# Computer-Aided Maintenance Management

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A maintenance management system (MMS) allows managers to organize and control maintenance work. A computer-aided maintenance management system (CAMM) is being developed to provide local highway agencies with a tool for developing and implementing an MMS in an economical manner. The CAMM consists of three modules: the MMS development module, the MMS data base module, and the MMS analysis module. The three modules are integrated to function as a unit. The development module allows management to tailor the elements of the MMS, such as maintenance activities, performance standards and quantity standards, and road distresses most likely to be encountered, to the agency's needs. The data base module allows the user to establish and edit the road inventory, pavement condition, personnel, equipment, and material data bases. The analysis module runs the developed MMS. The software will generate performance budgets and schedules for the selected work. CAMM helps managers schedule, budget, and select activities for road maintenance and provides road authorities with the schedule and budget needed to secure political support and funding for adequate road maintenance.

A maintenance management system (MMS) allows managers to organize and control maintenance work. MMSs use information on pavement maintenance needs, available equipment and personnel, and scheduling data to generate work programs and performance budgets for roadway maintenance. MMSs are widely used by state highway agencies and large municipal and county highway agencies. The technology is equally applicable to smaller agencies.

The Federal Highway Administration supports the transfer of technology to local highway agencies through the Rural Technology Assistance Program and technology transfer centers. Under this program, the FHWA sponsors the development and teaching of a 2-day course on MMSs. The workbook for the course provides sufficient detail to allow a small highway agency to establish a manual system (*1*). However, because of the low cost and ready availability of microcomputers, it is believed that a computerized version of the system would be a greater benefit to potential users.

Highway agencies placed several restrictions and conditions on the program, including

1. Use of a DOS-based microcomputer with 640k of RAM and a hard disk,
2. Menu drivers to minimize the need for computer knowledge by the user,
3. Default selections whenever practical (defaults are limited to flexible pavements for the initial development),
4. Maximum flexibility in the options available to the user for defining the needs of the local agency, and
5. Use of a high-level computer language so the program can be released to users without the need to purchase proprietary software (PASCAL was selected for program development).

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Although the program was developed to be as easy to use as possible, it does not relieve the user of understanding maintenance management and its application in a specific case. Hence, the name selected for the program was Computer-Aided Maintenance Management, or CAMM.

Figure 1 shows the organizational structure of CAMM. The maintenance management process is accomplished in three modules for (*a*) development and editing of the system, (*b*) data base development and maintenance, and (*c*) maintenance management analysis.

The development module allows the user to tailor the required elements of the MMS to the needs of the highway agency. The data base module uses the results of the development step to create the data base structure required by the agency and allows the user to enter and edit data elements. Finally, the analysis module performs calculations, including developing budgets and scheduling work.

Figure 1 shows the CAMM menus for module selection. The desired option is highlighted by pressing arrow keys and selected by pressing the return key.

## DEVELOPMENT MODULE

There are several approaches to developing and implementing an MMS. The following discusses the elements in MMSs (see Table 1) and the CAMM implementation.

### Objective Statement

The objective statement defines the maintenance goals for the management unit. Without clearly stated goals, the management will not know what is expected from the system, and it will be difficult to evaluate and improve the system.

The objective statement section in CAMM allows the user to write an objective statement using a simple line editor. The objective statement contains qualitative information about the goals and limitations of the system. An objective statement is an important part of an MMS, but the objective statement in CAMM does not interact with the other components of the system.

| Main Modules | Components |
|---|---|
| DEVELOP/EDIT | Objective Statement<br>Work Activities<br>Road Class<br>Resources<br>Quantity Standards<br>Performance Standards<br>Inventory<br>Pavement Condition<br>Calculation Units<br>Reports and Forms<br>Matching |
| DATA BASES | Road Inventory<br>Road Distress<br>Maintenance Needed<br>Maintenance Accomplished |
| ANALYSIS | Performance Budget<br>Scheduling<br>Crew-Day Cards |

**FIGURE 1 CAMM menu system.**

### Work Activity

A work activity describes a specific function that will be performed by the maintenance crews, such as crack sealing, mowing, and pothole patching. Only those activities that require a significant amount of work by the agency should be defined. More than 200 work activities are performed by highway maintenance. The FHWA training course recommends developing an MMS for the 35 to 45 activities that represent approximately 80 percent of the work. Use of a greater number of work activities can create confusion and excessive paperwork. A system that handles the majority of the important activities and is easy to use is preferable to a detailed system that may not be implemented because of its complexity. CAMM is designed to handle 60 work activities.

The work activity section of CAMM allows the user to define the work activities needed. The user is provided with a default list of work activities. The user selects from these or creates others matching the needs of the agency.

CAMM provides several information fields for each work activity. The information required for a work activity consists of the following:

- A numeric code is used to identify the activity. It is preferable to have similar codes for each major work activity (for example, 100 to 199 for roadway surface and 200 to 299 for shoulders). This maintains consistency in the system. Duplicate codes are not allowed by CAMM.
- A unique name describes the activity. Duplicate names are not allowed by CAMM.
- Possible starting day is the earliest time in the year that an activity can be performed.
- Expected starting day is the normal starting date for the activity.
- Expected ending day is the normal ending date for the activity.
- Possible ending day is the latest possible ending date for the activity.
- Frequency is the frequency of the activity. This can be seasonal, routine, when needed, and so forth.

The major work activities defined in CAMM are roadway, shoulders and approaches, roadside, major structures, traffic services, snow and ice control, service functions and overhead, extraordinary maintenance, drainage, and miscellaneous. These activities can be used in the default format, added to, or edited, to customize the system to the user's needs.

The possible starting and ending dates for an activity indicate the earliest and latest dates that the activity can be performed. The expected dates define the normal dates for performing the activity. The difference between them allows flexibility in the scheduling of work.

### Road Class

The amount of maintenance required on a road can depend on the classification of the road. The road class screen of CAMM allows the user to define the class of roads used by the agency. The default classes are primary, secondary, and arterial. The classes can be edited by the user.

### Resources

Resources consist of labor, equipment, and material. Each type of resource is defined on a separate screen. When scheduling is performed, the resources data base is checked to verify the availability of the resources.

Labor class, number of employees, hourly wage, and employment status are recorded in the labor section (for example, truck driver, 12, $10.00/hr, permanent). Labor includes permanent and temporary employees.

The type of equipment used and the unit cost are recorded in the equipment section [for example, dump truck (5 $yd^3$),

TABLE 1 ELEMENTS OF MAINTENANCE MANAGEMENT

| | |
|---|---|
| OBJECTIVE STATEMENT | The objective statement defines the maintenance goals for the management unit. |
| WORK ACTIVITIES | A work activity describes a specific function that will be performed by the maintenance crews, such as: crack sealing, mowing, pothole patching, etc. |
| ROAD CLASS | Road classification allows the agency to allocate different levels of work to the various road classes. |
| QUANTITY STANDARDS | A quantity standard is an average annual value that specifies how often a work activity should be performed in order to maintain the road feature at the desired level of service. |
| PERFORMANCE STANDARDS | The performance standard is a written procedure for each work activity. |
| INVENTORY | This is an inventory of the physical characteristics of the road, such as: width, number of lanes, number of gutters, etc. |
| PAVEMENT CONDITION | Road condition consists of the type, extent, and severity of the distress experienced by the pavement. |
| CALCULATION UNITS | The units are the units used for all calculations in MMS. |
| RESOURCES | This is the type of resources used in a MMS. The resources consist of: labor, equipment, and material. |
| REPORTS AND FORMS | Reports and forms are used by management to monitor and schedule work. |

$25.00/hr]. The equipment can be owned by the agency or rented when needed.

Unit costs for the materials are provided in the material section (for example, concrete, $50.00/yd$^3$.

CAMM compares the available resources with the performance standards. Only the entries in the resources section are allowed in the performance standards. This ensures consistency within the management system.

### Quantity Standards

A quantity standard specifies how often a work activity should be performed to maintain the road feature at the desired level of service. The quantity standard is expressed as the number of work units per year. For example, the quantity standard for lawn mowing could be 4.0 mowings per year. For a slurry seal that is performed every 10 years, the quantity standard would be 0.1.

Each road class can have a unique quantity standard for each work activity. For example, the amount of pavement maintenance required on a primary road will usually be more than that required on a secondary road; therefore, the primary road would have a larger value for that particular quantity standard. CAMM requires the user to enter a quantity standard for each work activity. The program compares the quantity standard list with the work activities list and identifies the work activities that need a quantity standard.

### Performance Standards

A performance standard defines the method for performing a work activity. Performance standards specify the most efficient combination of crew size, type of equipment, and materials required for a particular activity. The performance standard also includes an estimated average daily production rate for each work activity.

The elements of a performance standard implemented in CAMM include

- Name and code corresponding to the work activity (each work activity has a unique performance standard),
- Description and purpose of the work activity,
- The criteria for performing the work activity,
- The number and skill level of crew required,
- The types and amount of equipment required,
- The types and amount of material required,
- A verbal description of the recommended work method, and
- The average daily work expected to be performed by the crew.

CAMM provides a default list of performance standards corresponding to the default work activities list. The user can edit the default performance standards. New performance standards can be added when the user has defined a new work activity. CAMM checks that each work activity has a performance standard.

### Inventory

An effective management system must have a data base consisting of the physical attributes of the road such as section identification, district, area, width, number of lanes, gutters, pavement material, and bridges.

One of the most important requirements of an MMS is the need to uniquely define each pavement section. The default method provided in CAMM is based on the road name, beginning point, and ending point. The beginning and ending points can be mileposts, cross streets, or other physical features. Each road section should have homogeneous features such as width, gutters, pavement type, and so forth.

CAMM provides management with a default list of inventory items. The user is free to select any of these items or to add new items that meet the needs of the agency. The inventory elements defined in this module are used to define the structure of the inventory data base.

### Pavement Condition

Pavement condition is defined by the type, extent, and severity of the pavement distress. Whereas average pavement maintenance budgets can be estimated on the basis of historical data, development of work schedules for the repair and maintenance of specific pavement sections requires knowledge of the condition of the pavement sections. This fact was not recognized in the FHWA training course, so the pavement condition feature of CAMM is a new development. Traditionally, pavement condition surveys are associated with pavement management systems. The two systems, however, should be integrated and should operate from common pavement inventory and conditions data bases. In broad terms, the pavement management system could be used for the selection and scheduling of major rehabilitation and overlay projects, and the MMS could focus on the repair of specific pavement distresses and other maintenance activities.

The pavement condition section of CAMM provides the user with a default list of pavement distresses for flexible pavements (*2*) (see Figure 2). The user can select distresses from this list or add new distresses. Descriptions and severity information are provided by CAMM for each of the default distresses. The user can edit the descriptions or add descriptions that meet the needs of the agency. Each pavement distress must have a description of how severity and extent are measured. In addition, a work activity for the repair of the distress is required.

### Calculation Units

The calculation units section defines the calculation units for each work activity. For example, the units for pothole patching could be in tons, square yards, and so on. These units will be used for all budget calculations. CAMM provides a default unit for each activity. The user can edit the units or add units for new work activities. All work activities must have calculation units.

### Number of Workdays

The number of workdays section provides the user with a default list of the number of available workdays for each month. The user can edit the list if necessary. The number of workdays is required for the planning analysis of work schedules.

### Reports and Forms

Reports and forms are used by management to monitor and schedule work. An efficient MMS requires continual updating. The management agency must be aware of daily work progress.

The reports and forms section allows the user to customize reports and forms. The reports and forms are generated in the analysis module. A default list of forms and reports is available. Reports and forms can be selected and edited from this list. If a report or form that does not exist is needed, the agency can create it. The following is a list of the available reports and forms:

- *Crew-day cards* is a report that summarizes the time involved in performing the activity and the amount of material used. Management gives each crew a crew-day card specifying the amount of work to be completed for that day. At the end of the day the crew specifies the amount of work completed and the amount of time and material used for the work activity. Management reviews the crew-day card to determine if

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DISTRESS TYPE

 ALLIGATOR OR FATIGUE CRACKING
 BLEEDING
 BLOCK CRACKING
 CORRUGATION
 DEPRESSION
 JOINT REFLECTION CRACKING FROM PCC SLAB
 LANE/SHOULDER SEPARATION
 LANE/SHOULDER DROPOFF OR HEAVE
 LONGITUDINAL AND TRANSVERSE CRACKING
    (NON-PCC SLAB JOINT REFLECTIVE)
 PATCH DETERIORATION
 POLISHED AGGREGATE
 POTHOLES
 PUMPING AND WATER BLEEDING
 RAVELING AND WEATHERING
 RUTTING
 SLIPPAGE CRACKING
 SWELL
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**FIGURE 2 Pavement distresses (2).**

the crew is on schedule. This information is used in the analysis module to update the budget and schedule.

- *Work schedules* is the schedule of work planned.
- *Activity summary reports* on monthly, quarterly, and annual bases compare the completed and planned work.
- *Maintenance needed reports* record the location, type of problem, and date reported. This information is entered in the road distress data base and used by the analysis module in budgeting and scheduling work.
- *Condition survey* is a form, filled out by the survey crew, that specifies the distress of the pavement.

### Matching

Each pavement distress can have a level of severity ranging from low to high. CAMM allows the user to select the number of severity levels for each pavement distress and to match the work activity for each severity level. For example, alligator cracking with a low severity requires only a skin patch, whereas a high severity requires a full-depth patch.

## DATA BASE MODULE

The MMS data base module allows the user to enter inventory and pavement condition data for each road segment and for the resources used. The fields in the data base are defined by the development module. Each road section must be uniquely defined by the section identification fields. The data base module checks the section identification fields to ensure a unique identification for each road section.

User-accessible data bases in CAMM include (*a*) road inventory, which contains information for each road segment, such as length, width, type of asphalt, and so forth; and (*b*) pavement distress, which contains the type of pavement distress found in each road segment.

The data base module allows the user to view or edit one record at time, search or sort the data base on a user-specified field, and scroll or browse through the data base.

The program automatically checks for unique identification of road sections. The road inventory data base establishes the master list of road sections. A section must be defined in the inventory data base before data on maintenance and condition can be entered.

In addition to the user-generated data bases, CAMM generates data bases for needed and accomplished maintenance. The maintenance needs data base is generated on the basis of quantity standards and is used to generate the performance budget. The maintenance accomplished data base is generated when the user enters the data from the crew-day cards. This data base provides historical information about the productivity of the maintenance crews. This data base will be extremely useful for evaluation and revision of the MMS practice of the agency.

## ANALYSIS MODULE

The analysis module determines the activities to be performed and calculates the funding required for labor, equipment, and material. The work load is scheduled and balanced. Reports are generated to assign work and to oversee progress.

The analysis module generates the performance budget, schedules work, updates schedule and budget with crew-day cards, and generates reports.

### Performance Budget

The performance budget is computed on the basis of the required work. Performance budgets allow management to present a list of work activities and the cost of each activity. This helps management show why the money is needed.

The performance budget uses information provided in the development and data base modules to perform the necessary calculations.

The performance budget module has three parts. The initial performance budget generates the initial budget, the update performance budget is based on feedback from crew-day cards, and the remaining budget generates the remaining cost until the end of the analysis period.

For a user-defined analysis period, the initial performance budget function generates the following reports: needed work for each road section; crew days required for each work activity; total cost for all work; cost for each activity; cost for each activity for each road segment; and labor, equipment, and material requirements.

The update performance budget function (*a*) uses the updated schedule to revise the budget and (*b*) accounts for increases in crew days due to the crew falling behind schedule or the addition of new work activities.

The remaining budget function computes the amount of money required to complete all work activities for a specified analysis period. This is the difference between the updated budget and the amount of work completed.

The results of the performance budget can be categorized into various costs for each activity as follows: total cost to perform a specific work activity, total crew days required, cost of labor per day, cost of equipment per day, cost of material per day, total labor cost for the activity, total equipment cost for the activity, total material cost for the activity, and total cost for each road segment.

### Scheduling

CAMM provides the user with a spreadsheet for scheduling and leveling work loads. The user is able to schedule work within the allowable range of months defined in the work activity section of the development module.

The user can override the range of months. For example, if an activity is not normally performed between November and January, the user can override CAMM and schedule within these months if necessary.

Seasonal fluctuations occur in the work load, which result in either an oversupply or an undersupply of resources. For example, a large labor force required in the summer would result in too large a work force for the winter. It would be more efficient to balance the work load throughout the year. Work load leveling is a technique that balances these fluctuations. A range within 5 percent of the work load is adequate for work load leveling.

CAMM totals the work scheduled for each month. The user can level work loads by adding or subtracting crew days for each month.

The initial schedule, which works like a spreadsheet, displays a list of all work activities in a column and all the months in the analysis period in a row. It allows the user to schedule crew days for each month, keeps a running total of the number of crew days that still need to be scheduled, sums the crew days for each month to allow for work load leveling, displays possible and expected starting and stopping months, and prompts the user to save the changes.

The update schedule, which has a column for "additional crew days," will search the road condition data base to see if new work activities are needed. If so, it will add to the schedule, and the required crew days will be added to additional crew days. It allows the user to schedule additional crew days and indicates that a work activity is completed.

### Crew-Day Cards

Crew-day cards are issued every day for each activity. The crew-day card informs the crew of the amount of work to be completed for each day. At the end of the day, the crew records the amount of work completed on the crew-day card in terms of the daily productions units specified in the performance standard. For example, the crew would record the number of unpaved road miles that were graded that day.

The data are entered into CAMM, which determines whether the crew is on schedule. If the crew is behind schedule, CAMM calculates the additional crew days required to complete the activity and adds them to the schedule under the heading "additional crew days." Management must then update the schedule to accommodate the additional crew days. Once the schedule has been updated, the performance budget must be updated.

The crew-day card module compares the expected daily work rate with the actual amount of work completed. It adds additional crew days to the schedule if they are required to complete the work activity. It allows the user to indicate when the activity is finished. It updates the schedule to show that a job is finished and updates the Previous Maintenance Data Base.

### Generating Reports

The user specifies what reports to print. CAMM searches the appropriate data base and generates the report. The report can be defined in terms of road segment, district, or area.

## OPERATING CAMM

CAMM operates on a DOS-based microcomputer with a hard disk. Before running the program, the distribution disk should be copied into a unique path on the hard disk. From the DOS prompt in the program path, execution of the program is initiated by typing CAMM. An initial screen is displayed, followed by the main module selection menu.

CAMM is menu driven. The menus are arranged in the hierarchy given in Figure 1. The user selects an item from the menu with arrow keys and ENTER. The ESC key is used to return up the hierarchy of menus.

A menu is displayed for the selected element. The user either enters data or selects an option from the submenu. When an option in the menu is completed, the title for the option changes from white to magenta. CAMM does several consistency checks in the development module. For example, CAMM checks the performance standard resource requirements to ensure that the needed resources are defined in the resource list. If a performance standard is edited to include a resource that is not on the list, the color of the resource title can change from magenta (complete) to white (incomplete), warning the user that the resource list must also be

edited. All elements of the development module must be completed in a coherent fashion before proceeding to the analysis module.

## SUMMARY

MMSs are used by state highway agencies for the efficient planning and scheduling of maintenance activities. FHWA is interested in transferring this technology to local highway agencies with limited resources. The Roads and Streets Maintenance Management Systems short course effectively presents MMS concepts, but a microcomputer program of this method is needed for cost-effective implementation.

CAMM's menu-driven approach allows the user to develop an MMS that meets the needs of the agency without having to learn or understand computer programming. Because of CAMM's structure, the user can implement an MMS without using consultants or exhaustively studying MMS methods and procedures. The internal checks built into the development module ensure that all the required elements of the MMS are defined in a consistent manner before an analysis is performed. Coordination between the development and data base modules ensures that the correct structures for the data bases are defined.

The data base module allows the user to create and edit the required data elements. The data bases include both inventory and pavement condition data that are needed for developing maintenance budgets and schedules. The structure of the pavement condition data base promotes interfacing with a pavement management system.

The analysis module generates the usual reports needed by management. A spreadsheet function facilitates the development of a balanced work schedule. Field data from crew-day cards can be entered to update both the data bases and the work schedule.

Development and documentation of CAMM is scheduled to be completed by December 1990. Preliminary alpha testing of the system indicates that CAMM is a powerful yet easy-to-use tool. The next step in the development of the program will be implementation by local highway agencies.

## REFERENCES

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