SCHEDULING LARGE PROJECT INTO WORK PACKAGES

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SCHEDULING LARGE PROJECT INTO WORK PACKAGES

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ABBREVIATIONS

A.H.P.	Analytic Hierarchy Process
AoA	Activity on Arc
AoN	Activity on Node
Atv	Activities
CPM	Critical Path Method
IPA	Immediately Preceding Activities
M^3T^3	Manpower, money, materials, tools, transport, and time
OR	Operations Research
PERT	Project Evaluation and Review Technique
RHS	Right Hand Side
RM	Ringgit Malaysia (Unit of Malaysian currency)
WBS	Work Breakdown Structures
WP	Work Package

NOTATIONS

A_k	number of activities in work package k.
B_k	budget allocated to work package k.
(i,j)	an activity represented on a network diagram from node i to node j, replaceable by an alphabet.
C_{ij}	cost to complete activity (i,j).
D_{ij}	duration of activity (i,j).
E_k	excess of allocation up to work package k.
K	number of periodic allocations or number of work packages.
L	number of activities in a project.
M	number of pairs of immediately related activities (i.e. activities (i,j) and (j,m)) or sum of incoming activities multiplied by outgoing activities (head * tails) for every nodes. It can also be defined as the number of triples (i,j,m) where both (i,j) and (j,m) are activities.
N	number of nodes in a network diagram.
P_k	Work Package k.
R_k^B	reserved portion of budget allocation for work package k.

$R\%$ percentage of allocation reserved in every work package.

X_{jk} schedule time for node j in work package k. This variable is relevant only to it's respective work package if the related activity, (i,j) or (j,m), is assigned to the package.

S_p sum of schedule time in work package p,

$$\sum_{i=1}^{N} X_{ip}, \quad \text{for } p = 1,\ldots,K-1.$$

S_K sum of schedule time in work package K,

$$\sum_{i=1}^{N-1} X_{iK}.$$

T_k time when allocation for work package k will be released.

$\underline{V}$ ideal or minimum value for variable V.

$\overline{V}$ anti-ideal or maximum value for variable V.

W_k weight for E_k in objective function.

U_{ik} weight for X_{ik} in the objective function.

α_q weight used in scaling function replacing W_k and U_{ik}.

$$Z_{ijk} = \begin{cases} 1, & \text{if activity } (i,j) \text{ is assigned to package } k. \\ 0, & \text{otherwise.} \end{cases}$$

ABSTRAK

PENSKEDULAN PROJEK BESAR KE DALAM PAKEJ KERJA

Penskedulan projek adalah salah satu daripada tiga peringkat utama di dalam sesuatu kitaran pengurusan projek. Ia merangkumi penentuan masa mula dan masa tamat bagi setiap aktiviti di dalam sesuatu projek. Satu kajian dan pengelasan terperinci terhadap literatur penskedulan projek dihuraikan di dalam thesis ini.

Dalam mengendalikan projek yang besar, kebiasaannya projek berkenaan akan dibahagikan kepada beberapa pakej kerja dengan tujuan untuk mengurangkan permasalahan pengurusan, untuk membahagikan kerja di antara beberapa unit yang beroperasi, dan/atau untuk mengambilkira kekangan kewangan seperti peruntukan berperingkat. Tesis ini mencakupi satu masalah untuk menskedulkan projek ke dalam pakej kerja tertakluk kepada catuan kewangan atau peruntukan berperingkat. Jangkamasa dan kos bagi setiap aktiviti adalah tetap. Model matematik dihasilkan untuk mengumpuk dan menskedulkan setiap aktiviti di dalam projek berkenaan ke dalam pakej kerja supaya memperolehi skedul yang baik dengan matlamat berbilang. Matlamat yang ditentukan, mengikut keutamaan, adalah: untuk meminimumkan jangkamasa projek, untuk memaksimumkan penggunaan peruntukan yang diberi kepada setiap pakej kerja dan untuk menskedulkan setiap aktiviti seawal mungkin.

ABSTRACT

Project scheduling is one of the three major phases in a project management cycle. It deals mainly with determining the time at which each project activity is to be started and completed. A detailed review and classification of the project scheduling literature is presented in this thesis.

When dealing with a large project it is common practice to partition the project into several work packages in order to reduce management complications, to distribute work within several operating units and/or to cater for budget constraints such as periodic allocation. This thesis deals with the problem of scheduling a project into work packages due to cost rationing or periodic allocation. The duration and cost of each activity is fixed. A mathematical model is developed to assign and schedule activities in the project into work packages so as to obtain a good schedule with multiple objectives. The objectives considered, in order of priority, are: to minimize project duration, to maximize the usage of allocation given for each work package, and to schedule each activity as early as possible.

CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

Project management and scheduling have been receiving greater attention lately. This is due mainly to the fact that the size of projects are getting larger and more complex and the nation's economic growth demands more infrastructural projects. A project manager's responsibility is to complete the project in a manner that will optimize the project's worth without violating any of the operational conditions. He/she is responsible for planning, organizing, executing, controlling and evaluating the project.

Project management and scheduling are considered a permanent challenge for OR (Operations Research) (see Tavares, 1990), because OR has always been concerned with the management of a large project with multiple constraints, and often with conflicting objectives. Project management is defined as planning and managing time, material, personnel and costs to complete a particular project in an orderly, economical manner, and to meet the established objectives of time, cost and technical performances. Three major phases of a project management cycle are:

1. **Planning.** The initial phase of a project management cycle involves the process of breaking down the project into distinct activities. The duration of these activities are then estimated and an arrow diagram or network diagram is constructed with each of its arcs representing an activity. The entire network diagram provides a graphic representation of the relationships between the activities of the project. The construction of the network diagram in the planning phase requires us to study each job carefully, in terms of its cost and duration, and to determine the interdependencies of these jobs. Generally, the planning phase represents a process of determining what jobs have to be done, the cost and duration of each job, and the sequencing of each job in order to complete the project.

2. **Scheduling.** The second phase of a project management cycle involves the construction of a time chart, detailing the times when each job or

activity is to begin and end. Generally, the scheduling phase determines when each activity needs to be done. In addition, we can pinpoint the critical activities (in terms of time) that require special attention if the project is to be completed as scheduled. For the noncritical activities, the schedule can be used to determine the amount of slack or float times available that can be utilized when such activities are delayed or when duration for noncritical activities are increased due to limited resources (Time/Resources Trade-off).

3. **Controlling.** The final phase in a project management cycle is project control, where the progress of the project is monitored during the implementation stage. This includes the use of the network diagram with scheduled time and milestones for making periodic progress reports. The schedule may then be analyzed and updated when necessary.

Although project scheduling is just one part of the project management cycle, the resulting schedule will affect practically every management goal in the implementation of the project. Consequently, the development of a project schedule should be considered as a major portion of the total management of the project; it therefore warrants an in-depth study.

Various scheduling procedures have been developed since the mid-20th century, starting from the use of Gantt charts, followed by the use of analytical techniques such as critical path method (CPM) and the project evaluation and review technique (PERT). Other procedures frequently used in the development of project scheduling system include mathematical programming methods and heuristic methods. The literature on the project scheduling systems will be discussed and classified in detail in Chapter 2.

A wide variety of commercial project management software packages for personal computer systems have emerged over the past few years. Among these packages are HORNET, PERTMASTER ADVANCE, PLANTRAC, PRIMAVERA, MACPROJECT, and HTPM (see Wit, 1990).

1.2 RESOURCE CONSTRAINTS AND WORK PACKAGES

Project network diagram is one of the project representation techniques for planning, scheduling and control purposes. A simple example will be employed to illustrate the use of this representation technique. Data for the example problem is abstracted from Elmaghraby (1977) and summarized in Table 1.1. The project network diagram shows, in graphical form, the precedence relationship of the activities.

Table 1.1 Data for the Example Problem.

(Abstracted from Elmaghraby, 1977)

Activity	Nodes (beg., end)	Durations	Cost
A	(1,2)	10	2081
B	(1,3)	8	3218
C	(1,4)	13	9263
D	(2,4)	6	4070
E	(2,7)	28	1758
F	(3,4)	5	8479
G	(3,6)	23	9455
H	(4,5)	8	410
I	(5,6)	9	7701
J	(5,7)	10	9340
K	(6,7)	11	9476
--------	----------	---------	-----
TOTAL	(1,7)	44[1]	65251

Network diagrams have been used widely to develop schedules through CPM/PERT techniques. There are two basic types of network representations; the Activity on Arc (AoA) network and the Activity on Node (AoN) network. The AoA convention will be used in this thesis because in AoA one node can represent start time for several activities therefore it involves less decision variables for scheduling. Unlike in AoA, in AoN representation, each node represents an activity. This then requires each

---

1 Minimum project duration calculated as the longest path from node 1 to node 7, considering all activities are scheduled together.

activity to be scheduled separately by a decision variable, consequently increasing the number of decision variables involved. In order to reduce the number of decision variables in the scheduling phase, the AoA representation is used.

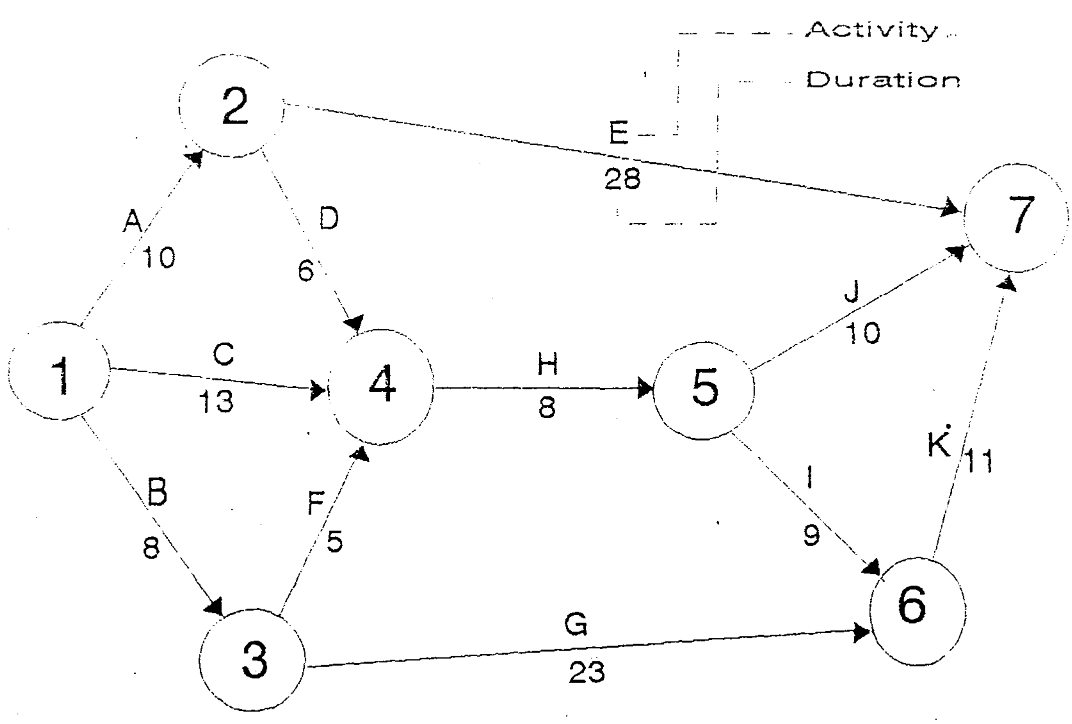

Figure 1.1 The AoA Network Diagram for an Example Problem.

The AoA network for the example problem is shown in Figure 1.1. As the name implies, the activities are represented by the arcs connecting each pair of nodes. The activity duration is shown below the activity name. This does not actually show a project schedule, but it does include all of the precedence relationships and part of the information necessary to schedule a project. Table 1.2 shows the Immediately Preceding Activities (IPA) list for the example problem in Figure 1.1.

Table 1.2 The IPA List for the Problem in Figure 1.1.

ACTIVITY	IPA
A	-
B	-
C	-
D	A
E	A
F	B
G	B
H	C,D,F
I	H
J	H
K	G,I

Each activity requires certain resources for completion. These resources may include manpower, money, materials, tools, transport and time (M^3T^3). One problem in determining a project schedule is that there may be limitations on the use of these resources. There are two major types of resource constraints: constraints on the total amount of resource used (e.g. only RM[2] 3 Million is allocated for the entire project), and constraints on the rate at which the resource is used (e.g. only RM 1 million per year will be allocated). A resource is doubly constrained when there are constraints on both the total amount used and the usage rate for a given resource.

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2 RM is unit of currency in Malaysia called Ringgit Malaysia.

When dealing with a large project, it is a common approach to partition it into smaller more manageable sub-units or work packages (Deckro, 1992). Dividing the project into work packages is also advantageous when there are limitation on the resources such as cost rationing or budgetary constraint. **Work package** is defined as a package consisting of one or more cost significant activities. The content of a work package may be limited to the work which can be performed by a single operating unit, such as a building contractor, in an organization or may require the contributing services of several operating units. The overall responsibility for the work content of a work package should be assigned to a single organization or responsible individual.

Figure 1.2 shows the decomposition of network from Figure 1.1 into work packages. The solid lines and circles represent the network for the respective work packages, WP, while the dotted lines mean the activities will be carried out in other work packages. Referring to Figure 1.2, the capital letters A through K in each network represent the activities, while the number associated with each activity is the activity duration. The number within each circle is the node number and the number just outside the circle is the schedule time for the node or the earliest start time for the succeeding activities.

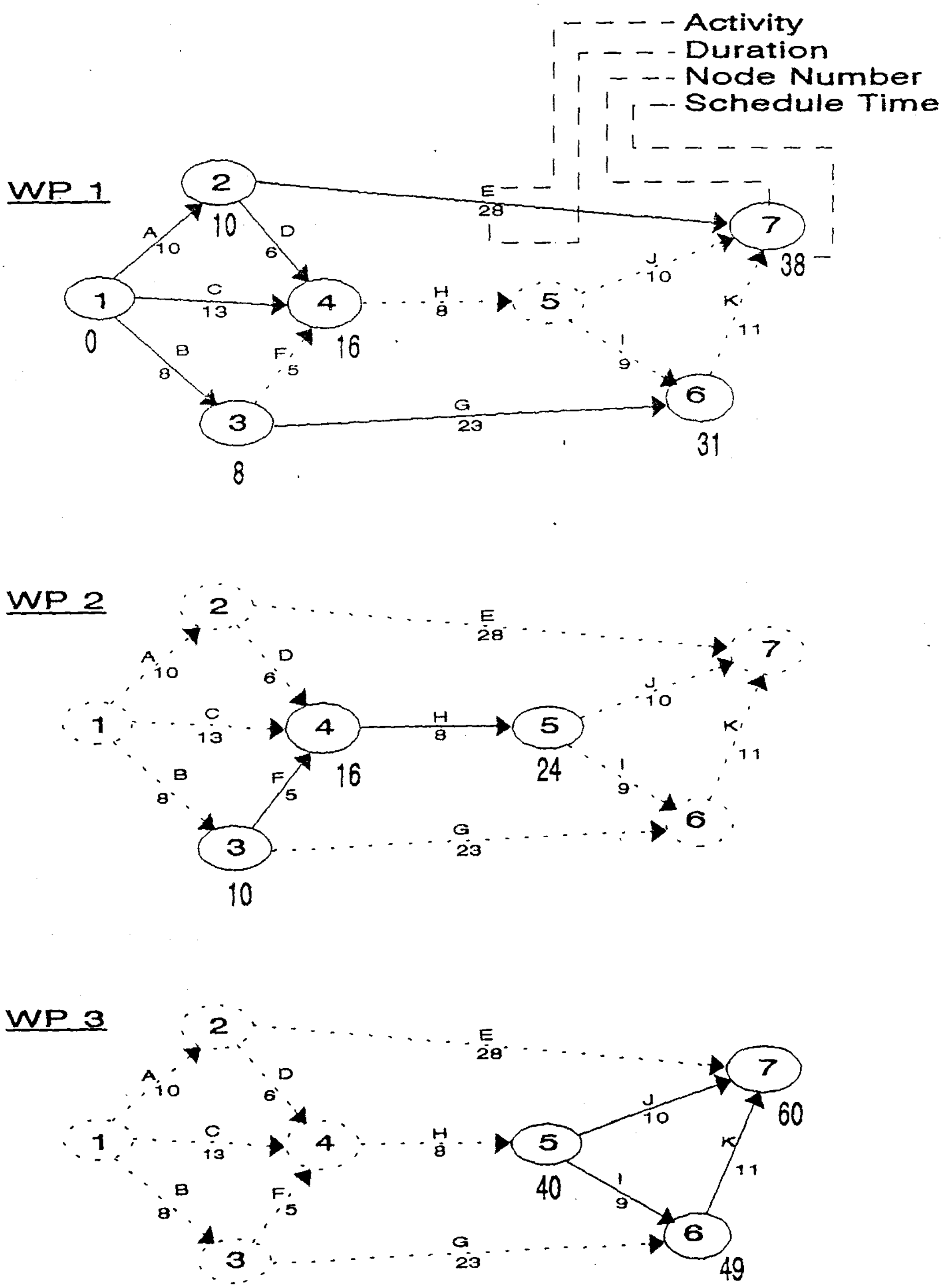

Figure 1.2 Example of Work Packages for AoA Network.

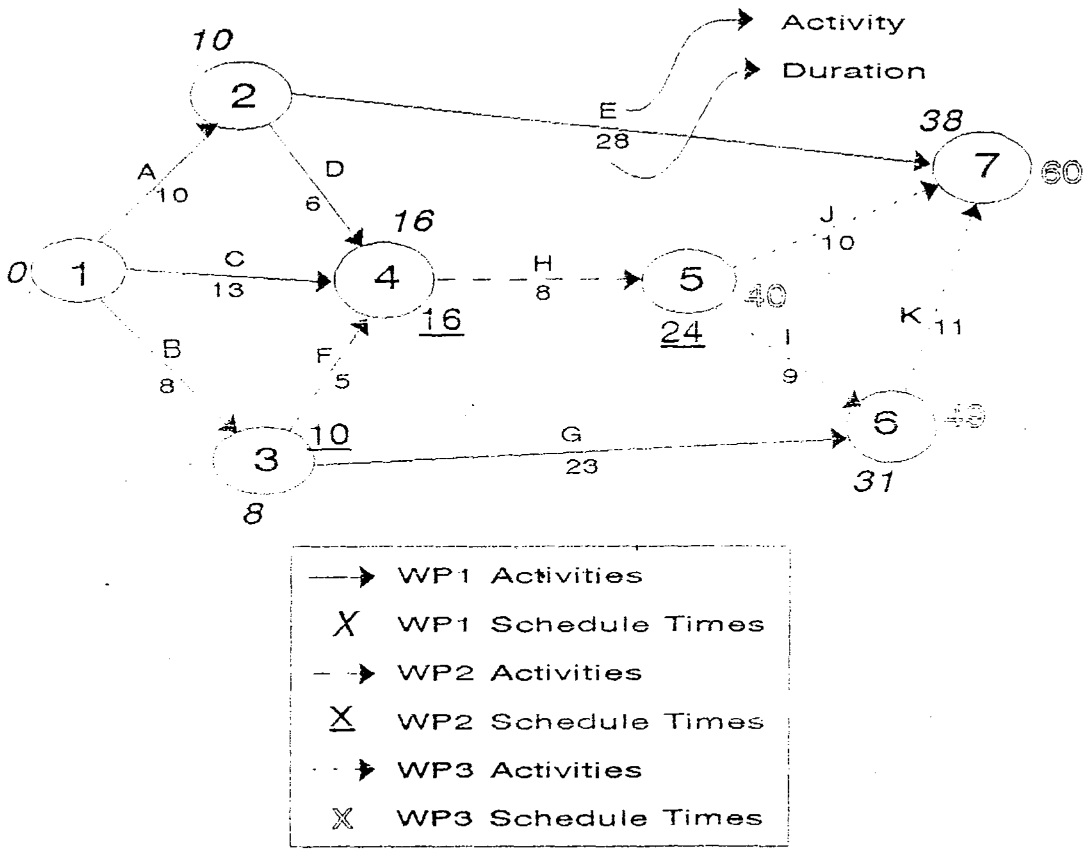

Figure 1.3 Another Example of Work Packages Representation.

Figure 1.3 shows another example of work packages representation network where work packages are differentiated using different types of lines (i.e. solid lines, dashes, and dots). The schedule time for each work package is also differentiated by the use of different lettering fonts (i.e. italic, underline, and double). Another method to represent work packages in a network diagram, if there are many work packages involved, is by using coloured lines and coloured numbers. All of the work packages can then be clustered or grouped together to represent the whole project as shown in Figure 1.4.

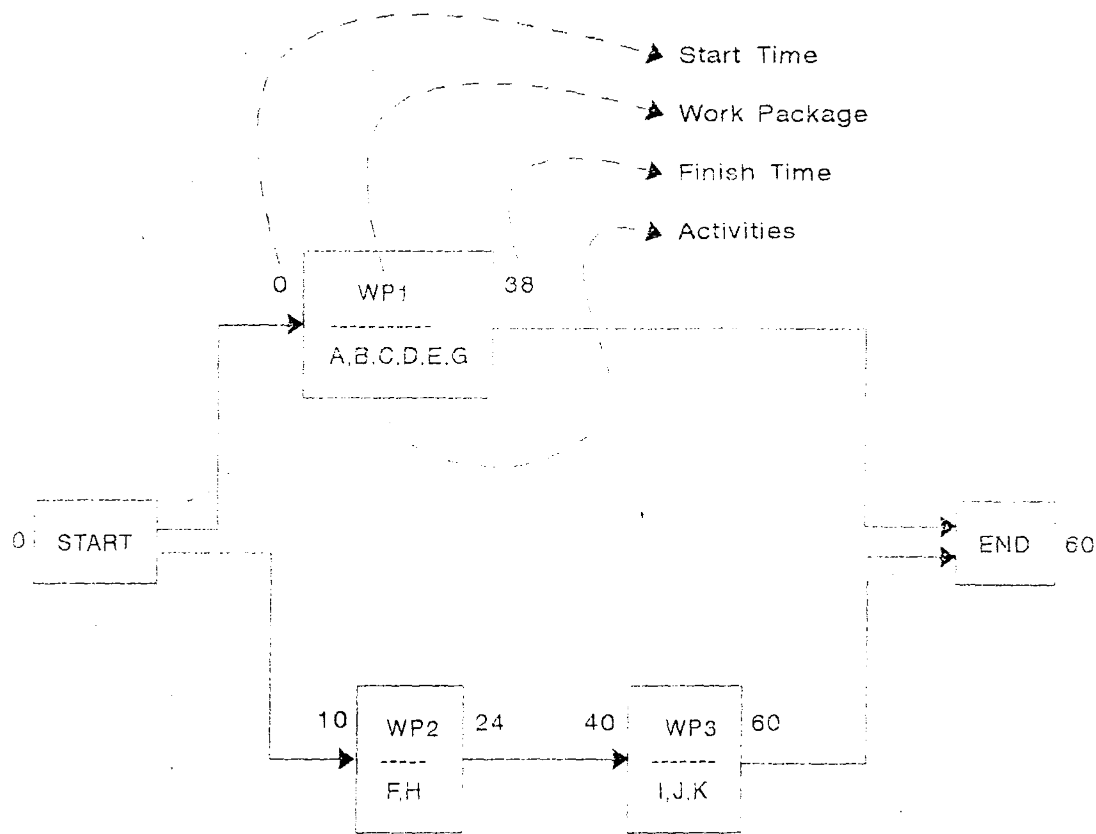

Figure 1.4 Clustered Network Diagram for the Example Project.

Figure 1.4 can be shown on a Gantt Chart, as in Figure 1.5. Here we clearly emphasize that even though the start time of every work package is sequential, the completion of every work package is not necessarily sequential. Subsequently, later work package can start before the completion of an earlier work package without violating the precedence relationships.

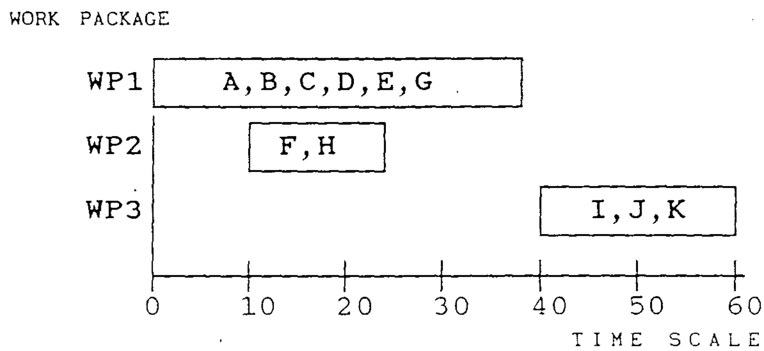

Figure 1.5 Work Packages Representation on Gantt Chart.

Even though many software packages have been designed to make it easier for the project manager to plan and schedule, but none of the software package can schedule a project with work packages without pre-assigning activities to work packages. Therefore, the purpose of this research is to develop a model for the optimal scheduling of project into work packages with budgetary constraint. Throughout this thesis, the project to be considered will be a construction project.

Finally, scheduling a project into work packages mainly involved determining the number of work packages as well as assigning activities of the project to one of the work packages to achieve an optimum schedule. The optimal solution will be considered achieved when the decision maker is satisfied with the presented output of the project schedule. This concept will be further defined and developed in Chapter 3 and Chapter 4.

1.3 PURPOSE OF THIS RESEARCH

The purpose of this research is to develop a mathematical model to generate an optimal schedule for a project which has to be performed in stages. Each stage of the project is called a work package which consists of one or more activities of the project. Work load in each work package will depend on the amount of allocation provided for that particular stage. Excess allocation from any work package will be added to the allocation given to the next work package. Therefore, the sum of allocations for the whole project must be equal to or larger than the total cost of the project.

The mathematical model developed in this research will schedule a project with periodic allocations. The main objective is to minimize project duration through scheduling without involving crashing of activities. In this thesis, we will assume that all activities have fixed costs and fixed durations, and the overall project cost is therefore fixed no matter how the project is scheduled. Minimum project duration must be achieved only through assigning activities to work packages. Each work package can handle only a limited number of activities depending on the amount of money allocated to it and each work package can be launched only after the allocation is released. Several possible extensions to the general model will also be provided to facilitate any additional requirements.

1.4 SIGNIFICANCE TO ORGANIZATION

A large project is usually carried out in stages in order to reduce management complications, to distribute work within several operating units and/or to cater for budget constraints such as periodic allocation. It is a normal practice in large government projects that the allocation for such project be provided in stages over a certain period of time.

Basically, planning for the implementation of a project involves two parties: project management department and finance department. First, the project management department will determine activities in the project and prepare a preliminary proposal on the implementation of the project. Then the project management department will submit the proposal to the finance department for approval in terms of the proposed budget requirements. If the proposal is approved in total, including the budget requirements, then the project is ready to be implemented or handed over to a contractor or contractors. On the other hand, it is quite common that the proposal cannot be approved as proposed due to budget constraint and needs to be replanned according to the ability of the finance department to provide periodic allocations. Subsequently, in our case, we assume that allocations, in terms of amount and time that each periodic allocation will be provided, will be determined by the finance department.

Therefore to cater for such limitations by the finance department, the implementation of the project has to be replanned or partitioned into stages or work packages which consist of one or more activities each. Each work package will be planned according to the availability of sufficient allocation and when it will be provided by the finance department.

The main objective is to minimize the project duration through scheduling without violating the cash flow constraint. Eventually, this procedure will benefit those who want a project with cost constraint completed as early as possible. The project management department will also benefit from this procedure because the activities in every work package will be assigned and scheduled by the model. The contractor has only to implement the project as scheduled.

1.5 SCOPE OF THIS RESEARCH

A review of the project scheduling literature is presented in Chapter Two. It includes the general classifications of the objectives and techniques used in project scheduling problems. The general characteristic of the mathematical programming technique in project scheduling is also illustrated by using a simple example. A specific review of recent project decomposition literature is also presented and discussed.

Chapter Three is devoted to the discussion of a generalized problem formulation for scheduling a project into work packages. In this chapter we will emphasize the problem objectives, constraints and the setting of the priorities or weights in the objective function. All assumptions is also stated and justified. Finally, the approach to solve the project scheduling problem model in this research will be elaborated.

Chapter Four develops the model formulation which includes the baseline model and, subsequently, the respective linear programming model for the approach adopted. The use of weighting factor in the multiple objectives linear programming (MOLP) procedure, which is known to be very crucial, will be discussed in detail. A few possible extensions of the model are then explored to facilitate any additional requirements by the decision maker. Advantages and disadvantages of these formulations will also be discussed in this chapter.

A numerical example is employed to derive and test the model in Chapter Five. This is to provide confidence and better understanding of the research done. Output analysis and sensitivity analysis are also carried out in this chapter.

Finally, Chapter Six presents the conclusions of this research. It includes a brief discussion of the significance of this research and suggestions for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The importance of project scheduling techniques is reflected in the numerous survey papers such as that of Rosenbloom (1964), Carruthers and Battersby (1966), Davis (1966), Herroelen (1972), Davis (1973), Davis (1974), Dunne and Klementowski (1982), Gupta and Taube (1985), and Kramer (1985). In this thesis the review of the literature is presented according to the problem objectives, including any special aspects considered, and the solution techniques or methodologies used to schedule the project. A brief description of Mathematical Programming Scheduling Techniques will be included. A specific review of recent project decomposition literature is also presented and discussed.

2.2 PROJECT SCHEDULING LITERATURE

A schedule is derived upon completion of the planning stage. There are many ways of scheduling a project in order to achieve certain objectives. Three basic types of objectives have been used to perform project scheduling. These objectives are related to:

1. Time,
2. Project cost, and
3. Resource usage.

Time-related project scheduling objectives usually minimize the project's duration. Other time-related objectives are meeting project due date and time/cost tradeoffs, that is to reduce project duration at the minimum cost. In many projects, time-related objectives involve every party in the project (i.e. the owner, consultant, architect and the contractor). This is because, under normal circumstances, every party wants his project to be completed as soon as possible. Therefore, it is not surprising to find that time-related objective is the most popular objective used in the project scheduling literature.

Objectives related to project cost will either minimize the project cost or maximize the project value. Objectives related to resource usage are to allocate resources to activities in a project in an efficient manner, to level resource requirements throughout the project to ensure that every resource available is planned to be used effectively in the project, and to determine if any additional resource is required or any resources available are in excess.

Project scheduling works done in general are as shown in Table 2.1, which is updated from that of Kramer (1985). Table 2.1 classifies the project scheduling literature on the basis of the desired objective, and it includes any special aspects taken into consideration by the respective author. Two of the recent articles taken from this survey, which are related to project decomposition and work packages will be discussed in detail in section 2.5 and 2.6. The detailed discussion will emphasize the strengths and weaknesses of the literature compared to the proposed work.

Table 2.1

Project Scheduling Objectives and Special Aspects.

(Updated from Kramer, 1985)

(a) For Time Related Objectives:

SPECIFIC OBJECTIVE	SPECIAL ASPECT	REFERENCES
Minimize Project Duration	Machine Sequencing	Balas (1970)
	Multi resource Const.	Bell & Han (1991) Davis & Heidhorn (1971) Demeulemeester & Herroelen (1992) Patterson (1984) Patterson & Roth (1976) Stinson, Davis, & Khumawala (1978)
	Doubly Const. Resources	Weglarz (1981)
	A* Search Technique	Bell & Park (1990)
	Local Search Techniques	Sampson & Weiss (1993)
	Operations Sequencing	Bulfin & Parker (1976)
	Project Sequencing	Gorenstein (1972)
	Multiproject Scheduling Limited Resources	Pritsker, Watters, & Wolfe (1969)
	Resource Constrained	Cooper (1976) Davis (1975) Schrage (1970) Schrage (1972) Talbot & Patterson (1978) Zaloom (1971)
	Resource Allocation	Davies (1973) Hastings (1972) Slowinski (1980)
	Comparison of Heuristic	Davis & Patterson (1975)
	Using Lagrange Mult.	Fisher (1973)

Table 2.1(a), continued

SPECIFIC OBJECTIVE	SPECIAL ASPECT	REFERENCES
Minimize Project Duration (continue)	Multi-Pass Heuristic Decomposition Proc.	Holloway, Nelson, & Suraphongschai (1979)
	Networks Decomposition	Parikh & Jewel (1965)
	Bounding Duration	Kambarowski (1992)
	Environmental Impact	Kefalas (1976)
	Critical Paths Deter.	Koehler & McClure (1979)
	Horizon-Varying	Patterson & Huber (1974)
	Backtracking Algorithm	Patterson, Talbot, Slowinski & Weglarz (1990)
	Precedence Diagramming	Wiest (1981)
Minimize Project Delay	Multiproject Scheduling	Kurtulus & Davis (1982) Pritsker, Watters, & Wolfe (1969)
	Updating Schedule	Tsubakitani & Deckro (1990)
Reduce Duration at Min Cost	Cost Duration Analysis	Dessouky & Dunne (1971)
	Time/Cost Tradeoff	Phillips & Dessouky (1977)
Optimum Schedule	Multi-Heuristic Proc	Boctor (1990)
	Preemption of Jobs	Kaplan (1988)
	Tolerance Features	Vasko, Wolf, Stott, & Woodyatt (1993)
	Multi-stage	Tavares (1990)
	Parkinson's Law and Behavioral Effects	Gutierrez & Kouvelis (1991)
Preserve Schedule	Project Compression	Yau & Ritchie (1990)

Table 2.1, continued

(b) For Cost Related Objectives:

SPECIFIC OBJECTIVE	SPECIAL ASPECT	REFERENCES
Minimize Project Cost	Resource Allocation	Berman (1964) Charles Clark (1961)
	Multi-Resource Sche.	Dar-El & Tur (1977)
	Work Packages and Budgeting	Deckro, Hebert, & Verdini (1992)
	Job Assignment	Drexl (1991)
	Due-Dated Events	Elmaghraby & Pulat (1979)
	Project Cost Curves	Fulkerson (1961)
	Production Planning	Graves & McGinnis (1982)
	Preselective Strategies	Igelmud & Radermacher (1983a) & (1983b)
	Inflation Factor	Jolayemi & Oluleye (1993)
	Minimizing Cost	Mason & Moodie (1971)
	Repetitive Projects	Moselhi & El-Rayes (1993)
	Networks Decomposition	Parikh & Jewell (1965)
	Project Cost Polygons	Prager (1963)
Maximize Discounted Profit	Failure Probabilities	Henig & Levi (1990)

Table 2.1(b), continued

SPECIFIC OBJECTIVE	SPECIAL ASPECT	REFERENCES
Minimize Discounted Cost	Net Present Value	Bey, Doersch, & Patterson (1981)
	Development Prog.	Dogrusoz (1961)
	Projects Sequencing	Erlenkotter (1973a) Erlenkotter (1973b) Erlenkotter & Rogers (1977)
Maximize Present Value	Net Present Value	Bey, Doersch, & Patterson (1981)
	Cost Control	Doersch & Patterson (1977)
	Time Manipulation	Elmaghraby & Herroelen (1990)
	Payment Scheduling	Grinold (1972)
	Sequencing/Scheduling	Gupta, Kyparisis, & Ip (1992)
	Backtracking Algorithm	Patterson, Talbot, Slowinski & Weglarz (1990)
	Networks Cash Flows	Russell (1970)
	Comparison Of Heuris.	Russell (1986)
Maximize Return	Timing Uncertainty	Frizelle (1993)
Minimize Deferred Costs	Construction Delay	Alfeld (1990)
	Deferral Costs Prob.	Lawler (1964)