Chapter 1
Introduction to Project Management

Chapter Contents

OVERVIEW .......................................................... 3
DATA FLOW ......................................................... 3
   The CPM Procedure ........................................... 4
   The GANTT Procedure ........................................ 5
   The NETDRAW Procedure .................................... 6
   The PM Procedure ............................................ 7
   Communication between Procedures ....................... 8
DECISION SUPPORT SYSTEMS ................................. 9
DECISION ANALYSIS ............................................ 10
   The DTREE Procedure ....................................... 10
EXAMPLES ........................................................ 11
   Example 1.1. Project Definition .............................. 11
   Example 1.2. Work Breakdown Structure .................... 13
   Example 1.3. Project Scheduling and Reporting .......... 15
   Example 1.4. Summary Report ................................ 17
   Example 1.5. Resource-Constrained Scheduling .......... 19
   Example 1.6. Multiple Projects .............................. 23
   Example 1.7. Sequential Scheduling of Projects .......... 31
   Example 1.8. Project Cost Control ......................... 34
   Example 1.9. Subcontracting Decisions .................... 41
PROJECT MANAGEMENT SYSTEMS .............................. 44
THE PROJMAN APPLICATION .................................... 45
WEB-BASED SCHEDULING SYSTEMS ............................ 45
MICROSOFT PROJECT CONVERSION MACROS ................ 46
EARNED VALUE MANAGEMENT MACROS ...................... 46
REFERENCES ....................................................... 46
Chapter 1
Introduction to Project Management

Overview

This chapter briefly describes how you can use SAS/OR software for managing your projects. This chapter is not meant to define all the concepts of project management; several textbooks on project management explain the basic steps involved in defining, planning, and managing projects (for example, Moder, Phillips, and Davis 1983). Briefly, a project is defined as any task comprising a set of smaller tasks that need to be performed, either sequentially or in parallel. Projects can be small and last only a few minutes (for instance, running a set of small computer programs), or they can be mammoth and run for several years (for example, the construction of the Channel Tunnel).

SAS/OR software has four procedures that can be used for planning, controlling, and monitoring projects: the CPM and PM procedures for scheduling project activities subject to precedence, time, and resource constraints; the GANTT procedure for displaying the computed schedule; and the NETDRAW procedure for displaying the activity network. These procedures integrate with the SAS System so that you can easily develop a customized project management system. The Projman application, a user-friendly graphical user interface included as part of SAS/OR software, is one such system.

This chapter gives a brief introduction to the CPM, GANTT, NETDRAW, and PM procedures and shows how you can use the SAS System for project management.

In addition to these four procedures and the Projman application, which are the major tools for the traditional functions associated with project management, SAS/OR software also contains a procedure for decision analysis, the DTREE procedure. Decision analysis is a tool that attempts to provide an analytic basis for management decisions under uncertainty. It can be used effectively as an integral part of project management methods. A brief introduction to PROC DTREE is provided in the section “Decision Analysis” on page 10.

Data Flow

This section provides an overview of how project information is stored in the SAS System in data sets and how these data sets are used by the CPM, GANTT, NETDRAW, and PM procedures. Maintaining the project information in SAS data sets enables you to merge project information easily from several sources, summarize information, subset project data, and perform a wide variety of other operations using any of the many procedures in SAS software. Each of the SAS/OR procedures also defines a SAS macro variable that contains a character string indicating whether
The CPM Procedure

PROC CPM does the project scheduling and forms the core of the project management functionality in SAS/OR software. It uses activity precedence, time, and resource constraints, and holiday and calendar information to determine a feasible schedule for the project. The precedence constraints between the activities are described using a network representation, either in Activity-On-Arc (AOA) or Activity-On-Node (AON) notation, and input to PROC CPM in an Activity data set. The two different representations are described in Chapter 2, “The CPM Procedure.” The Activity data set can also specify time constraints on the activities and resource requirement information. The Activity data set is required. Resource availability information can be specified using another data set, referred to here as the Resource data set. Holiday, workday, and other calendar information is contained in the Holiday, Workday, and Calendar data sets; each of these data sets is described in detail in Chapter 2, “The CPM Procedure.” The schedule calculated by PROC CPM using all the input information and any special scheduling options is saved in an output data set, referred to as the Schedule data set. For projects that use resources, individual resource schedules for each activity can be saved in a Resource Schedule output data set. Resource usage information can also be saved in another output data set, referred to as the Usage data set. Figure 1.1 illustrates all the input and output data sets that are possible with PROC CPM. In the same figure, _ORCPM_ is the SAS macro variable defined by PROC CPM.

Figure 1.1. Input and Output Data Flow in PROC CPM

The three output data sets produced by PROC CPM contain all the information about the schedule and the resource usage; these data sets can be used as input to either PROC GANTT or PROC NETDRAW or to any of the several reporting, charting, or plotting procedures in the SAS System.

The Schedule data set can also contain additional project information such as project ID, department and phase information, accounting categories, and so on, in the form of ID variables passed to it from the Activity input data set with the ID statement.
These variables can be used to produce customized reports by reordering, subsetting, summarizing, or condensing the information in the Schedule data set in various ways.

**The GANTT Procedure**

PROC GANTT draws, in line-printer, high-resolution graphics, or full-screen mode, a bar chart of the schedules computed by PROC CPM. Such a bar chart is referred to as a Gantt chart in project management terminology. In addition to the Schedule data set, PROC GANTT can also use the Calendar, Workday, and Holiday data sets (that were used by PROC CPM when scheduling the activities in the project) to mark holidays and weekends and other nonwork periods appropriately on the Gantt chart. You can indicate target dates, deadlines, and other important dates on a Gantt chart by adding CHART variables to the Schedule data set. Furthermore, the GANTT procedure can indicate milestones on the chart by using a DURATION variable in the Schedule data set.

Precedence information can be used by PROC GANTT in either Activity-on-Node or Activity-on-Arc format to produce a Logic bar chart that shows the precedence relationships between the activities. The precedence information, required for drawing the network logic, can be conveyed to PROC GANTT using the Activity data set or a Logic data set, as described in Chapter 6, “The GANTT Procedure.”

The Gantt procedure also supports an automatic text annotation facility, using the Label data set, which is designed specifically for labeling Gantt charts independently of the SAS/GRAPH Annotate facility. The specifications in this data set enable you to print label strings with a minimum of effort and data entry while providing the capability for more complex chart labeling situations.

The Gantt procedure is Web-enabled. The HTML= option enables you to specify a variable in the Schedule data set that defines a URL for each activity. If you route the Gantt chart to an HTML file using the Output Delivery System, then you can click on a schedule bar and browse text or other descriptive information about the associated activity. You also use this information to create custom HTML files with drill-down graphs. PROC GANTT also produces an Imagemap data set that contains the outline coordinates for the schedule bars used in the Gantt chart that can be used to generate HTML MAP tags.

As with PROC CPM, PROC GANTT also defines a macro variable named _ORGANTT that has a character string indicating if the procedure terminated successfully. Figure 1.2 illustrates the flow of data in and out of PROC GANTT.
The NETDRAW Procedure

PROC NETDRAW draws project networks. The procedure automatically places the nodes in the network and draws the arcs connecting them, using the (activity, successor) relationship as specified by the Network data set described in Chapter 7, “The NETDRAW Procedure.” The Network data set, used as input to PROC NETDRAW, can be an Activity data set, a Schedule data set, or a Layout data set, as described in Chapter 7. If a Schedule data set, output by PROC CPM, is used as the Network data set, the network diagram also contains all the schedule times calculated by PROC CPM. The procedure can draw the diagram in line-printer mode as well as in high-resolution graphics mode. Further, you can invoke the procedure in full-screen mode, which enables you to scroll around the network to view different parts of it; in this mode, you can also modify the layout of the network by moving the nodes of the network.

By default, PROC NETDRAW uses the topological ordering of the activity network to determine the X coordinates of the nodes. In a time-based network diagram, the nodes can be ordered according to any SAS date, time, or datetime variable in the Network data set. In fact, PROC NETDRAW enables you to align the nodes according to any numeric variable in this data set, not just the start and finish times.

You can produce a zoned network diagram by identifying a ZONE variable in the input data set, which divides the network into horizontal bands or zones. This is useful in grouping the activities of the project according to some appropriate classification. The NETDRAW procedure also draws tree diagrams. This feature can be used to draw work breakdown structures or other organizational diagrams (see Example 1.2).

PROC NETDRAW produces an output data set (Layout data set), which contains the positions of the nodes and the arcs connecting them. This output data set can also be used as an input data set to PROC NETDRAW; this feature is useful when the same project network is drawn several times during the course of a project. You
may want to see the updated information drawn on the network every week; you can save computer resources by using the same node placement and arc routing, without having the procedure recompute it every time. PROC NETDRAW defines the macro variable _ORNETDR, which contains a character string indicating if the procedure terminated successfully.

The NETDRAW procedure is also Web-enabled (like PROC GANTT), and it supports the HTML= and IMAGEMAP= options.

Figure 1.3 illustrates the flow of data in and out of PROC NETDRAW.

---

The PM Procedure

PROC PM is an interactive procedure that can be used for planning, controlling, and monitoring a project. The syntax and the scheduling features of PROC PM are virtually the same as those of PROC CPM; there are a few differences, which are described in Chapter 3, “The PM Procedure.” As far as the flow of data is concerned (see Figure 1.4), the PM procedure supports an additional data set that can be used to save and restore preferences that control the project view. The scheduling engine used by the PM procedure is the same as the one used by PROC CPM; the same macro variable, _ORCPM_, is used to indicate if the schedule was computed successfully.
Communication between Procedures

Figure 1.1, Figure 1.2, Figure 1.3, and Figure 1.4 illustrate the data flow going in and out of each of the four procedures: CPM, GANTT, NETDRAW, and PM, respectively. The data sets described in the previous sections store project information and can be used to communicate project data between the procedures in the SAS System. Figure 1.5 shows a typical sequence of steps in a project management system built around these procedures.
Of course, this is only one possible scenario of the use of these procedures. In addition, you may want to use PROC NETDRAW to check the logic of the network diagram before scheduling the project using PROC CPM. Further, the data flow shown in Figure 1.5 may represent only the first iteration in a continuous scheme for monitoring the progress of a project. As the project progresses, you may update the data sets, including actual start and finish times for some of the activities, invoke PROC CPM again, produce updated Gantt charts and network diagrams, and thus continue monitoring the project.

For example, a project management system designed for scheduling and tracking a major outage at a power plant may include the steps illustrated in Figure 1.6. In the sequences of steps illustrated in both these figures, you can use PROC PM to update most of the activity information using the procedure’s graphical user interface.

Thus, SAS/OR software provides four different procedures designed for performing many of the traditional project management tasks; these procedures can be combined in a variety of ways to build a customized comprehensive project management system. The section “Examples” on page 11 illustrates several applications of the procedures in typical project management situations.

**Figure 1.6.** Scheduling a Power Plant Outage

**Decision Support Systems**

In addition to the CPM, GANTT, NETDRAW, and PM procedures, which are the major tools for the traditional functions associated with project management, SAS/OR software has several procedures that can be used to create a many-faceted Decision Support System. Traditional CPM/PERT techniques form only one part of effective project management and may be considered as a specialized application of Decision Support Systems (Williams and Boyd 1990). SAS/OR software contains several mathematical programming procedures that can be used to design effective systems for solving inventory control, transportation, network flow, transshipment, product-mix, cutting stock problems, and so on. These procedures are discussed in detail in the SAS/OR User’s Guide: Mathematical Programming.
Decision analysis is another important tool that is receiving recognition as a component of project management. The next section briefly describes PROC DTREE and the role it can play in making important decisions in project management.

**Decision Analysis**

There are several stages in the course of a project when critical decisions are to be made regarding the future path that is to be followed. In fact, the most crucial decision might be to decide at the beginning whether to embark on the project or not. Other important decisions that could benefit from using decision analysis tools may be subcontract awarding, subproject termination in a research and development (R&D) environment, what-if analysis, and so on. Decision analysis techniques can be used effectively in such situations to help make decisions under uncertainty.

**The DTREE Procedure**

PROC DTREE interprets a decision problem represented in SAS data sets, finds the optimal decisions, and plots on a line printer or a graphics device the decision tree showing the optimal decisions. A decision tree contains two types of nodes: decision nodes and chance nodes. A decision node represents a stage in the problem where a decision is to be made that could lead you along different paths through the tree. A chance node represents a stage in the problem where some uncertain factors result in one of several possible outcomes, once again leading you to different branches of the tree, with associated probabilities.

The structure of a decision model is given in the STAGEIN= data set. This data set, described in detail in Chapter 5, “The DTREE Procedure,” specifies the name, type, and attributes of all outcomes for each stage in your model. This is the only data set that is required to produce a diagrammatic representation of your decision problem. To evaluate and analyze your decision model, you need to specify the PROBIN= and PAYOFFS= data sets. The PROBIN= data set specifies the conditional probabilities for every event in your model. The PAYOFFS= data set specifies the value of each possible scenario (sequence of outcomes). The objective is to use the information summarized in these data sets to determine the optimal decision based on some measure of performance. One common objective is to maximize the expected value of the return. Figure 1.7 illustrates the data flow for PROC DTREE.
Example 1.1. Project Definition

Suppose you want to prepare and conduct a market survey (Moder, Phillips, and Davis 1983) to determine the desirability of launching a new product. As a first step, you need to identify the steps involved. Make a list of the tasks that need to be performed and obtain a reasonable estimate of the length of time needed to perform each task. Further, you need to specify the order in which these tasks can be done. The following DATA step creates a SAS data set, survey, representing the project.

This Activity data set contains a representation of the Survey project in Activity-On-Node format; a brief discussion of the two types of representations is given in Chapter 2, “The CPM Procedure.” The data set contains a variable activity listing the basic activities (tasks) involved, a variable duration specifying the length of time in days needed to perform the tasks, and, for each task, the variables succ1–succ3, which indicate the immediate successors. An ID variable is also included to provide a more informative description of each task. Thus, the activity ‘Plan Survey’ takes four days. Once the planning is done, the tasks ‘Hire Personnel’ and ‘Design Questionnaire’ can begin. The Activity data set also contains a variable named phase associating each activity with a particular phase of the project.
Chapter 1. Introduction to Project Management

data survey;
  format id $20. activity $8. succ1-succ3 $8. phase $9.;
  input id & activity & duration succ1 & succ2 & succ3 & phase $;
  label phase = 'Project Phase'
    id = 'Description';
datalines;
Plan Survey plan sur 4 hire per design q . Plan
Hire Personnel hire per 5 trn per . . Prepare
Design Questionnaire design q 3 trn per select h print q Plan
Train Personnel trn per 3 cond sur . . Prepare
Select Households select h 3 cond sur . . Prepare
Print Questionnaire print q 4 cond sur . . Prepare
Conduct Survey cond sur 10 analyze . . Implement
Analyze Results analyze 6 . . . Implement
;

The data set survey can be input to PROC CPM, which calculates how long the project will take given the current estimates of the durations. As a first step, you may want to graph the project network using PROC NETDRAW. In the initial stages of defining the tasks in a project, it is useful to see how the tasks relate to each other and perhaps modify some of the relationships. The following program invokes PROC NETDRAW; the ZONE= option is used to create a zoned network diagram with the activities grouped according to the phase of the project to which they correspond. The network diagram is shown in Output 1.1.1.

title ' ';
title2 h=3 c=black 'Conducting a Market Survey';

goptions hpos=100 vpos=65 border;

proc netdraw data=survey graphics;
  actnet/act=activity
    succ=(succ1-succ3)
    separatearcs
    xbetween=3 pcompress
    id=(id)
    height=1.5
    nodefid
    nolabel
    zone=phase
    zonepat
    frame;
  run;
Example 1.2. Work Breakdown Structure

A tree diagram is a useful method of visualizing the work breakdown structure (WBS) of a project. For the survey project, the activities are divided into three phases. In this example, the NETDRAW procedure is used to represent the work breakdown structure of the project. The following program saves the data in a Network data set that is input to PROC NETDRAW. The TREE option is used to draw the WBS structure in the form of a tree (Output 1.2.1).
data wbs;
  format parent $10. child $10. ;
  input parent & child & style;
  datalines;
Survey Plan 1
Survey Prepare 1
Survey Implement 1
Plan Plan S. 2
Plan Design Q. 2
Prepare Hire P. 3
Prepare Train P. 3
Prepare Select H. 3
Prepare Print Q. 3
Implement Conduct S. 4
Implement Analyze R. 4
Plan S. . 2
Design Q. . 2
Hire P. . 3
Train P. . 3
Select H. . 3
Print Q. . 3
Conduct S. . 4
Analyze R. . 4
;

goptions vsize=5.75 in hsize=4.0 in border;

title a=90 h=1 'Conducting a Market Survey';
title2 a=90 h=.8 'Work Breakdown Structure';

proc netdraw data=wbs graphics;
  actnet/act=parent succ=child tree
  rotate rotatetext coutline=black
context=white font=simplexu rectilinear
  htext=2 compress
  xbetween=15 ybetween=3 pattern=style
  centerid;
run;
Example 1.3. Project Scheduling and Reporting

Having defined the project and ensured that all the relationships have been modeled correctly, you can schedule the activities in the project by invoking PROC CPM. Suppose the activities can occur only on weekdays, and there is a holiday on July 4, 2003. Holiday information is passed to PROC CPM using the Holiday data set holidata. The following statements schedule the project to start on July 1, 2003. The early and late start schedules and additional project information are saved in the output data set survschd. The output data set produced by PROC CPM can then be used to generate a variety of reports. In this example, the data set is first sorted by the variable E–START and then displayed using the PRINT procedure (see Output 1.3.1).

```plaintext
data holidata;
   format hol date7.;
   hol = '4jul03'd;
   run;

proc cpm data=survey date='1jul03'd out=survschd
   interval=weekday holidata=holidata;
   activity activity;
   successor succ1-succ3;
   duration duration;
   id id phase;
   holiday hol;
```

```
Output 1.2.1. Work Breakdown Structure of SURVEY Project

Conducting a Market Survey
Work Breakdown Structure

* Diagram of Work Breakdown Structure *

Example 1.3. Project Scheduling and Reporting

Having defined the project and ensured that all the relationships have been modeled correctly, you can schedule the activities in the project by invoking PROC CPM. Suppose the activities can occur only on weekdays, and there is a holiday on July 4, 2003. Holiday information is passed to PROC CPM using the Holiday data set holidata. The following statements schedule the project to start on July 1, 2003. The early and late start schedules and additional project information are saved in the output data set survschd. The output data set produced by PROC CPM can then be used to generate a variety of reports. In this example, the data set is first sorted by the variable E–START and then displayed using the PRINT procedure (see Output 1.3.1).

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   format hol date7.;
   hol = '4jul03'd;
   run;

proc cpm data=survey date='1jul03'd out=survschd
   interval=weekday holidata=holidata;
   activity activity;
   successor succ1-succ3;
   duration duration;
   id id phase;
   holiday hol;
```

```
Output 1.2.1. Work Breakdown Structure of SURVEY Project

Conducting a Market Survey
Work Breakdown Structure

* Diagram of Work Breakdown Structure *

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```plaintext
data holidata;
   format hol date7.;
   hol = '4jul03'd;
   run;

proc cpm data=survey date='1jul03'd out=survschd
   interval=weekday holidata=holidata;
   activity activity;
   successor succ1-succ3;
   duration duration;
   id id phase;
   holiday hol;
```

```
Output 1.2.1. Work Breakdown Structure of SURVEY Project

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Work Breakdown Structure

* Diagram of Work Breakdown Structure *

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   format hol date7.;
   hol = '4jul03'd;
   run;

proc cpm data=survey date='1jul03'd out=survschd
   interval=weekday holidata=holidata;
   activity activity;
   successor succ1-succ3;
   duration duration;
   id id phase;
   holiday hol;
```

```
Output 1.2.1. Work Breakdown Structure of SURVEY Project

Conducting a Market Survey
Work Breakdown Structure

* Diagram of Work Breakdown Structure *

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```plaintext
data holidata;
   format hol date7.;
   hol = '4jul03'd;
   run;

proc cpm data=survey date='1jul03'd out=survschd
   interval=weekday holidata=holidata;
   activity activity;
   successor succ1-succ3;
   duration duration;
   id id phase;
   holiday hol;
```
run;

proc sort;
  by e_start;
run;

proc print;
run;

Output 1.3.1. Project Schedule: Listing

<table>
<thead>
<tr>
<th>Obs</th>
<th>activity</th>
<th>succ1</th>
<th>succ2</th>
<th>succ3</th>
<th>duration</th>
<th>id</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>plan sur</td>
<td>hire per</td>
<td>design q</td>
<td>per design q</td>
<td>4</td>
<td>Plan Survey</td>
</tr>
<tr>
<td>2</td>
<td>hire per</td>
<td>trn per</td>
<td>select h</td>
<td>print q</td>
<td>5</td>
<td>Hire Personnel</td>
</tr>
<tr>
<td>3</td>
<td>design q</td>
<td>trn per</td>
<td>select h</td>
<td>print q</td>
<td>3</td>
<td>Design Questionnaire</td>
</tr>
<tr>
<td>4</td>
<td>select h</td>
<td>cond sur</td>
<td>3</td>
<td>Select Households</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>cond sur</td>
<td>cond sur</td>
<td>3</td>
<td>Print Questionnaire</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>trn per</td>
<td>cond sur</td>
<td>3</td>
<td>Train Personnel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>cond sur</td>
<td>analyze</td>
<td>10</td>
<td>Conduct Survey</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>analyze</td>
<td></td>
<td>6</td>
<td>Analyze Results</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The schedule produced by PROC CPM is then graphed by invoking PROC GANTT, as shown in the following code. The CALENDAR procedure or NETDRAW procedure can also be used to display the schedule. The Gantt chart produced is shown in Output 1.3.2. Note that the precedence relationships are displayed on the Gantt chart.

goptions hpos=80 vpos=43;

title c=black 'Conducting a Market Survey';
title2 c=black h=1.5 'Early and Late Start Schedule';
proc gantt graphics data=survschd holidata=holidata;
  chart / holiday=(hol) interval=weekday
    skip=2 height=1.2 nojobnum
    compress noextrange
    activity=activity succ=(succ1-succ3)
    cprec=blue caxis=black;
  id id phase;
run;
Example 1.4. Summary Report

As mentioned in the section “Data Flow” on page 3, the output data set can be manipulated in several different ways. You can subset the project data to report progress on selected activities, or you can produce reports sorted by a particular field or grouped according to a natural division of the project activities. For large projects, you may want to get a summarized view of the schedule, with the start and finish times of only the major phases of the project.

For the survey project, suppose that you want a condensed report, containing only information about the start and finish times of the three different phases of the project. The following program summarizes the information in the data set survschd and produces a Gantt chart of the summarized schedule (shown in Output 1.4.1).

```sas
proc sort data=survschd;
    by phase;
run;

proc summary data=survschd;
    by phase;
    output out=sumschd min(e_start)= max(e_finish)= ;
    var e_start e_finish;
run;

proc sort data=sumschd;
    by e_start;
```
Chapter 1. Introduction to Project Management

format e_start e_finish date7.;
run;

goptions hpos=80 vpos=43;
title c=black h=3 'Conducting a Market Survey';
title2 c=black h=2 'Summarized Schedule';

proc gantt data=sumsched graphics
    holidata=holidata;
    id phase;
    chart / nojobnum
        nolegend
        interval=weekday
        height=2 skip=4
        ref='01jul03’d to ‘15aug03’d by week
        caxis=black
        holiday=(hol);
run;

Output 1.4.1. Summary Gantt Chart of SURVEY Project

Conducting a Market Survey
Summarized Schedule

<table>
<thead>
<tr>
<th>Project Phase</th>
<th>JUL 01</th>
<th>JUL 07</th>
<th>JUL 13</th>
<th>JUL 19</th>
<th>JUL 25</th>
<th>JUL 31</th>
<th>AUG 06</th>
<th>AUG 12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plan</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prepare</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Implement</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Example 1.5. Resource-Constrained Scheduling

The previous two examples illustrated some of the reports that can be generated using the Schedule output data set produced by PROC CPM. This section illustrates the use of PROC CPM to perform resource-constrained scheduling and to obtain a resource Usage output data set for generating reports of resource utilization during the course of a project. A primary concern in data processing centers is the number of processors needed to perform various tasks. Given a series of programming tasks, a common question faced by a data center operator is how to allocate computer resources to the various tasks.

Consider a simple job that involves sorting six data sets A, B, C, D, E, and F, merging the first three into one master data set, merging the last three into another comparison data set, and then comparing the two merged data sets. The precedence constraints between the activities (captured by the variables task and succ), the time required by the activities (the variable dur), and the resource required (the variable processor) are shown in the following code:

```plaintext
data program;
  format task $8. succ $8. ;
  input task & succ & dur processor;
datalines;
Sort A  Merge 1  5  1
Sort B  Merge 1  4  1
Sort C  Merge 1  3  1
Sort D  Merge 2  6  1
Sort E  Merge 2  4  1
Sort F  Merge 2  6  1
Merge 1  Compare 5  1
Merge 2  Compare 4  1
Compare . 5  1
;
```

If the programming project is scheduled (in absolute units) without any resource constraints, it will take 15 time units for completion and will require a maximum availability of six processors. Suppose now that only two processors are available. The resin data set limits the availability of the resource to 2, and PROC CPM is invoked with two input data sets (Activity data set program and Resource data set resin) to produce a resource-constrained schedule.

PROC CPM produces two output data sets. The Schedule data set (progschd) contains the resource-constrained schedule (S_START and S_FINISH variables) in addition to the early and late start unconstrained schedules. The Usage data set (progrout) shows the number of processors required at every unit of time, if the early start schedule or the late start schedule or the resource-constrained schedule were followed, in the variables eprocessor, lprocessor, and rprocessor, respectively; the variable aprocessor shows the number of processors remaining after resource allocation. The two output data sets are displayed in Output 1.5.1.
data resin;
   input per processor;
datalines;
0 2
;

proc cpm data=program resin=resin
   out=progschd resout=progrout;
   activity task;
duration dur;
successor succ;
   resource processor/per=per;
run;

title 'Scheduling Programming Tasks';
title2 'Data Set PROGSCHD';
proc print data=progschd;
run;

title2 'Data Set PROGROUT';
proc print data=progrout;
run;

The Schedule and Usage data sets, displayed in Output 1.5.1, can be used to generate any type of report concerning the schedules or processor usage. In the following program, the unconstrained and constrained schedules are first plotted using PROC GANTT (see Output 1.5.2).
**Output 1.5.1.** Data Sets PROGSCHD and PROGROUT

### Scheduling Programming Tasks

**Data Set PROGSCHD**

<table>
<thead>
<tr>
<th>Obs</th>
<th>task</th>
<th>succ</th>
<th>dur</th>
<th>processor</th>
<th>S_START</th>
<th>S_FINISH</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sort A</td>
<td>Merge 1</td>
<td>5</td>
<td>1</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>Sort B</td>
<td>Merge 1</td>
<td>4</td>
<td>1</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>Sort C</td>
<td>Merge 1</td>
<td>3</td>
<td>1</td>
<td>10</td>
<td>13</td>
</tr>
<tr>
<td>4</td>
<td>Sort D</td>
<td>Merge 2</td>
<td>6</td>
<td>1</td>
<td>0</td>
<td>6</td>
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<tr>
<td>5</td>
<td>Sort E</td>
<td>Merge 2</td>
<td>4</td>
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<td>11</td>
<td>15</td>
</tr>
<tr>
<td>6</td>
<td>Sort F</td>
<td>Merge 2</td>
<td>6</td>
<td>1</td>
<td>5</td>
<td>11</td>
</tr>
<tr>
<td>7</td>
<td>Merge 1</td>
<td>Compare</td>
<td>5</td>
<td>1</td>
<td>13</td>
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<tr>
<td>8</td>
<td>Merge 2</td>
<td>Compare</td>
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<td>Compare</td>
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<td>5</td>
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</table>

**Data Set PROGROUT**

<table>
<thead>
<tr>
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<th><em>TIME</em></th>
<th>Eprocessor</th>
<th>Lprocessor</th>
<th>Rprocessor</th>
<th>Aprocessor</th>
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<tbody>
<tr>
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<td>6</td>
<td>6</td>
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</tr>
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<td>3</td>
<td>5</td>
<td>6</td>
<td>2</td>
<td>0</td>
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<td>25</td>
<td>24</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>

```goptions hpos=80 vpos=43; title 'Scheduling Programming Tasks'; title2 h=1.5 'Comparison of Schedules'; proc gantt data=progschd graphics; chart / increment=2 caxis=black; id task; run;```
Next, the Gplots procedure is invoked using the Usage data set to compare the unconstrained and the constrained usage of the resource (see Output 1.5.3).

/* Create a data set for use with PROC Gplots */
data plotout;
   set progrout;
   label _time_=’Time of Usage’;
   label processor=’Number of Processors’;
   label resource=’Type of Schedule Followed’;
   resource=’Constrained’;
   processor=rprocessor; output;
   resource=’Early Start’;
   processor=eprocessor; output;
   run;

axis1 minor=none width=3;
axis2 length=80 pct;
symbol1 i=steplj;
symbol2 i=steplj l=3;

title2 h=1.5 ’Comparison of Processor Usage’;
proc gplot data=plotout;
   plot processor * _time_ = resource/ vaxis=axis1
      haxis=axis2
      caxis=black;
   run;
Example 1.6. Multiple Projects

Often a project is divided into several subprojects, each of which is then broken into activities with precedence constraints. For reporting or accounting purposes, it may be essential to group activities or to aggregate the information pertaining to activities in a given group. Sometimes, totally different projects use a common pool of resources and you may want to schedule all the projects using the common pool; you may want to vary the priority with which the resources are allotted to the activities on the basis of the projects to which they belong. Often, you have several projects that are essentially the same, with only a few minor differences; these projects may also share a common pool of resources. In such cases, you may want to have a project template listing all the activities and their precedence relationships; for each specific project you can copy the template, make any modifications that are necessary for the given scenario, and determine the project schedule accordingly.

This example illustrates some of these possibilities for a multiproject scenario. The project is first scheduled using PROC CPM, and then the PM procedure is used with the same input data set to illustrate the project displayed in the PM Window.
Consider a publishing company that accepts manuscripts from different authors for publication. The publication of each book can be treated as a project. Thus, at a given point in time, several projects, almost identical in nature, may be in progress. Some of the resources that may be needed are a technical editor, a copyeditor, and a graphic artist. All the books that are currently being worked on share a common pool of these resources. This example uses a simplified version of such a scenario to illustrate some of the ways in which you can handle multiple projects competing for the same pool of resources.

The network in Output 1.6.1 represents some of the tasks required to publish one book and the precedence constraints among these tasks; the durations in the diagram are in weeks. Suppose that the generic project data are in the data set book, which is displayed in Output 1.6.2. This data set is used as a template for creating the Activity data set for any book publishing project.

Suppose that the company is working on two books simultaneously. The editor and artist must now allocate their time between the two books. The following program uses the template data set book to create Activity data sets book1 and book2 corresponding to the publication of each book. Any modifications to the generic project data can be made in the DATA step or by using PROC PM. In this example, the duration for the first activity, ‘Preliminary Edit,’ is changed to two weeks for the second book. The two Activity data sets book1 and book2 are also displayed in Output 1.6.2.
Example 1.6. Multiple Projects

```sas
data book1;
  length act $6. succ $6.;
  set book;
  subproj = "Book 1";
  act = "B1"||task;
  if succ ^= " " then succ = "B1"||succ;
run;

title 'Publishing Book 1';
proc print data=book1;
  var subproj task act succ id dur editor artist;
run;

data book2;
  length act $6. succ $6.;
  set book;
  subproj = "Book 2";
  act = "B2"||task;
  if act = "B2PEDT" then dur = 2;
  if succ ^= " " then succ = "B2"||succ;
run;

title 'Publishing Book 2';
proc print data=book2;
  var subproj task act succ id dur editor artist;
run;
```
As a next step, the data sets for the two subprojects are combined to form an Activity data set for the entire project. A variable \texttt{priority} is assigned the value ‘1’ for activities pertaining to the first book and the value ‘2’ for those pertaining to the second one. In other words, Book 1 has priority over Book 2. The Resource data set specifies the availability for each of the resources to be 1. The input data sets, \texttt{books} and \texttt{resource}, are displayed in Output 1.6.3.

```plaintext
data books;
  set book1 book2;
  if subproj = "Book 1" then priority = 1;
  else priority = 2;
run;

title 'Publishing Books 1 and 2';
proc print data=books;
  var subproj priority task act succ id dur editor artist;
run;

data resource;
  input avdate & date7. editor artist;
  format avdate date7.;
```
Example 1.6. Multiple Projects

```plaintext
datalines;
1jan03 1 1;

title 'Resources Available';
proc print data=resource;
    run;
```

### Output 1.6.3. Input Data Sets for Book Publishing Example

Publishing Books 1 and 2

<table>
<thead>
<tr>
<th>Obs</th>
<th>subproj</th>
<th>priority</th>
<th>task</th>
<th>succ</th>
<th>id</th>
<th>dur</th>
<th>editor</th>
<th>artist</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Book 1</td>
<td>1</td>
<td>PEDT</td>
<td>B1PEDT</td>
<td>B1REV</td>
<td>Preliminary Edit</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Book 1</td>
<td>1</td>
<td>PEDT</td>
<td>B1PEDT</td>
<td>B1GRPH</td>
<td>Preliminary Edit</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Book 1</td>
<td>1</td>
<td>REV</td>
<td>B1REV</td>
<td>B1CEDT</td>
<td>Revise Book</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>Book 1</td>
<td>1</td>
<td>GRPH</td>
<td>B1GRPH</td>
<td>B1CEDT</td>
<td>Graphics</td>
<td>3</td>
<td>.</td>
</tr>
<tr>
<td>5</td>
<td>Book 1</td>
<td>1</td>
<td>CEDT</td>
<td>B1CEDT</td>
<td>B1PRF</td>
<td>Copyedit Book</td>
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<td>1</td>
</tr>
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<td>6</td>
<td>Book 1</td>
<td>1</td>
<td>PRF</td>
<td>B1PRF</td>
<td>B1PRNT</td>
<td>Proofread Book</td>
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<td>1</td>
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<td>B1PRNT</td>
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</tr>
<tr>
<td>8</td>
<td>Book 2</td>
<td>2</td>
<td>PEDT</td>
<td>B2PEDT</td>
<td>B2REV</td>
<td>Preliminary Edit</td>
<td>2</td>
<td>1</td>
</tr>
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<td>11</td>
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<td>2</td>
<td>GRPH</td>
<td>B2GRPH</td>
<td>B2CEDT</td>
<td>Graphics</td>
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<tr>
<td>14</td>
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<td>2</td>
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<td>B2PRNT</td>
<td></td>
<td>Print Book</td>
<td>2</td>
<td>.</td>
</tr>
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</table>

Resources Available

<table>
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<tr>
<th>Obs</th>
<th>avdate</th>
<th>editor</th>
<th>artist</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>01JAN03</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

PROC CPM is then invoked to schedule the project to start on January 1, 2003. The PROJECT statement is used to indicate the subproject to which each activity belongs. The data set bookschd (displayed in Output 1.6.4) contains the schedule for the entire project. The ADDACT option on the PROC CPM statement adds observations for each of the subprojects, ‘Book 1’ and ‘Book 2,’ as well as one observation for the entire project. These observations are added at the end of the list of the observations corresponding to the observations in the input data set. The Usage data set booksout is also displayed in Output 1.6.4.
Chapter 1. Introduction to Project Management

```
proc cpm data=books resin=resource
   out=bookschd resout=booksout
date='1jan03'd interval=week
  addact;
act     act;
dur     dur;
succ    succ;
resource editor artist / per=avdate avp rcp
             rule=actprty actprty=priority
delayanalysis;
   id     id task;
project subproj;
run;
```

Compare the E-START and S-START schedules (in the data set bookschd) and note that on January 1, the activity ‘B1PEDT’ for Book1 is scheduled to start while the preliminary editing of book 2 (activity B2PEDT) has been postponed, due to subproject ‘Book 1’ having priority over subproject ‘Book 2.’ On January 22, there is no activity belonging to subproject ‘Book 1’ that demands an editor; thus, the activity ‘B2PEDT’ is scheduled to start on that day. As a result, the editor is working on an activity in the second project for two weeks starting from January 22, 2003; when ‘B1CEDT’ is ready to start, the editor is not available, causing a delay in this activity. Thus, even though the first book has priority over the second book, the scheduling algorithm does not keep a resource waiting for activities in the first project. However, if you enable activity splitting, you can reclaim the resource for the first book by allowing activities in the second project to be split, if necessary. For details regarding the scheduling algorithm allowing splitting of activities, see Chapter 2, “The CPM Procedure.”

**Note:** The entire project finishes on April 1, 2003; resource constraints have delayed project completion by four weeks. The variable R-DELAY in the Schedule data set bookschd indicates the amount of delay in weeks caused by resource constraints. The value of R-DELAY does not include any delay in the activity that is caused by a resource delay in one of its predecessors. See Example 2.15 in Chapter 2, “The CPM Procedure,” for more details about the R-DELAY variable.
Output 1.6.4. Data Sets BOOKSCHD and BOOKSOUT

Schedule for Project BOOKS

<table>
<thead>
<tr>
<th>P</th>
<th>F</th>
<th>S</th>
<th>R</th>
<th>R</th>
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</tr>
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<tbody>
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<td>O</td>
<td>e</td>
<td>a</td>
<td>_</td>
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<tr>
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<td>D</td>
<td>a</td>
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<tr>
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<td>j</td>
<td>R</td>
<td>V</td>
<td>t</td>
<td>c</td>
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</tbody>
</table>

1. Book 1 . 2 B1PEDT B1REV 1 Preliminary Edit PEDT 1 . 01JAN03
2. Book 1 . 2 B1PEDT B1GRPH 1 Preliminary Edit PEDT 1 . 01JAN03
3. Book 1 . 2 B1REV B1CEDT 2 Revise Book REV 1 . 08JAN03
4. Book 1 . 2 B1GRPH B1CEDT 3 Graphics GRPH 1 . 08JAN03
5. Book 1 . 2 B1CEDT B1PRF 1 Copyedit Book CEDT 1 . 05FEB03
6. Book 1 . 2 B1PRF B1PRNT 1 Proofread Book PRF 1 . 12FEB03
7. Book 1 . 2 B1PRNT 1 Print Book PRNT 1 . 12FEB03
8. Book 2 . 2 B2PEDT B2REV 2 Preliminary Edit PEDT 2 . 01JAN03
9. Book 2 . 2 B2PEDT B2GRPH 2 Preliminary Edit PEDT 2 . 01JAN03
11. Book 2 . 2 B2GRPH B2CEDT 3 Graphics GRPH 1 . 05FEB03
12. Book 2 . 2 B2CEDT B2PRF 1 Copyedit Book CEDT 1 . 05MAR03
14. Book 2 . 2 B2PRNT 2 Print Book PRNT 2 . 12MAR03
15. 9 1 Book 1 . . . 01JAN03
16. 10 1 Book 2 . . . 01JAN03
17. 13 0 . . . 01JAN03

S E L
--- --- ---
F _ _ _ _ _ _ _ E U
I S I S I D L P
T N T N E A P
O I A I A I L Y L
b S R S R S A _ _
s H T H T H Y R R

<table>
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<th>Aditor</th>
<th>Artist</th>
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</table>

Resource Usage for Project BOOKS
The output data sets `bookschd` and `booksout` can be used to produce graphical reports of the schedule and the resource usage. In particular, the Schedule data set can be used to produce a zoned, time-scaled network diagram as shown in Output 1.6.5. The program used to produce the network diagram is shown in the following code. In this example, only the leaf tasks (those without any subtasks) are used to draw the network diagram. Further, the activities are aligned according to the resource-constrained start times and grouped according to the subproject.

```sas
options hpos=98 vpos=60;
pattern1 v=e c=green;
pattern2 v=e c=red;
title c=black h=4 'Schedule for Project Books';
proc netdraw data=bookschd(where=(proj_dur=.) graphics;
 actnet / act=task succ=succ
  id=(task) nodedid nolabel
  xbetween=8 htext=3 pcompress
  zone=subproj zonepat zonespace
  align=s_start separatearcs;
  label subproj = 'Subproject';
run;
```

**Output 1.6.5.** Resource Constrained Schedule for Project Books

The same project can also be scheduled using the PM procedure, as shown in the following statements. The resulting PM Window is shown in Output 1.6.6. The advantage with using PROC PM is that you can use the PM Window to edit the activity information, such as the durations, resource requirements, and so forth.
Example 1.7. Sequential Scheduling of Projects

Suppose the schedule displayed in Output 1.6.4 is not acceptable; you want the first book to be finished as soon as possible and do not want resources to be claimed by the second book at the cost of the first book. One way to accomplish this is to enable activities related to the second book to be split whenever the first book demands a resource currently in use by the second book. If you do not want activities to be split, you can still accomplish your goal by sequential scheduling. The structure of the input and output data sets enables you to schedule the two subprojects sequentially.

This example illustrates the sequential scheduling of subprojects ‘Book 1’ and ‘Book 2.’ The following program first schedules the subproject ‘Book 1’ using the resources...
available. The resulting schedule is displayed in Output 1.7.1. The Usage data set bk1out is also displayed in Output 1.7.1.

```sas
/*/ Schedule the higher priority project first */
proc cpm data=book1 resin=resource
  out=bk1schd resout=bk1out
date='1jan03'd interval=week;
  act    act;
dur    dur;
succ    succ;
resource editor artist / per=avdate avp rcp;
id    id;
run;
```

**Output 1.7.1.** Sequential Scheduling of Subprojects: Book 1

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<tr>
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<th>succ</th>
<th>dur</th>
<th>id</th>
<th>editor</th>
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</tr>
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<td>B1CEDT</td>
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**Resource Usage for sub-project BOOK1**

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<th>Aartist</th>
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</tr>
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</table>

The Usage data set produced by PROC CPM has two variables, Aeditor and Aartist, showing the availability of the editor and the artist on each day of the project, after scheduling subproject ‘Book 1.’ This data set is used to create the data set remres, listing the remaining resources available, which is then used as the Resource input data set for scheduling the subproject ‘Book 2.’ The following program shows the DATA step and the invocation of PROC CPM.

The schedule for publishing ‘Book 2’ is displayed in Output 1.7.2. The Usage data set bk2out is also displayed in Output 1.7.2. Note that this method of scheduling has
ensured that ‘Book 1’ is not delayed; however, the entire project has been delayed by two more weeks, resulting in a total delay of six weeks.

/ * Construct the Resource availability data set */
/ * with proper resource names */
data remres;
set bk1out;
  avdate=_time_; editor=aeditor;
  artist=aartist;
keep avdate editor artist;
format avdate date7.; run;

proc cpm data=book2 resin=remres
out=bk2schd resout=bk2out
  date='1jan03'd interval=week;
act act;
dur dur;
succ succ;
resource editor artist / per=avdate avp rcp;
  id id;
run;

Output 1.7.2. Sequential Scheduling of Subprojects: Book 2

Schedule for sub-project BOOK2

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Resource Usage for sub-project BOOK2

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Example 1.8. Project Cost Control

Cost control and accounting are important aspects of project management. Cost data for a project may be associated with activities or groups of activities, or with resources, such as personnel or equipment. For example, consider a project that consists of several subprojects, each of which is contracted to a different company. From the contracting company’s point of view, each subproject can be treated as one cost item; all the company needs to know is how much each subproject is going to cost. On the other hand, another project may contain several activities, each of which requires two types of labor, skilled and unskilled. The cost for each activity in the project may have to be computed on the basis of how much skilled or unskilled labor that activity uses. In this case, activity and project costs are determined from the resources used. Further, for any project, there may be several ways in which costs need to be summarized and accounted for. In addition to determining the cost of each individual activity, you may want to determine periodic budgets for different departments that are involved with the project or compare the actual costs that were incurred with the budgeted costs.

It is easy to set up cost accounting systems using the output data sets produced by PROC CPM, whether costs are associated with activities or with resources. In fact, you can even treat cost as a consumable resource if you can estimate the cost per day for each of the activities (see Chapter 2, “The CPM Procedure,” for details on resource allocation and types of resources). This example illustrates such a method for monitoring costs and shows how you can compute some of the standard cost performance measures used in project management.

The following three measures can be used to determine if a project is running on schedule and within budget (see Moder, Phillips, and Davis 1983, for a detailed discussion on project cost control):

- **Actual cost of work performed** (ACWP) is the actual cost expended to perform the work accomplished in a given period of time.
- **Budgeted cost of work performed** (BCWP) is the budgeted cost of the work completed in a given period of time.
- **Budgeted cost of work scheduled** (BCWS) is the budgeted cost of the work scheduled to be accomplished in a given period of time (if a baseline schedule were followed).

Consider the survey example described earlier in this chapter. Suppose that it is possible to estimate the cost per day for each activity in the project. The following data set `survcost` contains the project data (activity, `succ1–succ3`, `id`, `duration`) and a variable named `cost` containing the cost per day in dollars. In order to compute the BCWS for the project, you need to establish a baseline schedule. Suppose the early start schedule computed by PROC CPM is chosen as the baseline schedule. The Resource data set `costavl` establishes `cost` as a consumable resource, so that the CPM procedure can be used to accumulate costs (using the CUMUSAGE option).

The following program invokes PROC CPM with the RESOURCE statement and saves the Usage data set in `survrout`. The variable `ecost` in this Usage data set
contains the cumulative expense incurred for the baseline schedule; this is the same as the budgeted cost of work scheduled (or BCWS) saved in the data set basecost.

data survcost;
  format id $20. activity $8. succ1-succ3 $8. ;
  input id & activity & duration succ1 & succ2 & succ3 & cost;
datalines;
  Plan Survey plan sur 4 hire per design q . 300
  Hire Personnel hire per 5 trn per . . 350
  Design Questionnaire design q 3 trn per select h print q 100
  Train Personnel trn per 3 cond sur . . 500
  Select Households select h 3 cond sur . . 300
  Print Questionnaire print q 4 cond sur . . 250
  Conduct Survey cond sur 10 analyze . . 200
  Analyze Results analyze 6 . . . 500
;

data holidata;
  format hol date7.;
  hol = '4jul03’d;
  run;

data costavl;
  input per & date7. otype $ cost;
  format per date7.;
datalines;
  . restype 2
  1jul03 reslevel 12000
;
proc cpm date='1jul03’d interval=weekday
  data=survcost resin=costavl holidata=holidata
  out=sched resout=survrout;
  activity activity;
  successor succ1-succ3;
  duration duration;
  holiday hol;
  id id;
  resource cost / period = per
      obstype = otype cumusage;
  run;

data basecost (keep = _time_ bcws);
  set survrout;
  bcws = ecost;
  run;

Suppose that the project started as planned on July 1, 2003, but some of the activities took longer than planned and some of the cost estimates were found to be incorrect. The following data set, actual, contains updated information: the variables as and af contain the actual start and finish times of the activities that have been completed or are in progress. The variable actcost contains the revised cost per day for each activity. The following program combines this information with the existing project
data and saves the result in the data set \textit{update}, displayed in \textbf{Output 1.8.1}. The Resource data set \textit{costavl2} (also displayed in \textbf{Output 1.8.1}) defines \textit{cost} and \textit{actcost} as consumable resources.

```
data actual;
   format id $20. ;
   input id & as & date9. af & date9. actcost;
   format as af date7.;
datalines;
Plan Survey 1JUL03 8JUL03 275
Hire Personnel 9JUL03 15JUL03 350
Design Questionnaire 10JUL03 14JUL03 150
Train Personnel 16JUL03 17JUL03 800
Select Households 15JUL03 17JUL03 450
Print Questionnaire 15JUL03 18JUL03 250
Conduct Survey 21JUL03 . 200
;
data update;
   merge survcost actual;
   run;

title 'Activity Data Set UPDATE';
proc print;
   run;
data costavl2;
   input per & date7. otype $ cost actcost;
   format per date7.;
datalines;
   . restype 2 2
   1jul03 reslevel 12000 12000
;

title 'Resource Data Set COSTAVL2';
proc print;
   run;
```
Output 1.8.1. Project Cost Control: Progress Update

Activity Data Set UPDATE

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<th>activity</th>
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<td>plan sur hire per design q</td>
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</tr>
<tr>
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Resource Data Set COSTAVL2

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Next, PROC CPM is used to revise the schedule by using the ACTUAL statement to specify the actual start and finish times and the RESOURCE statement to specify both the budgeted and the actual costs. The resulting schedule is saved in the data set updsched (displayed in Output 1.8.2) and the budgeted and the actual cumulative costs of the project (until the current date) are saved in the data set updtrout. These cumulative costs represent the budgeted cost of work performed (BCWP) and the actual cost of work performed (ACWP), respectively, and are saved in the data set updtcost. The two data sets basecost and updtcost are then merged to create a data set that contains the three measures: bcws, bcwp, and acwp. The resulting data set is displayed in Output 1.8.3.

```
proc cpm date='1jul03'd interval=weekday
   data=update resin=costavl2
   out=updsched resout=updtrout
   holidata=holidata;
   activity activity;
   successor succ1-succ3;
   duration duration;
   holiday hol;
   id id;
   resource cost actcost / per = per
      obstype = otype
      maxdate = '21jul03'd cumusage;
   actual / a_start=as a_finish=af;
run;

   title 'Updated Schedule: Data Set UPDSCHED';
```
Chapter 1. Introduction to Project Management

```sas
proc print data=updsched;
run;

data updtcost (keep = _time_ bcwp acwp);
  set updtrout;
  bcwp = ecost;
  acwp = eactcost;
run;

/* Create a combined data set to contain the BCWS, BCWP, ACWP */
/* per day and the cumulative values for these costs. */
data costs;
  merge basecost updtcost;
run;

title 'BCWS, BCWP, and ACWP';
proc print data=costs;
run;
```

**Output 1.8.2.** Project Cost Control: Updated Schedule

---

**Updated Schedule: Data Set UPDSCHED**

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Output 1.8.3.  Project Cost Control: BCWS, BCWP, ACWP

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</table>

The data set costs, containing the required cost information, is then used as input to PROC G PLOT to produce a plot of the three cumulative cost measures. The plot is shown in Output 1.8.4.

Note: BCWS, BCWP, and ACWP are three of the cost measures used as part of Earned Value Analysis, which is an important component of the Cost/Schedule Control Systems Criteria (referred to as C/SCSC) that was established in 1967 by the Department of Defense (DOD) to standardize the reporting of cost and schedule performance on major contracts. Refer to Fleming (1988) for a detailed discussion of C/SCSC. Similar methods, such as the ones described in this example, can be used to calculate all the relevant measures for analyzing cost and schedule performance.
/* Plot the cumulative costs */
data costplot (keep=date dollars id);
  set costs;
  format date date7.;
  date = _time_;
  if bcws ^= . then do;
    dollars = BCWS; id = 1; output;
  end;
  if bcwp ^= . then do;
    dollars = BCWP; id = 2; output;
  end;
  if acwp ^= . then do;
    dollars = ACWP; id = 3; output;
  end;
run;

legend1 frame
  value=(c=black j=l 'BCWS' 'BCWP' 'ACWP')
  label=(c=black);

axis1 width=2
  order=('1jul03'd to '1aug03'd by week)
  length=60 pct
  value=(c=black)
  label=(c=black);

axis2 width=2
  order=(0 to 12000 by 2000)
  length = 55 pct
  value=(c=black)
  label=(c=black);

symbol1 i=join v=none c=green w=4 l=1;
symbol2 i=join v=none c=blue w=4 l=2;
symbol3 i=join v=none c=red w=4 l=3;
title c=black 'Comparison of Costs';

proc gplot data=costplot;
  plot dollars * date = id / legend=legend1
    haxis=axis1
    vaxis=axis2;
run;
Example 1.9. Subcontracting Decisions

Making decisions about subcontracting forms an important part of several medium-to-large scale projects. For example, in the pharmaceutical industry, the analysis of clinical trials may be a part of the drug development project that could either be accomplished by the company’s statistical group or be subcontracted to a statistical consulting firm. The decision may hinge upon how busy the local statistical group is with other projects that may delay the results of the analysis for the drug in question. Further, there may be more than one firm that is a likely candidate for performing the analysis. As a prerequisite for deciding whether to assign the analysis subproject to an external firm, you need to obtain a bid in the form of estimates of the cost and project duration from the competing firms as well as a corresponding estimate from the in-house team.

The cost corresponding to each possible subcontracting firm may be a combination of the actual costs (consulting fees and so on) and the tardiness of the project (tardiness being measured as the time difference between when the results are expected to be available and the target date for the availability of the results). The information required could be provided in terms of Gantt charts and cost analysis charts. Using this information, the project manager for the drug development project can use the principles of decision analysis to determine whether to do the analysis in-house or assign it to an outside consulting firm and to pick the firm to which the subcontract is to be assigned. Some of these ideas are illustrated in the following example.
Chapter 1. Introduction to Project Management

Output 1.9.1.  Input Data Sets for Decision Problem

Subcontracting Decision
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Subcontracting Decision
The Probability Data Set

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<tr>
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<td>On_Time</td>
<td>0.60</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Delay</td>
<td>0.40</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Consult1</td>
<td>Early</td>
<td>0.60</td>
</tr>
<tr>
<td>6</td>
<td>Consult1</td>
<td>Late</td>
<td>0.35</td>
</tr>
<tr>
<td>7</td>
<td>Consult1</td>
<td>Delay2</td>
<td>0.05</td>
</tr>
<tr>
<td>8</td>
<td>Consult2</td>
<td>Early</td>
<td>0.50</td>
</tr>
<tr>
<td>9</td>
<td>Consult2</td>
<td>Late</td>
<td>0.40</td>
</tr>
<tr>
<td>10</td>
<td>Consult2</td>
<td>Delay2</td>
<td>0.10</td>
</tr>
</tbody>
</table>

Subcontracting Decision
The Payoffs Data Set

<table>
<thead>
<tr>
<th>Obs</th>
<th><em>STATE1</em></th>
<th><em>STATE2</em></th>
<th><em>VALUE</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>On_Time</td>
<td>High</td>
<td>-12,000</td>
</tr>
<tr>
<td>2</td>
<td>On_Time</td>
<td>Low</td>
<td>-9,500</td>
</tr>
<tr>
<td>3</td>
<td>Delay</td>
<td>High</td>
<td>-15,000</td>
</tr>
<tr>
<td>4</td>
<td>Delay</td>
<td>Low</td>
<td>-11,500</td>
</tr>
<tr>
<td>5</td>
<td>Early</td>
<td></td>
<td>3,500</td>
</tr>
<tr>
<td>6</td>
<td>Late</td>
<td></td>
<td>1,500</td>
</tr>
<tr>
<td>7</td>
<td>Delay2</td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>

The stages of the decision problem are identified by the STAGEIN= data set, stage, displayed in Output 1.9.1. As a first step, the drug company needs to decide whether to perform the analysis in-house or to assign it to one of two consulting firms. If the in-house team is chosen, the resulting stage is a chance node, called ‘Complete,’ with two possible outcomes: ‘On-Time’ or ‘Delay’; if there is a delay, the resulting cost to the drug company is $10,000. For each of these two outcomes, there is a second chance event corresponding to the cost of the analysis. For each of the two consulting firms, the outcome can be one of three possibilities: ‘Early,’ ‘Late,’ or ‘Delay2’; if there is a delay, the drug company imposes a delay penalty of $9,000 on the firm, resulting in a net reward of $1,000 (penalty of $9,000 minus the cost of $10,000).
The PROBIN= data set, prob, identifies the various probabilities associated with the different possible outcomes at each of the chance events. The prob data set is also displayed in Output 1.9.1.

The rewards (or payoffs) associated with each of the end stages are listed in the PAYOFFS= data set, payoff (also listed in Output 1.9.1). For example, for the in-house team, the high (low) cost associated with completing the analysis on time is $12,000 ($9,500), and so on.

The following program invokes PROC DTREE to solve the decision problem. The complete decision tree, displayed in Output 1.9.2, represents the various stages and outcomes of the problem and identifies the optimal decision. In this example, the drug company should award the consulting contract to the second consulting firm as indicated by the dashed line for the corresponding branch of the tree.


title "Subcontracting Decision";

symbol1 f=marker v=P;
symbol2 f=marker v=U;
symbol3 f=marker v=A;

/* PROC DTREE statements */
proc dtree stagein=stage
    probin=prob
    payoffs=payoff
    nowarning;
    evaluate;
    treeplot / graphics font='Cumberland AMT'
        compress ybetween=1 cell
        lwidth=1 lwidthb=2 lstyleb=20
        hsymbol=2 symbolc=1
        symbold=2 symbole=3;
quit;
As illustrated in the section “Data Flow” on page 3 and the section “Examples” on page 11, the procedures of SAS/OR software, when combined with the other parts of the SAS System, provide a rich environment for developing customized project management systems. Every company has its own set of requirements for how project data should be handled and for how costs should be accounted. The CPM, GANTT, NETDRAW, and PM procedures, together with the other reporting, summarizing, charting, and plotting procedures, are the basic building blocks that can be combined in several different ways to provide the exact structure that you need. The interactive PM procedure can be used as the primary editing interface for entering all activity information for your projects. Further, the application building tools in the SAS System can be used to cement the pieces together in a menu-driven application. You can create easy-to-use applications enabling the user to enter information continually and to obtain progress reports periodically.
The Projman Application

The Projman application is a user-friendly graphical user interface for performing project management with the SAS System. Through the use of an interactive Gantt chart window provided by the PM procedure, you can easily create and manage multiple projects.

Projman is accessed by invoking the projman command in the SAS windowing environment or by selecting Solutions->Analysis->Project Management from the primary SAS menu. Projman enables you to define multiple projects, information about which are stored in a project dictionary data set. This project dictionary provides a convenient way to manage all the data sets associated with each project.

Projman also provides a variety of project reports. These reports include Gantt charts, network diagrams, calendars, and tabular listings as well as resource usage and cost reports. You can modify these reports to add your own personalized reports to the application.

For details about the Projman application, see Chapter 8, “The Projman Application.”

Web-Based Scheduling Systems

The examples in this chapter describe several scenarios that illustrate the different ways in which the project management procedures can be used to define, manage, and monitor projects. As described in the previous sections, the SAS System can be used to create comprehensive Decision Support systems or project management systems, in particular, using the procedures described in this book. With the availability of SAS/IntrNet software, you can also create Web-based project management or scheduling systems where the browser is used to display schedules and resource usage information that is updated using the CPM procedure’s scheduling engine.

Examples of such Web-based applications are available at SAS Institute’s external Web site at the following url: http://support.sas.com/sassamples/demos/supplychain/demos. In particular, the “Enterprise-Wide Resource Management” (EWRM) demo uses several of the ideas described in this chapter and illustrated in the examples throughout this book to create an application that schedules the tasks required for the maintenance of aircraft engines at a hypothetical service facility.

Note: The EWRM Web demo is a client-server application driven from your desktop and running at SAS Institute in Cary, NC. You can access the demo from SAS Institute’s Supply Chain Web site (http://support.sas.com/sassamples/demos/supplychain/demos/ewrm/ewrm–index.html). The graphs and reports in the demo have not been saved, but are calculated on demand; this means that they change dynamically as the data used to calculate them change. This demo requires Internet Explorer, version 5.0 or later.
Microsoft Project Conversion Macros

%MSPTOSAS is a SAS macro that converts Microsoft Project® data to a form that is readable by the PM procedure. The macro generates the necessary SAS data sets, determines the values of the relevant options, and invokes an instance of the PM procedure with the converted project data. %SASTOMSP is a SAS macro that converts data sets used by the PM and CPM procedures into a file that is readable by Microsoft Project. For details about the macros, see Chapter 4, “The Microsoft Project Conversion Macros.”

Earned Value Management Macros

*Earned value* refers to the amount of work that has been completed within a project to date. In earned value management (EVM), this earned value is compared to the original budget and schedule in order to measure project performance, estimate future costs, and predict the project completion date.

The earned value management macros are divided into two sets. The first set is used to analyze schedule and cost data and to derive earned value metrics. The second set is used to graphically represent the results from the first set. For details, see Chapter 9, “The Earned Value Management Macros.”

References


