Use of the Preconstruction Engineering Management System To Develop, Schedule, and Monitor the North Carolina Highway Capital Improvement Program

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The preconstruction engineering procedures required to develop highway improvement programs are inherently complex. Procedural complexity along with normal increases in the size of improvement programs have tended to focus attention on the need for new management systems capable of improving the efficiency and effectiveness of highway programming personnel. The Federal Highway Administration (FHWA) made an effort in the late 1970s to improve highway agency management practices by initiating the development of an information system called the Preconstruction Engineering Management System (PCEMS). The primary objective for this study was to test and evaluate PCEMS' potential for accomplishing the preconstruction functions of highway project scheduling and progress monitoring. Testing and evaluation results showed that the system could be effective in administering a large capital program and was subsequently used to schedule nearly sixteen hundred highway projects in the 1990–1996 Transportation Improvement Program. PCEMS will be used to monitor progress of that scheduled work during 1990 and determine the percentage of those projects that meet construction contract-letting dates. This paper describes how PCEMS was implemented and how it is being used to assist the preconstruction engineering staff with the scheduling phase of program development in North Carolina. Many of the study findings should be of interest to preconstruction engineering managers who must make scheduling decisions that involve balancing the money, time, and manpower required by the highway program developmental process.

The engineering tasks required for highway improvement program development and control have become very complicated. Engineers are increasingly concerned that management tools currently used for the development, scheduling, and monitoring of multimillion dollar highway programs are no longer adequate (*1*). Recently the Federal Highway Administration (FHWA) has made a concerted effort to assist highway agencies in improving their management practices. In 1979, the FHWA initiated a study to develop more effective management techniques (*2*). That study resulted in a prototypical computer system called the Preconstruction Engineering Management System (PCEMS).

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PCEMS is based on an operations research networking technique known as the Critical Path Method (CPM). CPM now enjoys wide acceptance among highway construction officials because it offers an excellent management technique for defining the most efficient approach to accomplishing any highway construction work program. Although several highway agencies have reported saving both time and money by using CPM during the construction phase of highway programs, it has seldom been used for the preconstruction phase (*2–4*).

Therefore the main thrust of this research effort was to investigate how the CPM concept could be used to more effectively manage all the preconstruction engineering activities required for implementation of the North Carolina Transportation Improvement Program (NCTIP). More specifically, the primary objective was to test and evaluate PCEMS' potential for accomplishing the preconstruction functions of highway project scheduling and progress monitoring.

The CPM provides the mathematical foundation for a major component of PCEMS known as the multiple project scheduling subsystem. This PCEMS subsystem can provide managers with a more rational approach for overcoming decision-making weaknesses in all preconstruction activities ranging from project programming to contract award. It could be expected that an improvement in management practices would lead to a less costly, more timely accomplishment of program objectives.

METHODOLOGY

The PCEMS is a computerized model designed to manage highway preconstruction engineering processes consisting of numerous activities. A computer is required to handle the large amount of data collected for or generated by those preconstruction engineering activities. The 71 computer programs contained within the PCEMS environment permit the creation, operation, maintenance, and reporting of numerous data files including CPM networks, activity responsibility, personal availability, planning values, calendar work days, project characteristics and status, multiple project schedules, and an archive of completed projects. These data files are utilized in the functional areas of (a) program development, (b) multiple project scheduling, (c) progress monitoring, and (d) activity planning value updating.

Program development is the functional area in which information is generated for use by executive level management for work program development. Multiple project scheduling is the functional area in which projects in the work program are scheduled in a multiple-project environment while considering personnel availability.

Progress monitoring is the functional area in which progress of highway projects is assessed and compared to the schedules estimated to meet desired bid awarding dates.

Activity planning value updating is the functional area that provides for the capability of updating estimated planning values to reflect changed work conditions and technical processes (*5–7*).

DATA SOURCE

The PCEMS is designed to use data currently residing in files that are generated by a highway agency's normal planning, design, construction, operational, and administrative processes. Data extracted from such existing files serve as the original input required for PCEMS computer runs that build several basic data files. These minimum data requirements that initiate the program development phase of PCEMS include a CPM network file, an activity responsibility file, a base planning value file, a calendar file, a person-hour availability file, a schedule period file, and a project characteristics value description file.

Provisions exist in the PCEMS model for both the development and updating of its data base. New data may be added and old data changed or deleted in any PCEMS file at any point in the preconstruction engineering process (*5–7*).

OVERVIEW OF THE NORTH CAROLINA HIGHWAY PROJECT DEVELOPMENT PROCESS

The highway project development process includes many preconstruction engineering activities from planning, programming, design, and traffic operations. Activities from each of these functional areas must be properly interfaced and linked as a continuum to ensure the timely delivery of a safe, dependable, and cost-effective highway service (*8*).

A generalized procedural framework providing that interface is shown in Figure 1. The framework and time requirements as shown in this figure are very similar to those used by the NCDOT and indicate that the programming phase of the developmental process consists of 15 steps. The scheduling step is now being handled by the Program and Policy Analysis Branch using the PCEMS. PCEMS was used to schedule almost 1,600 highway projects in November 1989 and will be used to help monitor progress of the scheduled work during 1990.

Based on that feedback, management can determine the system's overall effectiveness by the percentage of projects meeting the scheduled construction contract-letting dates. Such information will also suggest changes in system parameters that may be required to increase that effectiveness over time.

Because of its potential for work-progress monitoring and a proven scheduling capability, PCEMS may become one of the most important management tools used for the annual update of NCTIP.

Highway projects considered for inclusion in the annual update of NCTIP are identified and initiated from both technical and nontechnical sources. Technical sources include the Highway Performance Monitoring System (*9*), the Bridge Management System (*10*), and the Urban Transportation Planning Process (*11*). Nontechnical sources include private citizens, special interest groups, and elected officials (*12*).

Currently the NCTIP has a seven-year planning horizon and contains more than 1,500 projects. Figure 2 illustrates how a wish list of highway projects is generated each year and subsequently analyzed, prioritized, programmed, and finally published as the NCTIP (*4,13*).

ORGANIZATION, MANAGEMENT, AND STAFFING REQUIREMENTS

Organizational structure and management style are the most important factors contributing to the successful implementation and operation of PCEMS. Teamwork between management and the technical support staffs provides the only assurance that PCEMS will work. Active participation in the implementations of PCEMS by agency personnel already involved in the preconstruction engineering process encourages teamwork.

It should also be noted that implementation team members from the chief executive officer to the working technician can develop an understanding of and commitment to the philosophy and function of PCEMS. A firm commitment from top management is certainly required to assure the initial success of system implementation, but even greater commitment and support from working level engineers and technicians is required to ensure the operational success of PCEMS over time.

The PCEMS implementation manual proposes an organizational structure designed to accomplish the participation, understanding, commitment, and support objectives mentioned above. That organizational proposal has structural components consisting of a steering committee, a computer operations group, and several technical panels. Proposal specifications relative to personnel composition, duties, responsibilities, roles, and working relationships are given in an Implementation Manual (*1*). NCDOT engineers used those specifications with minor modifications to successfully implement PCEMS in December 1985 with an implementation staff of approximately 30 engineering professionals.

The Steering Committee

The steering committee was composed of the Highway Administrator and his staff. During PCEMS implementation, the steering committee provided policy and procedure guidance, approval authority for technical recommendations, and top management support.

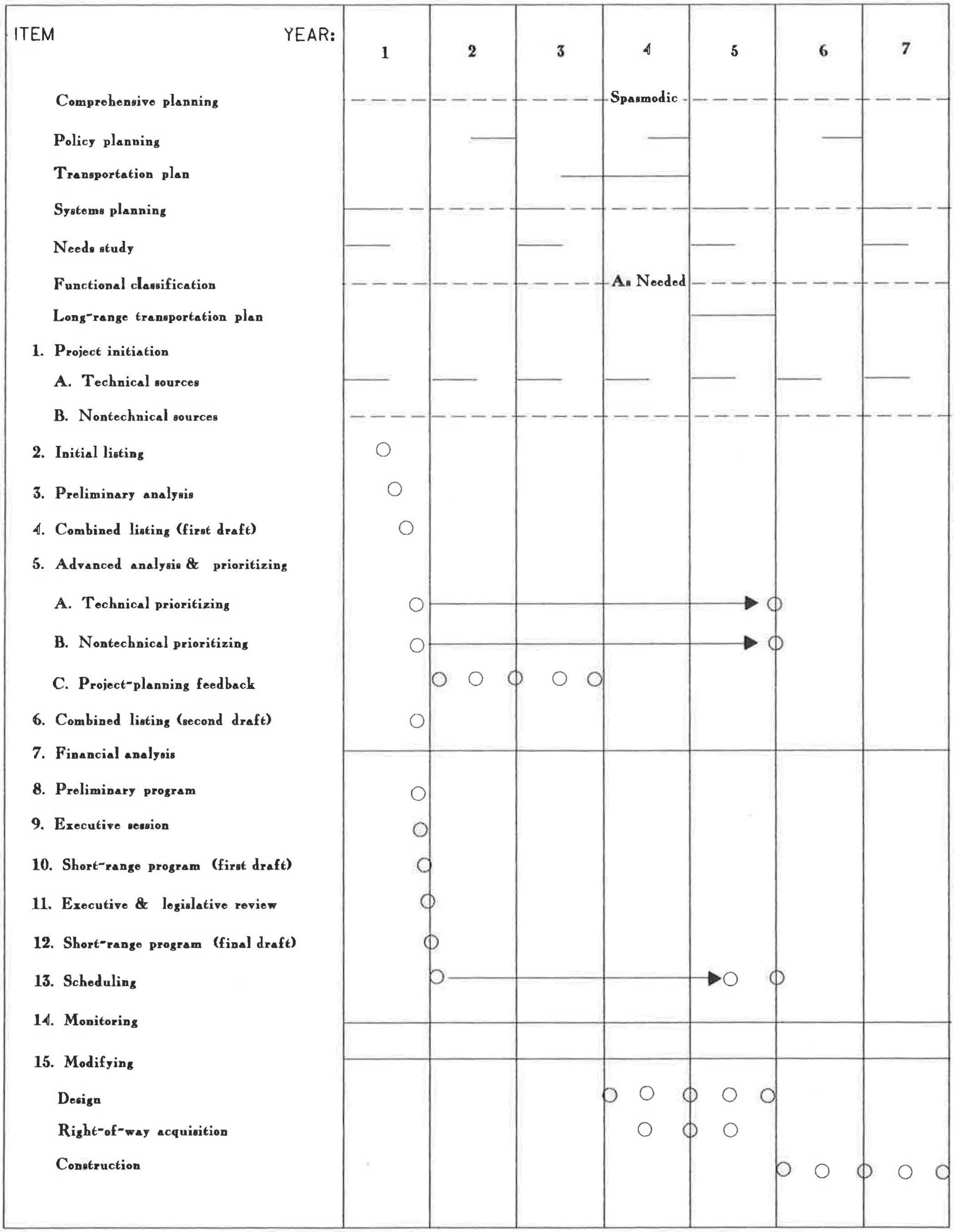

FIGURE 1 Planning, programming, and design process phasing (*7*).

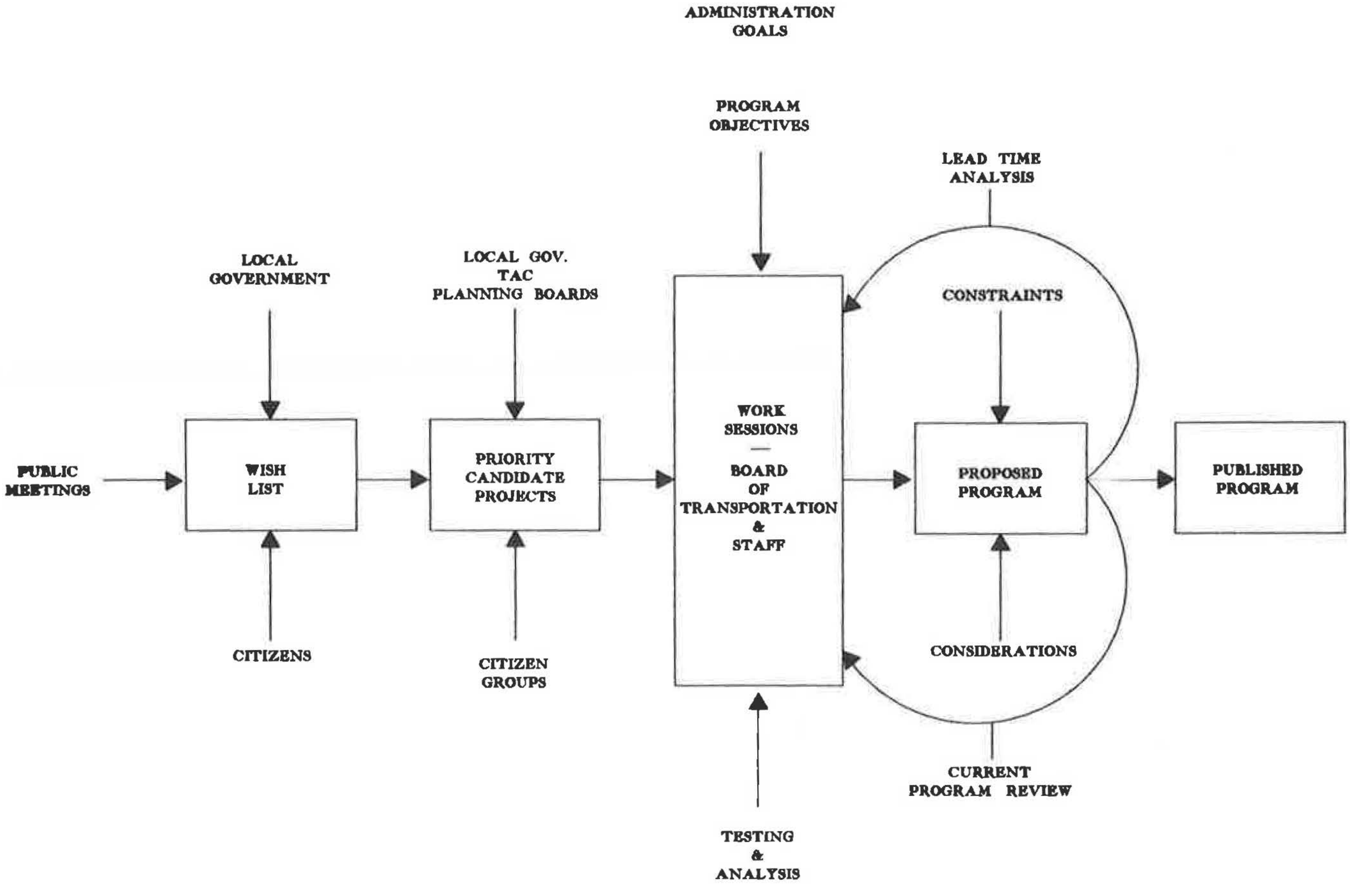

FIGURE 2 Highway needs identification (*6*).

Computer Operations Group

The computer operations group implemented the computer system and was responsible for staff training, documentation of the internal procedures required for continuous system operation, and liaison between the steering committee and the technical panels. The computer operations group consisted of two management operation engineers and a data processing representative.

Technical Panels

The technical panels contained two or three engineering specialists in the functional areas of planning, right-of-way, geotechnical investigation, location and surveys, traffic operations, design, hydraulics, and materials engineering. The technical panels worked with the computer operations group to develop detailed activity descriptions, time requirements, and logical networks used to build computer models that accurately represent the ongoing North Carolina Department of Transportation (NCDOT) highway project development process.

Technical panel responsibilities included developing the task, activity, and network hierarchy required for CPM of analysis and scheduling; developing base person hours, base elapsed time, complexity factors for each activity and additives used by PCEMS to calculate total activity time requirements; and determining and recommending improvements to increase the efficiency and productivity of the NCDOT preconstruction engineering process.

FACTORS, PRINCIPLES, AND PROCEDURES FOR MODIFICATION, IMPLEMENTATION, AND OPERATION OF PCEMS

As with any prototypical computer system, PCEMS must be modified and adapted to the organizational and operational requirements of the implementing agency. Such efforts are greatly influenced by factors relative to the agency's internal fiscal, legal, and administrative policies. PCEMS' scheduling and monitoring subsystems are sensitive to these influencing factors. The literature discusses how such influencing factors can be identified and reflected in modification principles that in turn can serve as the rational basis for the procedural steps required for system implementation and subsequent operation (*5,13*).

Factors Influencing the Modification of PCEMS

The most important factors influencing the modification and adaptation of PCEMS to a particular highway agency are

- Type, form, and stability of the highway capital improvement program per se;
- Agency's organizational structure;
- Management's goals and information requirements;
- Preconstruction work analysis, scheduling, reporting, and monitoring policies; and
- External agency actions.

Guiding Principles for Modification of PCEMS

The literature suggested that the main principles serving as criteria for the conceptual redesign or modification of PCEMS should be reflected from the influencing factors listed (*13,14*). The most important of those principles relative to PCEMS are restated as follows:

1. A prioritized improvement program is the primary input for project scheduling.
2. The importance of the project scheduling effort is directly related to the size and complexity of the highway network as well as increased funding availability.
3. Project scheduling must be integrated with financial procedures.
4. Top level management support is essential to a successful project scheduling and monitoring effort.
5. Scheduling and monitoring policies are a function of management goals and objectives.
6. Information needs for each level of management must be met by the project scheduling and monitoring system.
7. Scheduling allows management to balance project workloads with available person resources.
8. Scheduling procedures must be adapted to the agency's existing organizational structure.
9. Responsibility for project scheduling and monitoring functions should be housed in a high level office responsive to the chief executive officer.
10. The project management system must be able to accommodate policy changes.
11. All external review, approval, or coordination activities must be scheduled.
12. Scheduling must be able to accommodate uncontrollable factors such as federal funding action, inflation, labor problems, and changes in technology.
13. Scheduling and monitoring procedures must identify and accommodate legal restraints.
14. Standard agency terms should be used to describe components of the schedule.
15. The complete description of the preconstruction engineering work required for a particular project can be effectively represented by a network of activity arrows.
16. Realistic time estimates must be assigned to each activity.
17. Project schedules must be developed relative to both single- and multiple-project environments.
18. Activity schedule reports should provide scheduling information tailored to meet the needs of management and operations personnel.
19. Utilization of project schedules depends on and is initiated by effective monitoring procedures.
20. Project progress must be monitored regularly.
21. Project activity progress reports should be concise, simple, and timely.
22. The monitoring function should supply the project status information needs for each management level.
23. Progress reports provide management with a means for assessment and a basis for action.
24. Analysis of project status information may alert management to planned schedules not being met.
25. Once it has been determined that a project's planned schedule will not be met, then management action is required.
26. Improvement in project scheduling and monitoring methods enables management to identify and correct the causes of schedule delay.

Procedural Steps for PCEMS Implementation

The following procedural steps can be used to define the sequential process required to initialize use of the PCEMS system (*5*). These steps are reflected from or based upon the 26 scheduling and monitoring principles listed above and discussed elsewhere (*13*).

Step 1: Organize personnel into work centers for each functional area.

Step 2: Identify activities required for each network and define their relationship relative to project type.

Step 3: Estimate activity base-time requirements and define their relationship to project complexity characteristics.

Step 4: Prepare, code, and submit data for computer run to build the activity responsibility, calendar, schedule period, project characteristics value descriptions, report headings, activity networks, base planning time values, and personnel availability files.

Step 5: Code project attribute information for each project to be scheduled and build the project characteristics file.

Step 6: Use the project characteristics and base planning value files as input to generate the activity time and duration file.

Step 7: Distribute the activity time and duration reports to each work center for review.

Step 8: Code any necessary changes to the computer-generated activity times and duration values and submit for a computer override run.

Step 9: Use the updated activity time-duration and network files as input to generate the single project schedules.

Step 10: Distribute the single project schedule to the work centers for their review of the anticipated bid-letting dates and verification of start and finish dates for all project activities.

Step 11: Prepare and submit computer code to update the single project schedule with new or revised bid-letting dates.

Step 12: Prepare and submit code for computer runs that produce the multiproject schedules and reports.

Step 13: Review workload balance and if changes must be made loop back to Step 8. If workload is balanced, then distribute multiproject schedules to management.

Step 14: Prepare and submit code for computer runs that create the manpower report files and produce the short-range bid-letting schedule, the long-range bid-letting schedule, and the personnel utilization reports. Distribute reports to the appropriate management level.

Step 15: Monitor project progress, then prepare and submit code for computer runs updating the project schedule exception and status reports. These reports provide management with a rational basis for corrective action required by those projects not meeting the planned schedule.

COMPUTER FILE DEVELOPMENT

The PCEMS provides computerized file generation support for three distinct phases of the highway project development process. Figure 3 shows how PCEMS files are generated sequentially and suggests how they can be operationally maintained and/or updated during each phase as required. An overview of the data content for several of the more important PCEMS files is provided in the following paragraphs. A complete description of PCEMS' file generation, operation, updating, and maintenance functions is provided elsewhere (*5–7*).

Program Development Phase

NCDOT annually updates and reschedules the highway capital improvement program during the program development phase. Files either created or updated during this phase include CPM networks, activity responsibility, activity planning values, a work day calendar, personnel availability, the schedule period, project characteristics, and activity time and duration.

CPM network file–contains the logical arrangement of activities required for the preconstruction engineering development on each of several highway project types including new construction, reconstruction, rehabilitation, widening, and structures.

Activity responsibility file–provides a description for each network activity and specifies the work center type responsible for accomplishing each activity.

Activity planning value file–contains base estimates of person hours and days duration required to accomplish a particular activity. The computer will automatically adjust the base values according to project type and complexity.

Calendar file–specifies work days possible from 1978 through 2033 and is used for date and duration calculations.

Personnel availability file–provides work center names, managers, and person hours available for each scheduling period in both the single and multiple project scheduling environments.

Schedule period file–contains schedule periods of one, two, three, or four week lengths spanning a maximum of 10 years.

Project characteristics file–contains both general and specific characteristics for each new project that enters the PCEMS and serves as the basis for calculating the complexity and additive factors that may be required for activity time and duration adjustment.

Activity time and duration file–contains the person hours and days duration factors for each project activity. The computer automatically adjusts these time factors relative to the project length and complexity of the information obtained from the project characteristics file.

The program development phase concludes with the creation of the single project activity (SPA) schedule file.

Multiple Project Scheduling Phase

PCEMS actually begins the multiple project scheduling phase by preparing the SPA file for the multiple project scheduling environment and concludes with the creation of the multiple project schedule (MPS) file.

SPA-MPS interface file–contains the single-project activity schedules prepared for input to the multiple project prescheduler.

MPS preschedule file–contains reformatted SPA-MPS records needed by the main scheduling program. The prescheduler program eliminates all SPA-MPS dummy activities (i.e., activities required only for network logic and have no time requirements) and other activities whose late start dates prohibit their multiple project scheduling.

MPS schedule file–contains records of all the scheduled project activities output by the main scheduling program and based on project priority, early start date, and available personnel required to accomplish the preconstruction engineering work.

Progress Monitoring Phase

Activity progress reporting must be timely and accurate so that management can determine how well the actual start and completion dates for each project activity compare with those scheduled by PCEMS. If over time, the average difference between the actual and planned scheduled dates, is significant, then the activity planning value file containing the base time and duration estimates can be adjusted or updated and the entire capital improvement program easily rescheduled.

Progress/expenditure file–contains actual activity start date, completion date, or percentage completion information.

Archived project file–contains all those completed projects removed from active project files but kept for historical reasons.

Base planning value file–contains base estimates of time, duration, and complexity factors that can be modified or updated as revealed through progress monitoring.

PCEMS OUTPUT

Figure 3 shows that the PCEMS generates 18 computer reports. These reports are designed to provide management with timely scheduling and manpower utilization information. PCEMS Report 9 serves as an example and is shown in Figure 4.

In addition to printed reports, real-time monitor displays of reports 10, 11, 12, 16, and 17 can be invoked with the Customer Information Control System (CICS) procedures. These procedures provide an immediate response to management inquiries concerning project status and manpower utilization.

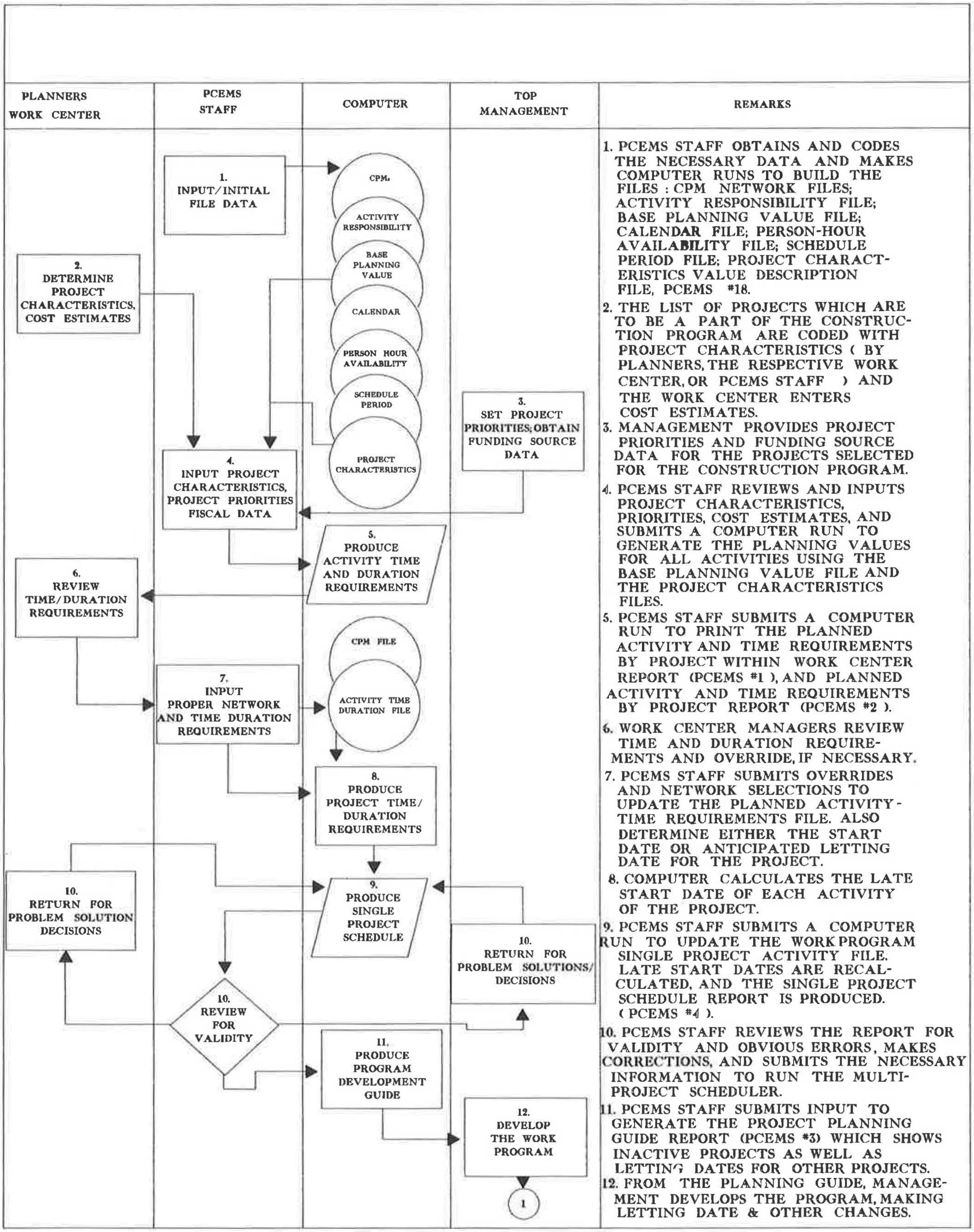

FIGURE 3 Program development, multiple project scheduling, program monitoring, and planning value updating (*1*). (*continued on next page*)

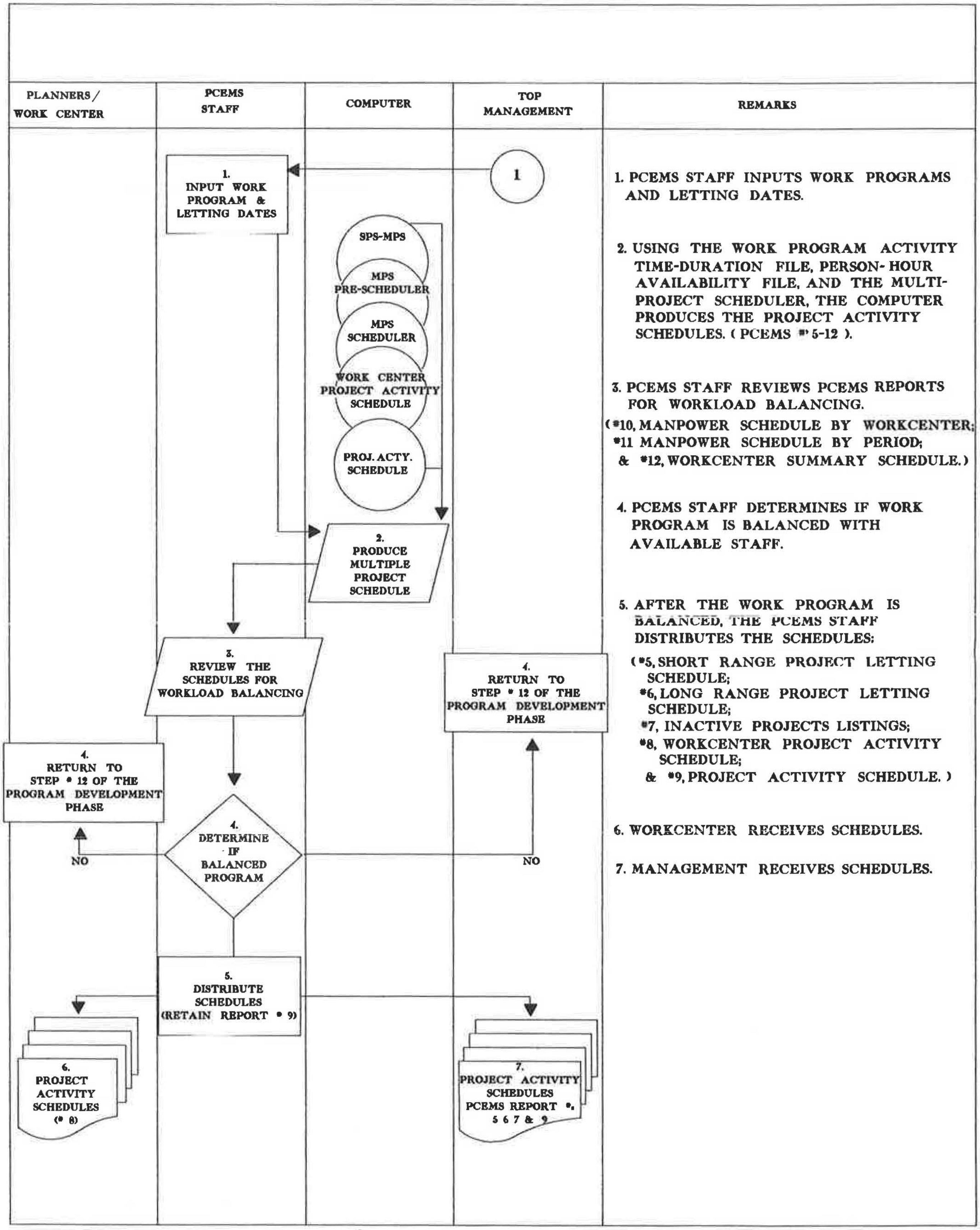

FIGURE 3 *(continued on next page)*

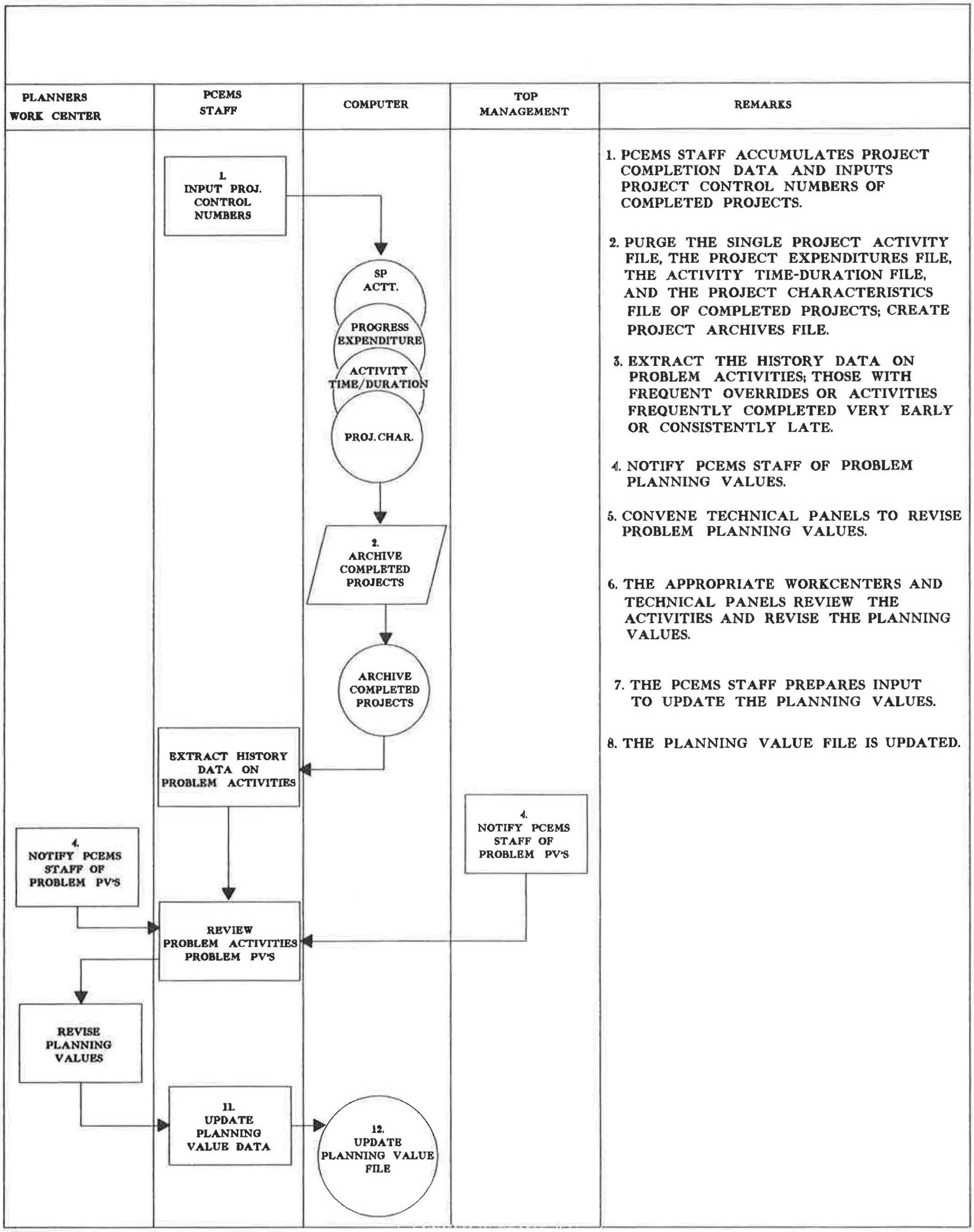

FIGURE 3 *(continued on next page)*

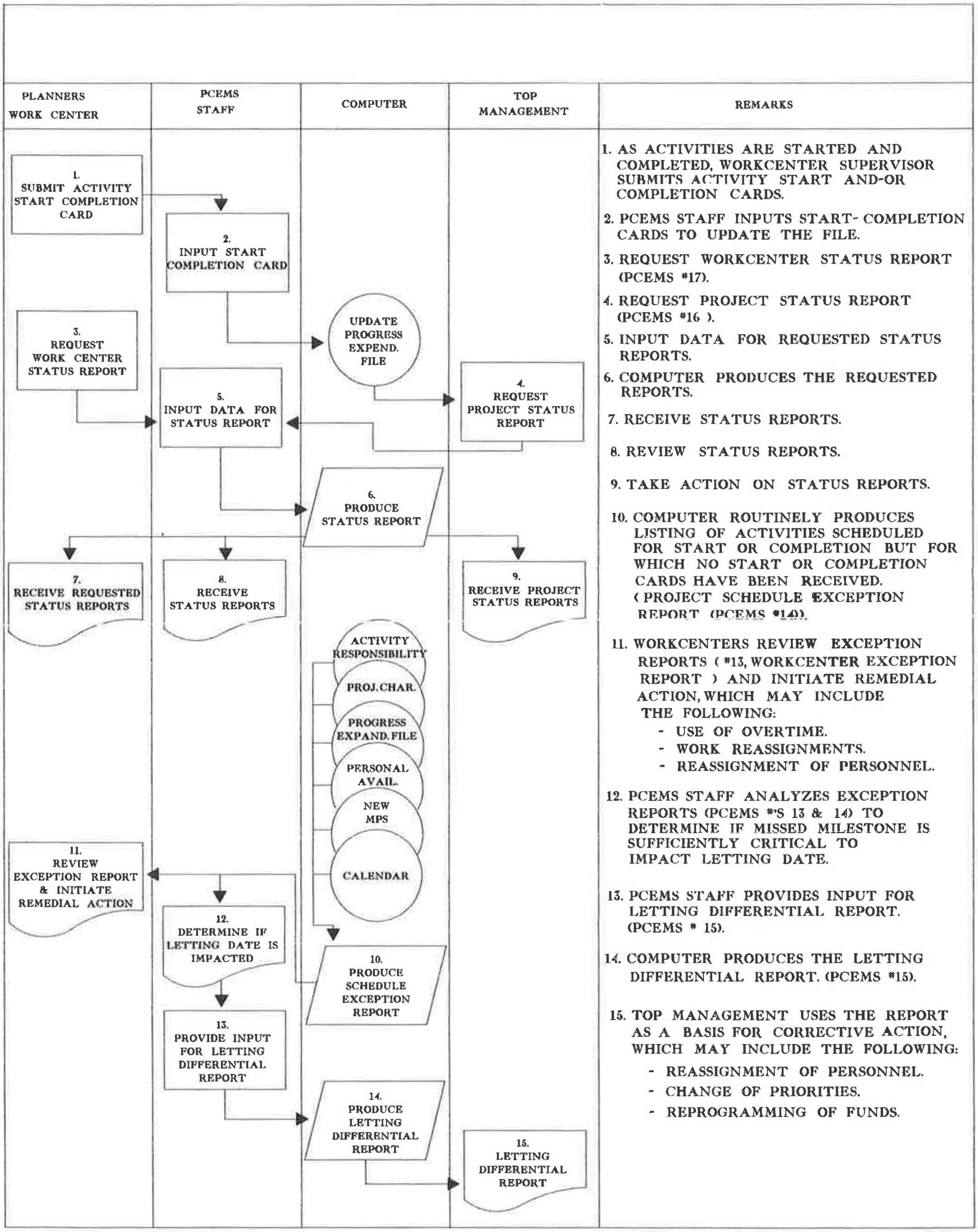

FIGURE 3 *(continued from previous page)*

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PCEMS REPORT #9 NORTH CAROLINA DEPARTMENT OF TRANSPORTATION
PROGRAM NO. HC044200
RUN DATE 12/21/89 P R O J E C T A C T I V I T Y S C H E D U L E

CONTROL NO. 0569 PROJECT NO. B-2572 NEW HENDERSON COUNTY

LOCATION/DESCRIPTION US 176. REPLACE BRIDGE NO. 127

ACT NO.	ACTIVITY DESCRIPTION	WORK CENTER	********** S C H E D U L E D ********** MANHRS	DURATION	START	COMPLETION
A195	PROJ.CONCEPT PREP.EXCEPT "W"	6700	130	14	09/09/93	09/28/93
A701	"W" PROJECT CONCEPT PREP.	7600	10	40	09/09/93	11/03/93
A101	PRLM.ENGR.ENVIR.FUNDS AUTH.	6200	1	10	11/04/93	11/18/93
A112	PRELIM. ENGR. FUNDS AUTH.	7300	1	20	11/04/93	12/06/93
A402	PRELIM. BRIDGE STUDY	3704	8	1	12/07/93	12/07/93
A341	BRIDGE DATA COLLECTION	3804	10	15	12/07/93	12/29/93
A551	TENTATIVE PAVEMENT DESIGN PREP	8400	8	3	12/08/93	12/10/93
A652	HYDRAULIC DESIGN	4400	120	8	12/08/93	12/17/93
A205	MATL (BORROW) DETERM.& REPORT	4000	120	20	12/08/93	01/07/94
A490	DESIGN REPORT TO MRG	3600	2	1	12/20/93	12/20/93
A704	MARKING & DELINEATION DESIGN	7700	5	5	12/20/93	12/28/93
A384	PRELIMINARY SIGNING (FOOTINGS)	3804	8	10	12/20/93	01/05/94
A720	PRELIMINARY SIGNING DESIGN	7800	80	30	12/20/93	02/02/94
A491	DESIGN APPROVAL	3600	2	10	12/21/93	01/06/94
A712	EARLY TRAF.CONT.REQUIR.STUDY	7700	2	5	01/07/94	01/13/94
A214	MATERIALS LAB TESTING	4900	24	15	01/24/94	02/11/94
A221	MATERIALS LAB TESTING & REPORT	4900	78	60	01/24/94	04/18/94
A219	MATERIALS REPORT PREPARATION	4900	1	1	02/14/94	02/14/94
A445	PROVIDE PRELM. CONST PHASE PLN	3704	8	1	04/19/94	04/19/94
A427	PREPARE STRUCTURE RECOM.	3704	8	1	04/19/94	04/19/94
A173	FHWA APPROVAL	7300	1	20	04/20/94	05/17/94
A713	PREP.PRELIM.TRAF.CONTR.CONCEPT	7700	5	20	04/20/94	05/17/94
A428	RECOM. TO STRUCTURE DESIGN	3704	8	1	05/18/94	05/18/94
A340	TYPE,SIZE & LOCATION DESIGN	3804	40	10	05/19/94	06/02/94

FIGURE 4 Example of PCEMS output.

During the course of this study PCEMS report numbers 1–6, 8–12, and 16–18 were printed and used extensively in the program development and multiple-project scheduling phases of the highway project development process for the 1990–1996 NCTIP (*13*). It is anticipated that reports 7 and 13–15 will prove useful for the monitoring phase in 1990.

An explanation of purpose, along with a printed sample showing content and format of the standard PCEMS reports 1–18, is contained in an installation guide (*3*). The report number titles are given in Figure 3.

SUBNETWORKING WITH A MICROCOMPUTER

A PCEMS network may contain a maximum of 300 activities. For a particular project type network, these 300 activities could be scheduled over eight or more years. Given this time frame, it is common for many PCEMS activities to have scheduled durations of 12 months or longer. For example, an activity representing an environmental impact statement (EIS) for an environmentally sensitive project may have a scheduled duration of two years. From a project management perspective, it would be desirable to divide such an activity into several subactivities that could be further scheduled on a weekly or even daily basis.

Because of the maximum activity constraint, the PCEMS does not internally provide this subsectioning capability. Externally, however, subnetworking can be easily accomplished by considering each type of PCEMS network as a supernetwork in which each activity can be broken into smaller, independent subnetworks. Given this conceptualization, work center managers can subsection each PCEMS activity into a logical network of subactivities with weekly or even daily time durations. Such networks can be conveniently scheduled with microcomputers.

An important secondary objective accomplished during this study was to specify a working interface between the mainframe-based PCEMS and microcomputer-based project management systems. A simple description of that interface is to use the activity start date as calculated in the PCEMS multiple-project scheduling environment as a starting point for further scheduling on the microcomputer. This means that an activity as output by PCEMS may have a very long duration that can be rescheduled on the microcomputer to yield weekly or even daily schedules.

SUMMARY

Management of the highway project development process requires consideration of many social, economic, and environmental factors. Over time, such factors tend to increase both in number and degree of complexity for preconstruction scheduling and monitoring activities required by the highway development process. Currently the single most important management tool used for highway project development is perceived to be a good scheduling and progress-monitoring system. There has even been national recognition of the need for a computer system design that could be used by state or regional highway agencies to resolve scheduling and monitoring problems.

In response to that national perception of need, the FHWA developed PCEMS, designed as a prototypical computer system that could be adapted to the management needs of any highway agency. Within the PCEMS environment is a scheduling and monitoring subsystem that management can use to ensure that each highway project in the capital improvement program advances through to the contract-letting date on time and within the budget constraints.

The primary objectives for this study were to (a) install, modify, and adapt the PCEMS scheduling and monitoring subsystem to the particular needs of the NCDOT; (b) use PCEMS to schedule all preconstruction engineering activities for the almost 1,600 projects in the capital improvement program; (c) develop a microcomputer method based on subnetworking concepts that could be used to convert long duration activity schedules output by PCEMS to short duration schedules; and (d) determine the effectiveness of PCEMS as a progress-monitoring tool. Three of these objectives were accomplished by the end of 1989 and study findings should be of interest to highway agency managers at all levels. It is anticipated that the effectiveness of PCEMS as a progress-monitoring tool will be determined in 1990.

FINDINGS

During this study, it was found that the PCEMS would (a) initialize and build several permanent computer files basic to project management of preconstruction highway engineering; (b) accept a prioritized listing of programmed projects and their particular characteristics as primary input from management; (c) schedule the projects relative to resource constraints; and (d) generate 18 reports providing preconstruction schedules for every management level responsible for developing the highway system.

CONCLUSIONS

The ways in which NCDOT engineers use PCEMS to develop, schedule, and monitor the preconstruction process for each project in its seven-year highway capital improvement program is described in this paper. The study focus was testing PCEMS' ability to help preconstruction engineering managers more effectively plan, schedule, budget, and monitor the work progress required in the highway project developmental process.

Based on study findings, it was concluded that PCEMS greatly improves the manager's effectiveness in accomplishing the goals of the highway program by assuring that the bid-letting date for each highway project is met. It is further concluded that PCEMS will continue to provide better scheduling and monitoring information to management which should lead to more effective decision making over time.

A final conclusion was that microcomputers can be used as a subnetworking tool to conveniently convert activities with long duration schedules into subactivities yielding weekly or even daily schedules.

REFERENCES

1. R. A. Johnson, F. E. Kast, and J. E. Rosenzweig. *The Theory and Management of Systems.* New York. McGraw-Hill Book Company, Inc., 1973.
2. *Preconstruction Engineering Management System Implementation Manual.* FHWA, U.S. Department of Transportation, Nov. 1982.
3. *Preconstruction Engineering Management System—Installation Guide.* Prepared by the South Dakota Department of Transportation for the FHWA, U.S. Department of Transportation, June, 1982.
4. *Statewide Highway Planning Procedures.* Prepared by Wilbur Smith Associates for FHWA, U.S. Department of Transportation, 1988.
5. *Preconstruction Engineering Management System—Operations Manual.* Prepared by the South Dakota Department of Transportation for the FHWA, U.S. Department of Transportation, Nov. 1984.
6. *Preconstruction Engineering Management System—Design Manual.* Vol. 1–3, Prepared by the South Dakota Department of Transportation for FHWA, U.S. Department of Transportation, Nov. 1984.
7. *Preconstruction Engineering Management System—Production Control Manual.* Prepared by the South Dakota Department of Transportation for FHWA, U.S. Department of Transportation, Nov. 1984.
8. *Priority Programming and Project Selection.* NCHRP Synthesis Report 48, TRB, National Research Council, Washington, D.C., 1978.
9. L. W. McPherson and M. R. Poole. Use of the Highway Performance Monitoring System to Determine Needs and Travel Cost on North Carolina Highways. In *Transportation Research Record 1156*, TRB, National Research Council, Washington, D.C. 1988.
10. K. M. Isa Al-Subhi, D. W. Johnston, and F. Farid. *Optimizing System-Level Bridge Maintenance, Rehabilitation, and Replacement Decisions.* Center for Transportation Engineering Studies,

Department of Civil Engineering, North Carolina State University, Raleigh, N.C., Jan. 1989.
11. Federal Highway Administration, U.S. Department of Transportation. *Program Documentation-Urban Transportation Planning.* Washington, D.C.: U.S. Government Printing Office, March 1972.
12. *North Carolina Highway Action Plan.* North Carolina Department of Transportation, Division of Highways, Jan. 1977.
13. *1990–1996 Transportation Improvement Program.* North Carolina Department of Transportation, Division of Highways, Nov. 1989.
14. *Transportation Programming Process.* Special Report 157, TRB, National Research Council, Washington, D.C., 1975.
15. *Principles of Project Scheduling and Monitoring.* NCHRP Synthesis Report 6, HRB, National Research Council, Washington, D.C., 1970.

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