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Data Requirement Analysis Of Construction Scheduling Methods

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Abstract
Several scheduling methods have been proposed to represent, monitor and control the complex and discrete tasks required for the completion of a construction project. These methods vary in complexity from simple to-do lists to bar charts, networking methods (AOA & AON), linear scheduling techniques, probabilistic methods, critical chains etc. Each method has its own advantages and disadvantages, area of application and data requirements. In this paper the requirements of the most common construction scheduling methods are analyzed in terms of data and dependencies in order to design a scheduling database, capable of holding all necessary information. It is argued that the maintenance of this scheduling database is practically feasible, allowing the study of different parts of a project (sub-projects, work packages etc.) using the most suitable method and, thus, in the most effective way.

Keywords
Scheduling methods, Data Analysis

1. Introduction

The planning, scheduling and control of construction projects has become more important these days, due to the competitiveness of construction companies and the growing complexity of projects. Many methods are used to represent the complex and discrete steps of a construction project. These methods vary in data requirements, difficulty, area of application, advantages and disadvantages, computational complexity and reporting capabilities. Although the AON networks are the most commonly used (mainly due to the availability of many commercial packages), there is evidence that other methodologies are also employed when the need arises (e.g. to deal with a linear project, to ensure continuous resource usage etc.).

In this paper we report the preliminary findings of an on-going research effort on construction scheduling aiming at analyzing the data requirements of different scheduling methods. The purpose is to develop a comprehensive database capable of holding all necessary data and, thus, facilitating in this way the application of the most efficient or the most "desired" (i.e. one with the most appropriate analysis or reporting capabilities) scheduling tool. If such a database is feasible and easily maintained, then it can prove a valuable scheduling tool by (a) holding and making readily available all necessary data and (b) assisting in the tranformation of a schedule produced in one method (e.g. AON) to another (e.g. Linear or Critical Constraints Schedule).

It should be noted at this stage that there is growing evidence from both literature and practice that (a) different scheduling methods are compared to select the most appropriate one for a project (see, for example, Fig. 1) and (b) that different methods may be employed for different parts of a project (Fig. 2).

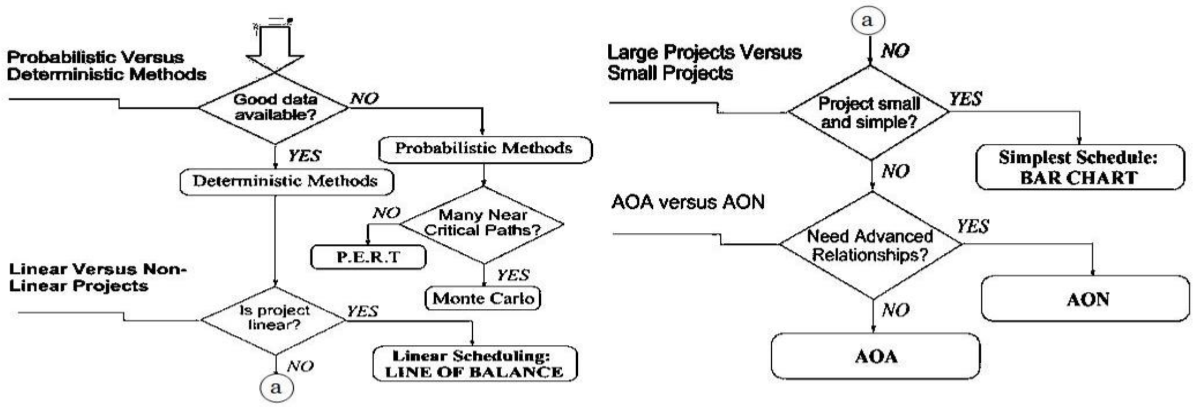
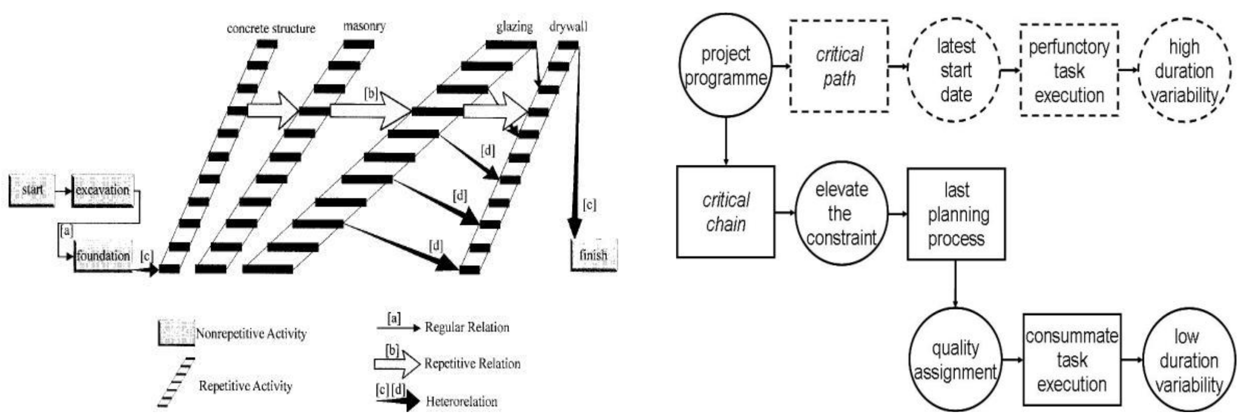


Figure 1. Flowchart assisting in scheduling method selection (adopted from Elias, 2004)



(a) Critical Path & Linear Scheduling (El Rayes, 2001)   (b) Critical Path & Critical Chain (Winch, 2002)

Figure 2. Examples on the use of combined scheduling methods

Furthermore, we are all aware of the fact that construction schedules are usually transformed to Gantt charts for communication purposes. Why should not it be possible to transform schedules to any other method as the need may be? (e.g. to consider space limitations or activity clashes?)

Last, but not least, no systematic effort was found in the literature to either develop a unified data model for all scheduling methods or address the related problem of transforming a schedule from one method to any of the others. It can be argued that the development of scheduling methods has been based on addressing a particular problem or circumstance. In this paper a somewhat different perspective is adopted; scheduling methods are considered comparatively from the stand point of the data required.

2. Literature Review

2.1 Historical perspective

Modern project management started between 1900 and 1950's. During this time, there was a greater need than ever before for the construction of complex projects which were better coordinated and delivered on time and within budget. Such well known projects of that period are the Pacific railroad and Hoover Dam. Henry Gantt introduced bar charts and bonusing schemes as management aids for World War I activities. At the same time, technology advancements allowed effective resource mobility and allocation (i.e. automobiles) and speedy information transfer and exchange (i.e. telegraph). There could not be, perhaps, a better setting for the advancement of project management as a discipline.

Further advancements, such as the photocopier (introduced by Xerox in 1959), complicated projects (such as "Polaris" for the development of ballistic missiles and "Apollo" for the exploration of the moon), the appearance of core project management tools (such as CPM, PERT and MRP), the introduction of the ARPANET (originator of the internet) and e-mail messaging (1972) and the establishment of several project management software companies (such as Artemis in 1977 and Scitor in 1979) assisted in the advancement of project management mainly as a time and cost scheduling technique.

In the 1980's the IT revolution started by Microsoft (which was established back in 1975), brought PC power to the hands of many. Furthermore, PCs coupled with LAN and Ethernet technology (introduced by Xerox) made project management techniques available to all those concerned. Since the 1990's, internet technology allowed people to browse, purchase and track products online effectively, allowing, thus, companies to become more productive, efficient and customer oriented. The project management community adopted internet to become more efficient in managing various aspects of projects.

2.2 Review of scheduling methodologies

Scheduling methodologies can be classified as CPM/PERT based, linear, simulation based, uncertainty dealing (probabilistic activity durations or conditional branching of activities etc.), resource constrained (e.g. CCM) etc. The major methodologies presented in the literature form the basis of this work and are, therefore, briefly reviewed in this section.

CPM (Critical Path Method) is based on a network diagram showing interrelationships between activities. CPM is further distinguished in the Activity-On-the-Arrow (AOA) and the Activity-On-the-Node (AON) methods. CPM does not consider interdependencies between activities or availability and work continuity of resources, although relevant extensions to the basic model have been proposed (e.g. Wang & Demetz, 2000 for projects with correlated activity durations or Ammar & Elbeltagi, 2001 for considering resource continuity, techniques for reciprocating activities etc.). For certain types of projects, such as linear or those with repeating phases, however, it is difficult to employ CPM.

For projects with uncertain activity durations, PERT (Program Evaluation and Review Technique), a method originally developed by the U.S. Navy in 1958, is used. It is a probabilistic method based on the estimation of the most likely, the optimistic and the pessimistic time estimate for each activity. Several variations of PERT have been introduced over the years, such as that proposed by Cotrell (1999) in which only two time estimates (most likely and pessimistic) for each activity are required.

For linear projects (such as highways, tunnels and pipelines) or those with repeating phases (such as skyscrapers), LSM (Linear Scheduling Methodologies) have been developed since the late '60s. Johnston

(1981) suggested a linear method for highway projects and Reda (1990) proposed a model that incorporates a graphical, an analytical and a network technique in order to schedule repetitive projects. Harmelink and Rowings (1998) proposed a method for the determination of the critical path in linear projects. Harris and Ioannou (1998) introduced in addition constraints for the continuous use of resources. Yang and Ioannou (2004) proposed the RP2 (Repetitive Project Planner) software for automating the process and addressed a long standing alleged deficiency of the method. Maximum time and distance constraints have been discussed in Kallantzis and Lambropoulos (2004). Eldin and Senouci (2000) suggested a method that incorporates non serial and discrete activities to linear projects. El-Rayes (2001) presented an OO model for repetitive construction scheduling.

Simulation techniques have also been proposed. Monte Carlo simulation originally proposed by von Newman and Morgenstern in the 40’s has been used since the early 70’s in the construction industry. Sawhney (1990) proposed HSM (Hierarchical Simulation Modelling) by combining WBS (Work Breakdown Structure) and process modelling and Senior (1995) introduced CYCLONE (Cyclic Operation Network) as a discrete-event simulation method to compute task late time and float. Senior and Halpin (1998) combined CPM and CYCLONE in PICASSO (Project Integrated Cyclic Analysis of Serial System Operations). Simulation issues are also discussed in Maio et al (2000), and Hajjar & AbouRizk (2002).

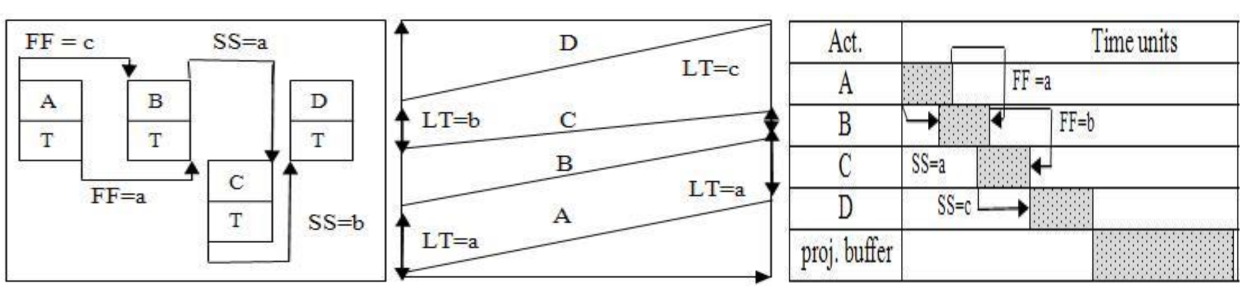
CCM (Critical Chain Method) is a rather recently proposed methodology based on the application of TOCs (Theory of Constraints) into project scheduling (Goldratt, 1997) which aims at calculating the longest path through a resource constrained network (termed “critical chain”). The method is discussed by Rand (2000). A case study is presented in Yang (2003). The comparative advantages are discussed by Herroelen and Leus (2001). CCM can be combined with the “last planner” technique, a lean construction technique, to reduce activity duration variability (Ballard & Howell, 1998).

Genetic algorithms have also been used mainly for resource scheduling (Hegazy, 1999, Leu et al. 2002, Senouci & Eldin, 2004). Petri Nets, originally developed in 1966, are graphical and mathematical tools performing static and dynamic modeling of existing or new systems. A method for construction scheduling using Petri nets has been proposed by Sawhney et al. (2004).

3. Analysis of Selected Scheduling Methods

For the purposes of this paper, the scope of the work has been limited to the four more common scheduling methods; CPM, PERT, LSM and CCM. They all require activity identification, activity duration (PERT requires three time estimates) and activity relationships. Distance constraints can be directly expressed in LSM, whereas they are approximated with SS and FF constraints in CPM (Harris & Ioannou, 1988) and CCM. The critical controlling path is calculated in LSM showing resource constraints similarly to the critical chain in CCM. Critical path in CPM, controlling sequence in LSM and critical chain in CCM do not, generally, coincide. Examples of can be found in Winch (2002).

The above analysis is summarized in Fig. 1 graphically for a project with four activities identified as A, B, C, and D (with respective time durations of T_A, T_B, T_C, T_D).



(a) CPM (b) LSM (c) CCM

Figure 3. Analysis of a project with CPM, LSM & CCM

The analysis of a project using different methods forms the first step towards the analysis of their respective data requirements.

4. Data Requirements Analysis

Following the analysis of the previous step, the data requirements of the selected methods can be summarized in terms of input (Table 1) and output (Table 2).

Table 1: Scheduling Method Input Data (*see notation at the end of the paper)

Scheduling method	Activity Description	Activity type	Act. Duration			Activity Location	Relationships between activities		Production rate (pr)	Quantity of work (Q)
			opt*	ml.*	pess.*		SS,SF, FF,FS*	LT,LD*		
	(1)	(2)	(3)			(4)	(5)	(6)	(7)	(8)
CPM	✓	✓		✓			✓			
LSM	✓	✓		✓		✓		✓	✓	✓
PERT	✓	✓	✓	✓	✓		✓			
CCM	✓			✓			✓			

Table 2: Scheduling Method Output Data (*see notation at the end of the paper)

Scheduling method	ES, EF	LS, LF	Total float	Free Float	Indep. float	Critical Path	Probabilistic estimation of project duration
	(9)	(10)	(11)	(12)	(13)	(14)	(15)
CPM	✓	✓	✓	✓	✓	✓	
LSM	✓					✓	
PERT	✓	✓	✓	✓	✓	✓	✓
CCM	✓	✓	✓			✓	

Tables 1 and 2 can then combined to formulate a transformation table (Table 3).

Table 3: Scheduling Method Transformation Table **(*see notation at the end of the paper)**

from / **to**	**CPM**	**PERT**	**LSM**	**CCM**

CPM		**Activity duration= (opt+4ml+pess)/6**	**LT => FF, SS/ FF/ SS** LD => SS (div) / FF (conv)	**Activity duration + safety time**
PERT	**opt, ml, pess. act. duration**		**opt, ml, pess.**	**mean=act. dur.+saf. time**
LSM	**Act. Location, pr,** FF,SS, FS, SF => LT, LD	**Act. Location, pr,** **FF,SS, FS, SF => LT, LD**		**Act. Location, pr, safety time, constraints**
CCM	remove safety time in activities, resource reqs	remove safety time in activities, resource reqs	**LT => FF, SS/ FF/ SS** **LD => SS (div) / FF (conv)**	

5. Conclusions

In this paper we dealt with the analysis of the data requirements of some of the scheduling methods found in literature. The analysis entailed three steps: (a) literature survey with a view of summarizing lines of thought and concepts, (b) development of project plans using different methods to be able to better appreciate the comparative advantages and shortcomings, (c) analysis of the data requirements for each of the methods studied in terms of input, output and transformations. Although this paper is part of an on-going research effort, it is argued that the process is valid and useful and may lead to the wider application of useful methods currently found in research articles.

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Notations

pr: Production Rate, ***opt, ml., pess:*** OPTimistic, Most Likely, PESSimistic time duration, ***ES, EF, LS, LF:*** Early Start, Early Finish, Late Start, Late Finish, ***LT, LD:*** Least Time interval, Least Distance.