Traffic Control and Service Facilities

Painting of pavement stripes and markings

Painting, repairing and replacement in kind of signs, guardrail, traffic signals, lighting standards, etc.

Maintaining rest areas and sanitary facilities

Replacement of roadside rest areas in kind

Additions of small numbers of conventional traffic control devices including signs.

Servicing highway and traffic control devices.

The furnishing of power for highway lighting and traffic control devices and the regular replacement of parts such as light bulbs.

Road Services

The cost of services performed directly for road users, among which are supervision of roadside rest areas, cleaning operations on roadsides, motor vehicle repair and towing services and operation of information booths.

(continued)

APPENDIX 4 (continued)

BETTERMENT

Improvements to a highway which enhance traffic operation thereon or increase the value or life of the facility, or its component parts, are considered to be betterments, provided such improvements are not so extensive as to be classed as construction or reconstruction. Modifications and additions of the type indicated in the following paragraphs are considered to be betterments.

Roadway Surfaces

The improvement of a surface to a higher type for 500 feet or more.

Resurfacing of concrete, brick or bituminous pavements with bituminous material $3/4$ inch or more in thickness for a length of 500 continuous feet or more.

Replacement of existing pavement with one of higher standard for 500 feet or more.

Widening of existing pavements (with or without resurfacing) without change in the number of lanes.

Addition of auxiliary lanes such as speed-change, storage or climbing lanes.

Addition of less than 500 feet of frontage road in any one mile.

(continued)

APPENDIX 4 (continued)

Shoulders and Side Road Approaches

Resurfacing, stabilizing or widening of shoulders for a length of 500 continuous feet or more and side road approaches.

Alinement, Profile and Superelevation

Minor changes in alinement and profile such as easing horizontal curves and eliminating irregularities in the profile.

Regrading and resurfacing to introduce or increase superelevation on curves.

Regrading and resurfacing to improve sight distance where such work does not exceed 1000 feet per mile.

Roadside and Drainage

Widening the road

Substantial flattening of side slopes.

Substantial addition to landscape treatment such as top-soil, sod, shrubs, trees, etc.

Extending old culverts and replacing headwalls.

Replacing a culvert with a facility of greater capacity.

Installation of additional pipe culvert or additional structure with a span not greater than 20 feet.

Installation or extension of curb, gutter or underdrain for a length of less than 500 feet in any one mile.

(continued)

APPENDIX 4 (continued)

Structures

Replacement of rails and floors to a higher standard.

Widening of bridges which are 100 feet or less between abutments.

Extensions and new installations of walls involving not more than 8 cubic yards of structural material.

Replacement of walls to a higher standard.

Traffic Control and Service Facilities

Replacement of all major signs on a route with a substantially improved set of signs.

In isolated cases, installation of a new or replacement of an old sign with one of superior design, involving oversize illumination or overhead installation.

Installation of traffic signal controls at intersections and protective devices at railroad grade crossing.

Installation of a lighting system or expansion of an existing system.

Extension or new installation of guardrail for 500 continuous feet or more.

Installation of new facilities for roadside rest areas or complete replacement with major modifications.

Channelization improvement of an intersection without substantial change in the scope of the original layout.

(continued)

APPENDIX 4 (continued)

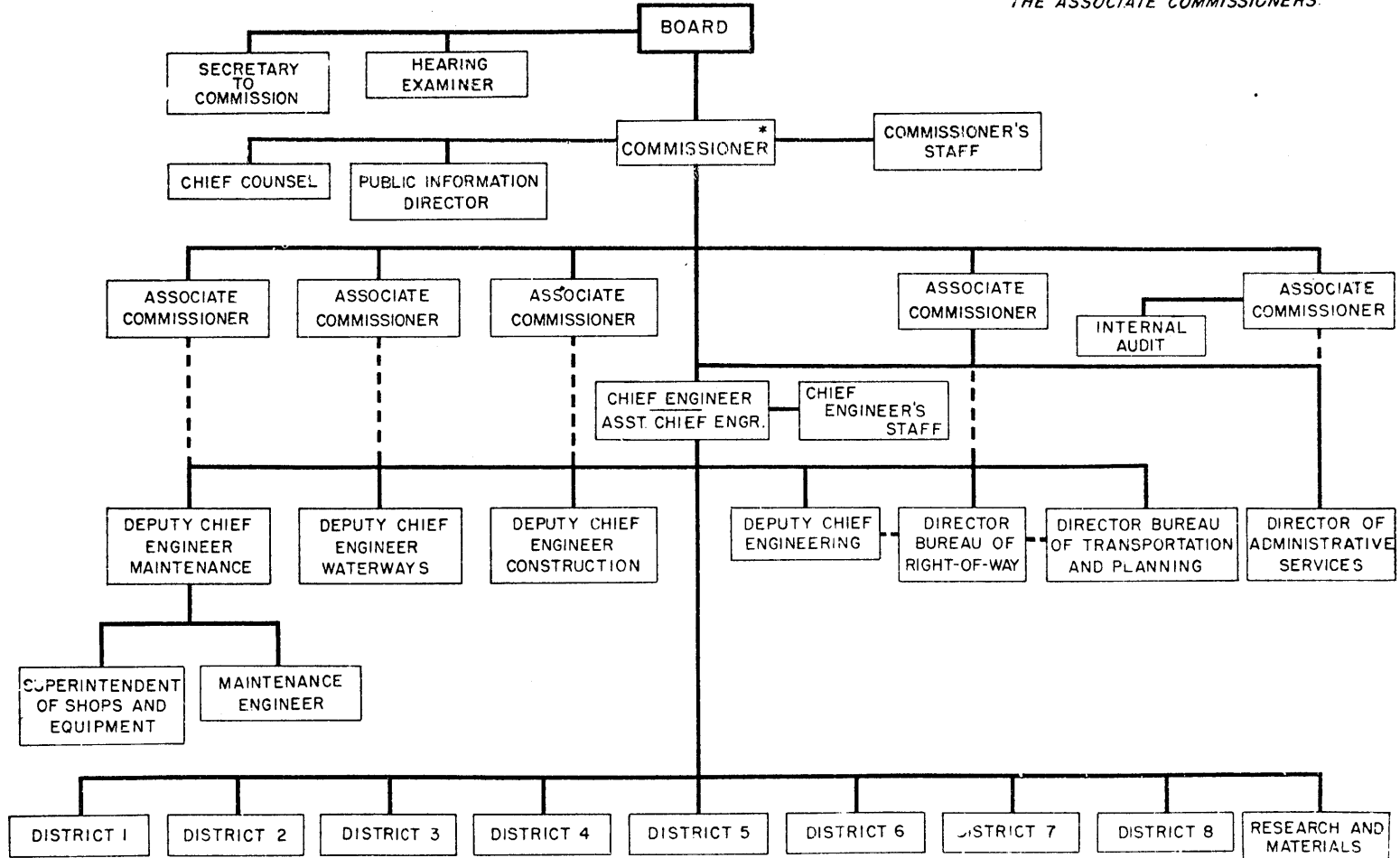
Miscellaneous

Sidewalks are considered betterments (The Department of Public Works, if requested by a municipality, will construct sidewalk up to but not including the surface. The municipality must agree to be responsible for: placing of the surface, securing all slope and drainage easements, claims from abutters, snow and ice control services and future maintenance. They must also agree that no assessments will be made against the abutters for the State portion of the work).

COMMONWEALTH OF MASSACHUSETTS

DEPARTMENT OF PUBLIC WORKS
ORGANIZATION CHART

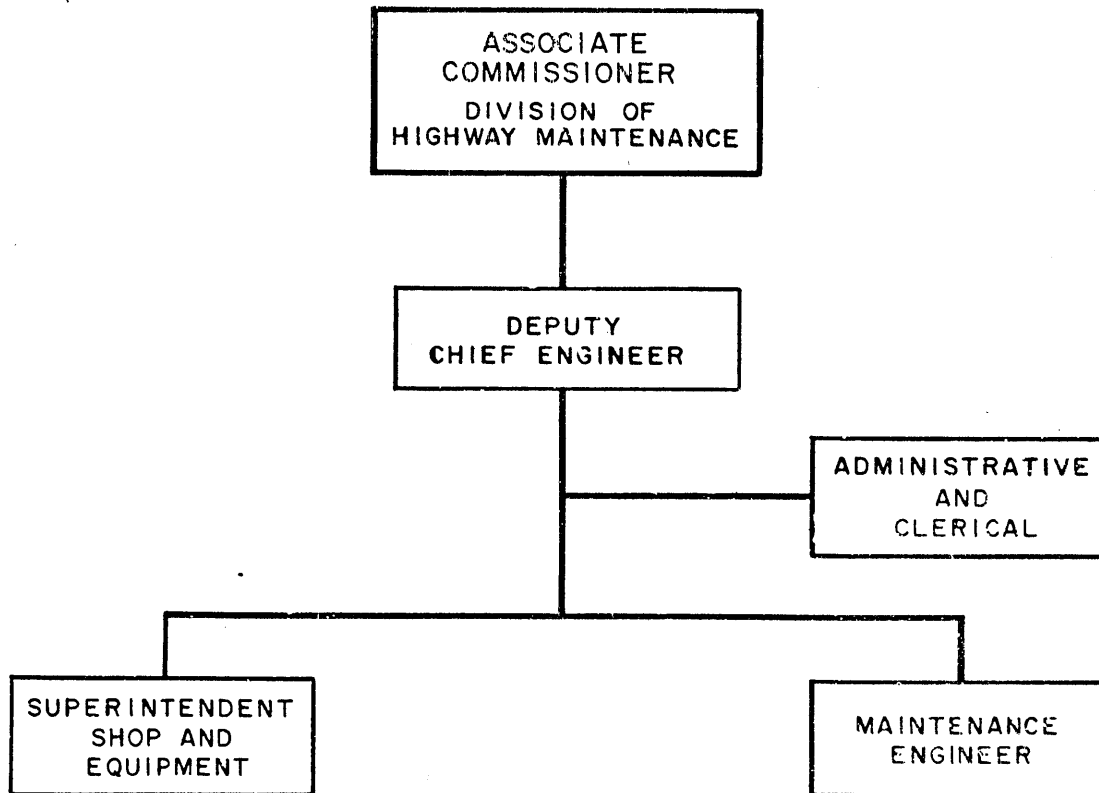
* ALSO FUNCTIONS AS ONE OF
THE ASSOCIATE COMMISSIONERS.



COMMONWEALTH OF MASSACHUSETTS
DEPARTMENT OF PUBLIC WORKS

HIGHWAY MAINTENANCE DIVISION

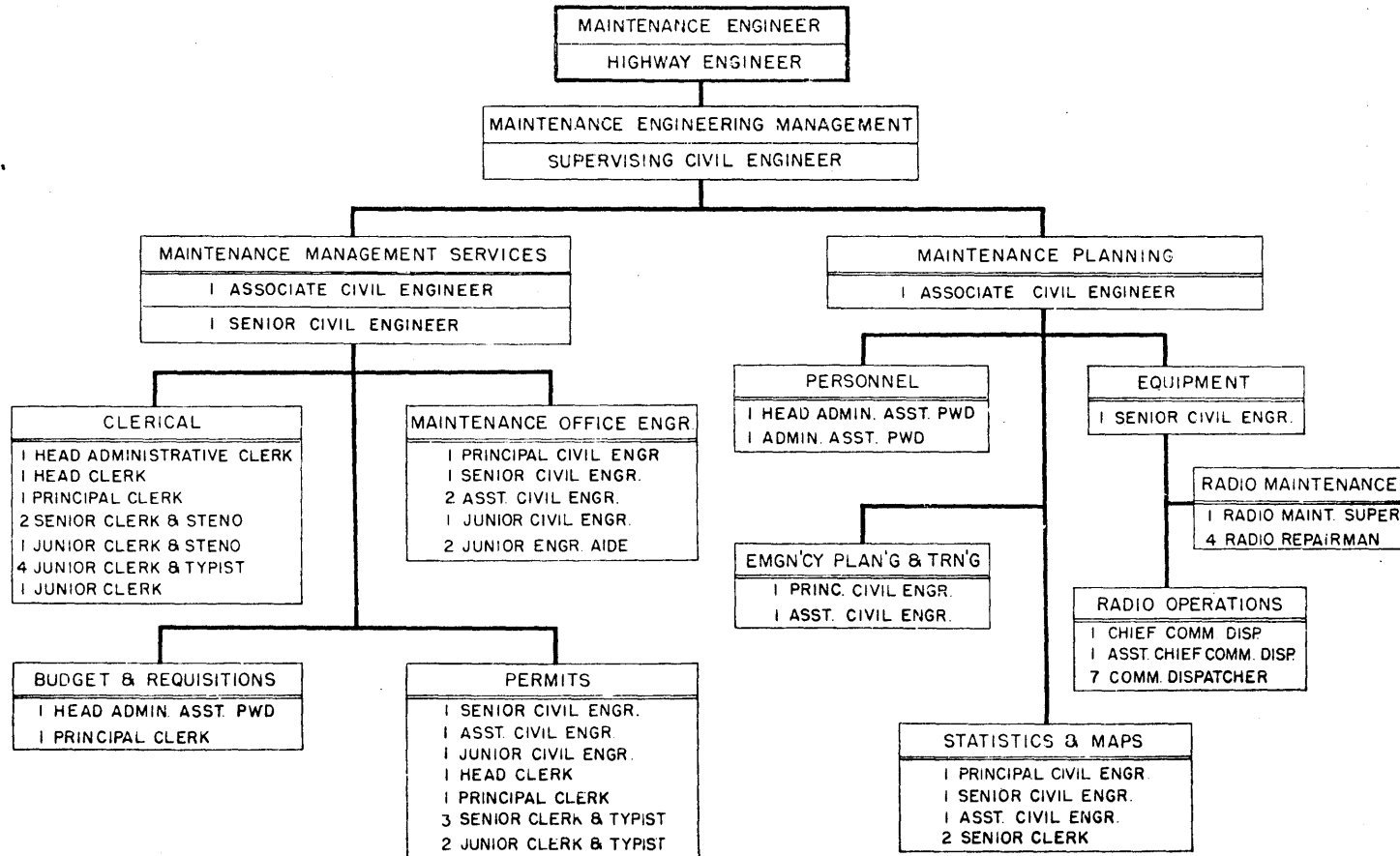
ORGANIZATION CHART



APPENDIX 5
(continued)

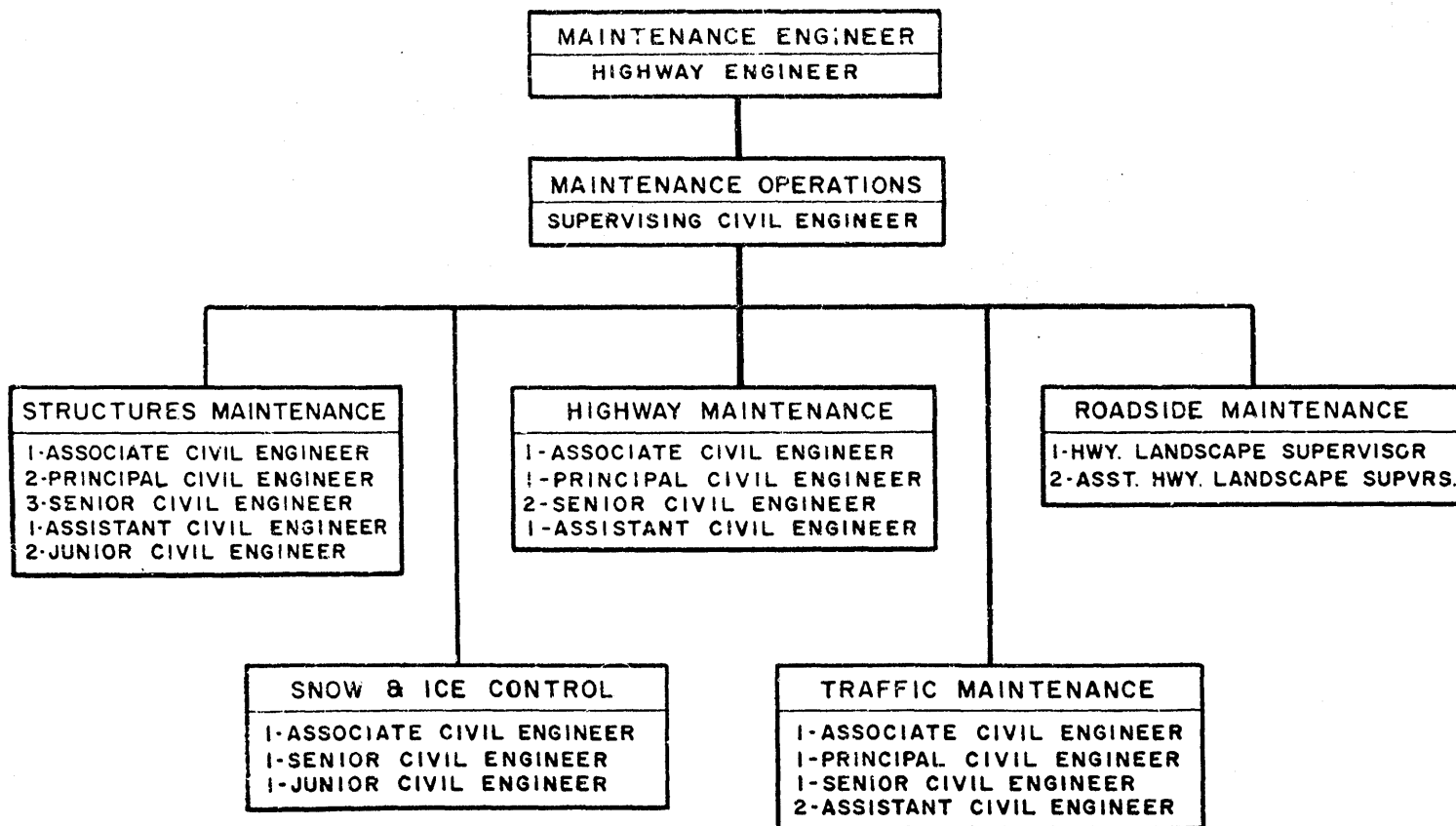
COMMONWEALTH OF MASSACHUSETTS
DEPARTMENT OF PUBLIC WORKS

BOSTON MAINTENANCE SECTION ORGANIZATION
(MANAGEMENT)



APPENDIX 5
(continued)

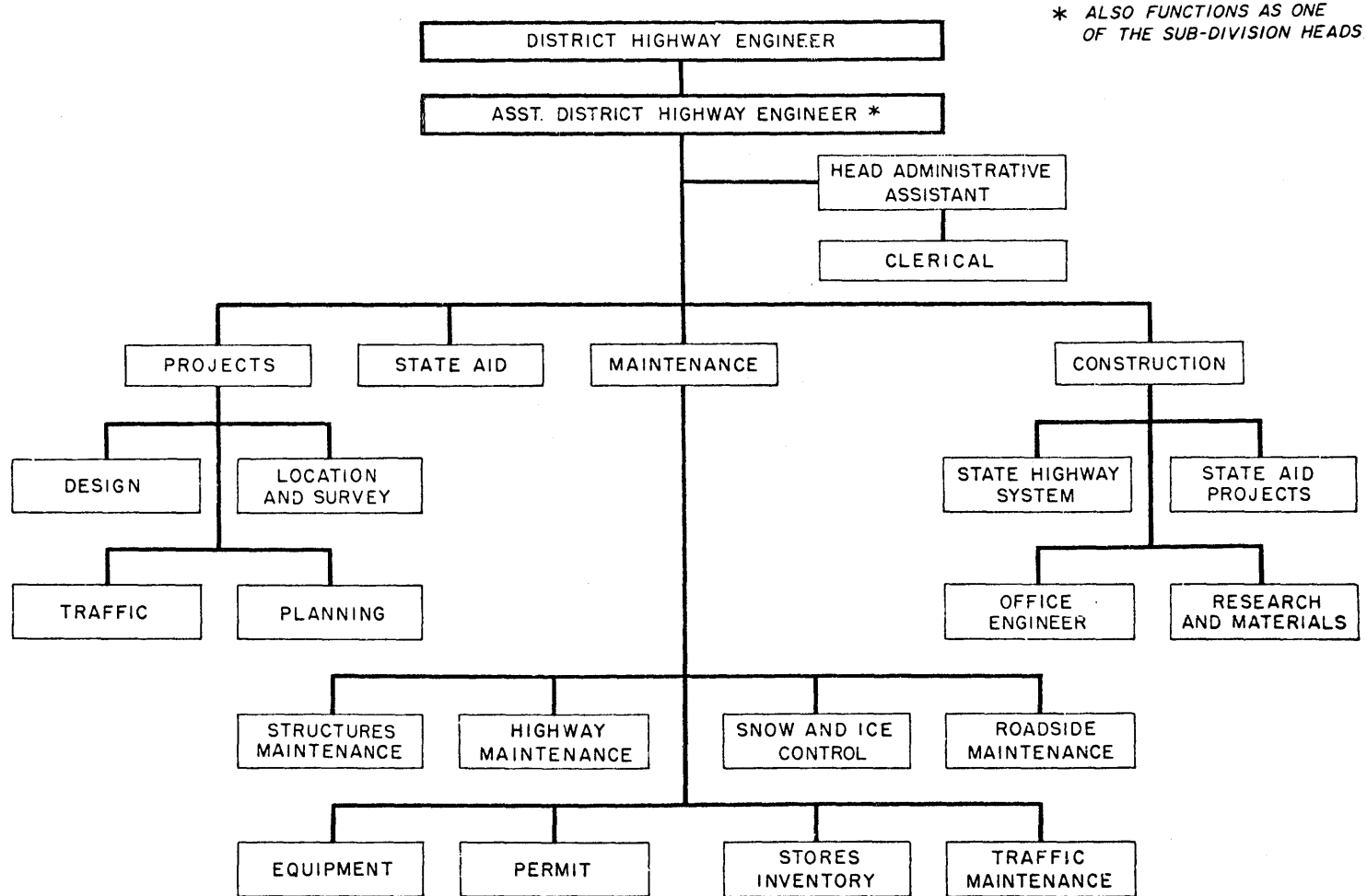
COMMONWEALTH OF MASSACHUSETTS
 DEPARTMENT OF PUBLIC WORKS
 MAINTENANCE SECTION ORGANIZATION (BOSTON OFFICE)
 (OPERATIONS)



APPENDIX 5
 (continued)

COMMONWEALTH OF MASSACHUSETTS
DEPARTMENT OF PUBLIC WORKS

DISTRICT ORGANIZATION



APPENDIX 5
(continued)

COMMONWEALTH OF MASSACHUSETTS
DEPARTMENT OF PUBLIC WORKS

General work assignment to foremen will be from District Maintenance Engineer and the Assistant District Maintenance Engineer as most foremen are concerned with work of two or more units and work priority will be established by them, based on advice from his engineers assigned to the various units.

STANDARD DISTRICT MAINTENANCE ORGANIZATION

