

Optimised Process for Integrated Construction Schedule Development

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Abstract. Planning and scheduling are crucial to the success of construction projects. Ineffective planning and scheduling are one of the most frequently cited reasons for time overruns. In addressing this ineffectiveness, a plethora of scheduling techniques have been developed to simulate the nature of work modelled with an acceptable level of abstraction. Activity-based scheduling was designed to represent complex project structures that have distinct activities. Meanwhile, other scheduling methods, such as the line of balance (LOB) are appropriate for modelling projects with repeating activities. Previous research has criticised earlier techniques for their inability to simulate design activities, and several alternative methods are proposed, such as the analytical design planning technique (ADePT). This study is presenting a conceptual model to integrate scheduling techniques to improve effectiveness. Qualitative methods were employed to achieve the research objectives due to the exploratory nature of and the need for in-depth analysis. The framework developed on three principal pillars; these are fittest representations, programme objectives, and constraints. It was found that engineering, preconstruction and construction require blend of techniques for effective schedules.

Keywords: Construction Management; Schedule Optimisation; Scheduling Techniques; Integrated Schedules

Introduction

Effective planning and scheduling are crucial for the success of projects. Earlier studies identified ineffective scheduling as one of the primary causes of construction project delay (Emam *et al.*¹). There are numerous sources of schedule inefficiencies such as the selection of unsuitable scheduling techniques, inadequate consideration of constraints, and inappropriate scheduling objectives.

In this study, a process for developing an integrated schedule is developed. The established methodology is a bottom-up approach where sub-schedules are developed using the fittest scheduling method; these sub-schedules are integrated into a later stage. The integration details are clearly identified to ensure consistency and logical dependencies between schedule's tasks. The framework assists project managers and schedulers in identifying requirements from each of the sub-programmes and subsequently, stakeholders. It also identifies the formulation that meets project objectives; while considering the various organisation and project-specific constraints.

Literature Review

There are extensive research efforts that focus on scheduling. These studies can be classified into categories such as scheduling methods, optimisation, automation, and quality assessment. The scheduling methods studies concentrate on developing theories for scheduling projects; critical path method (CPM) is an example of these developed theories. Optimisation is primarily solving the planning and scheduling problem to achieve the best possible solution to meet objectives without violating constraints. Recently there are several efforts dedicated to automating schedules generation using several techniques by obtaining data such as interdependencies between elements and quantity of works from models developed from building information modelling (BIM) (Kim *et al.*²). The quality assessment criteria are related to quality or health assessment of schedules, where schedules are checked against predefined criteria.

This section will carry out an extensive literature review of scheduling methods and optimisation as the focus for the current study.

Construction Scheduling Methods

Project scheduling methods can be broadly classified into network-based and location-based. Each of these broad scheduling groups can then be further broken down. Network-based schedules can be divided into deterministic and stochastic scheduling techniques. On the other hand, location-based

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scheduling contains two main groups; these are depending on the nature of repetition being based on units or locations production.

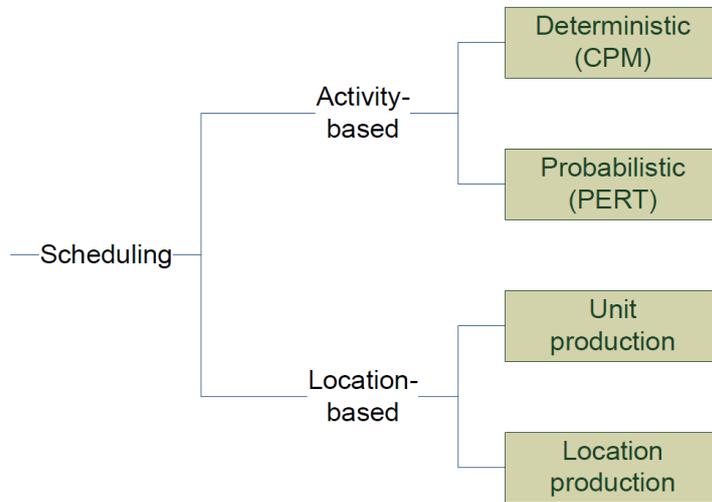


Figure 1: Scheduling techniques classification (Kenely and Seppänen³)

The focus of previous research has been to focus on scheduling methods. There were significant developments in scheduling theory introduced in the 1950s. Kelly and Walker⁴ developed the widely used CPM scheduling technique. CPM has several problems that were identified later on; the method is focused on scheduling activities by considering deterministic durations and precedence constraints. The method was criticised for being a one-dimensional representation of time which is not suitable to model construction projects with repeating activities (Galloway⁵). In addition, the technique did not allow for considering activities with elements of uncertainty. Moreover, CPM did not account for resource limitations; it is known that resources are scarce and have limits to their availability. In addressing the challenges above, Fazar⁶ introduced the programme evaluation and review technique (PERT), a new scheduling method that accounts for uncertainty using three points estimate (optimistic, most probable, and pessimistic) for each activity duration. The PERT approach attempted to address the shortage and lack of accounting for uncertainty in CPM, but it did not overcome other issues related to resource constraints and suitability to model projects with repeating activities.

The Line of Balance (LOB) scheduling method was introduced by Gehringer⁷ for the US Navy. LOB was introduced as a graphical planning method with a two-dimensional representation; the two dimensions are time and units produced. CPM was considered superior because it was based on mathematical calculations rather than a graphical representation of LOB. Al Sarraj⁸ presented mathematical formulation for LOB calculations to overcome the shortcoming above; it was argued that LOB is more suitable for projects with repeating activities (Galloway⁵). Suhail and Neale⁹ introduced a method that combines CPM and LOB, where calculations determine resource requirements to achieve project deadlines. Ammar¹⁰ integrated the two methods to exploit the benefits of both by accounting for resource continuity along with precedence constraints.

Optimisation problems contain three principal components thus; the objective function, constraints, and decision variables. Scheduling problems can consist of one or more objectives, and usually, these goals are of a conflicting nature. The common objectives in literature are either minimising or maximising objectives. Time, cost, and interruption are examples of minimisation problems. On the other hand, quality and profit are considered as maximisation objectives. Yamin and Harmlink¹¹ presented recommendations on scheduling methods to be used in different project types as shown in Table 1. Whilst the initiative of Yamin and Harmlink¹¹ was a motivation to rethink scheduling methodology, it

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focused on the nature of construction elements and ignored other crucial components to project success such as design and pre-construction scheduling. Their mapping was supported by a later study, where a survey and results by Emam *et al.*¹² confirmed their findings.

Table 1: Recommended scheduling techniques by Yemin and Harmlink¹¹ (2002)

Type of Project	Scheduling method
Linear and continuous projects	Linear Scheduling Method (LSM)
Multi-unit repetitive projects	Line-Of-Balance (LOB)
High-rise buildings	LOB, Vertical Planning Method (VPM)
Refineries and complex projects	PERT/CPM
Simple projects	Bar/Gantt charts

Engineering Scheduling

Engineering activities include all documentation required for accomplishing construction projects such as design, workshop drawings, material submittals, suppliers and subcontractors' prequalifications, and method statements. The majority of engineering documents share the common nature of being cyclic, where submittals have to be prepared and then reviewed. The result of reviews might be approval, requesting additional information (revise and resubmit), or rejection. The latter two cases require resubmittal of additional information or alternatives.

Design is a main contributor to schedules overrun in construction projects. The cause for design activities, not meeting schedules is attributable to the failure of traditional methods such as CPM to simulate the design activities. It goes through evolutions and review cycles that are of an iterative nature. Austin *et al.*¹³ recommended the analytical design planning technique (ADePT) as an alternative approach for design planning. The approach consists of four stages thus: modelling the design process, develop a dependencies matrix, represent information in the form of a schedule and finally controlling the schedule.

The first stage of ADePT (modelling of the design process), includes identifying the scope of the project. This stage also includes clear modelling customised to fit project requirements that may vary depending on contracts and legislation. The process modelling is then followed by developing a design structure matrix (DSM); it captures the dependencies between design activities to enable the development of feasible design schedules. The common practice in construction design scheduling is to group and overlap activities; DSM is used to develop design schedules with an explainable logic.

Preconstruction Scheduling

Preconstruction activities are crucial to enable successful projects completion. They are defined in this study as nonphysical activities involving third parties. Examples of preconstruction activities are procurement and statutory approvals.

Construction projects success depend on the procurement methods used. Procurement can be categorised into two broad categories, thus: procuring services and procuring products. Contractors' services are acquired in the form of subcontracts that can either include engineering, procurement or construction or any combination of these.

Products procurement is related to purchasing resources, i.e. material, equipment or subcontractors. The issue of equipment availability is considered along with construction scheduling resource constraints. Meanwhile, material scheduling requires additional effort to include associated tasks along supply

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chains, along with associated uncertainties. Emam *et al.*¹ found that the shortage of material is cited as the third most frequent cause of delay on construction projects in GCC countries.

Research Methodology

This section discusses the research methodology employed to develop the framework presented in this study. A deductive methodology was employed because it is more suitable to the problem characteristics. A qualitative approach was adopted due to the exploratory nature of the study and the need for an in-depth discussion which cannot be achieved through quantitative methods. The study commenced by conducting an in-depth literature review for current scheduling methodologies used in the construction industry, with emphasis upon identifying their shortfalls. Studies in the literature were then categorised for their relevance to scheduling various tasks within the process of construction project lifecycles. The broad categories considered are design, procurement and execution. An integrated model was formulated from the reviewed literature, which was then validated by semi-structured interviews with construction professionals. The model was revisited to enhance its ability to work in practice and achieve the ultimate goal of optimised integrated schedules for construction projects.

Research Sample

The most critical aspect of a research sample is to be representative of the population. The sample included construction planners and schedulers from different levels ranging from junior to managerial levels and working in a variety of construction disciplines such as infrastructure, buildings, tunnelling, and railway projects. Interviews were conducted with five construction professionals to achieve the study goals.

Questionnaire Design

Interview questions were designed based on a combination of literature review findings and the developed framework. The questionnaire was split into five sections: the first section was collecting background information of the interviewee; second part focused upon scheduling design activities and challenges associated with the process; the third section discussed the procurement and supply chain process scheduling along with levels of uncertainty accompanying them; fourth part was devoted to scheduling construction activities; and the last section is linked to integrating all these parts together.

Results

In this section, the interviews, discussion and analyses are summarised. The interviews started by briefing the practitioners on the research topic. In interviewee responses, it was emphasised that engineering activities are consistently a cause of delay. Several reasons were observed, such as several parties being involved, complicated coordination between disciplines, interdependencies, external and internal iterations. The internal and external iterations were elaborated by the need to design specific discipline works after finishing a certain degree of completion of other trades; an example of this iterative nature is the relationship between architects and electrical engineers. The architect's design progressed first to define rooms and layouts with electricity outlets and requirements prior to electrical engineers designing their networks. The electrical design is reviewed by architects upon completion to ensure the design is aligned with the intent. Later on, interior designers complete furnishing layouts and architects have to revisit electrical designs to ensure alignment. On the other hand, external cycles exist with design verification authority, which is normally employed by clients.

Procurement was observed to be a challenging and complicated process. It involves agreements with manufacturers, subcontractors, sub-designers and freight companies. The participants raised their concerns about the difficulties in managing multi-tier supply chains, where a problem at any point may have a knock-on effect on related works. It was reported that the most significant issues are directly

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related to the number of suppliers within the supply chain, along with their geographical spread across the globe. It was repeatedly stated that proper planning with contingencies that can absorb uncertain events occurring. Preconstruction activities are often planned in trackers where steps forming the process along with their associated duration are depicted, and backward calculations are performed from construction dates. These dates are correlated with construction schedule where links are established using task unique identifiers. However, there are constraints that drive the frontend of preconstruction activities, such as design completion. Integrating required by dates and design completion dates result in a start and finish to individual packages. If the sum of durations for procurement steps are bigger than calculated duration, this should be flagged as an issue to the current schedule. This process enables early warning to the management team and focuses their attention to critical items that require their interventions. However, additional information will be required to make informed decisions such as total float for succeeding activities.

In discussing the construction planning and scheduling approaches, the importance of resource availability was frequently stressed. Reference was made to resources with their variations as the workforce, equipment, material and cash. Participants from contractor backgrounds emphasised cash flow, along with a justification that it keeps projects running due to linking all activities with money, including subcontractor payments, labour wages and material costs. Participants from consultant and client backgrounds were stressing the importance of the availability of workforce and equipment. It was argued that resources are often not available due to inaccurate assessments and the under-estimation of requirements by contractors. In addition, it was stated that often, contractors are engaged in projects that exceed their capacity, and this is due to the uncertainty in the bidding process. Current construction scheduling practices were also criticised for being optimistically biased where durations assigned to activities.

Framework

The analysis of results was used to develop an integrated schedule development process. The developed framework is discussed in this section. It flows from the initiation process to finalising the schedules to be aligned with strategic directions of organisations. The framework also considers schedule updates and rescheduling to produce achievable forecasts based on current project status.

The process starts with identifying scheduling objectives and priorities to align with organisation strategic goals. In parallel, the process of selecting the appropriate programming technique based upon the project's nature and activity characteristics should be performed. Upon setting objectives and scheduling techniques, constraints are added to the model depending on rational sequencing of activities, organisational resource, and project-specific constraints such as access limitations. The problem is formulated using appropriate optimisation techniques. The model is used to produce optimum or near-optimal schedules for construction activities. One of the major challenges in producing construction programme is contribution of subcontractors. Interviewees highlighted that scheduling requirements are standards regardless the size, maturity, or complexity of the subcontract. These requirements were designed for more complex and mature contracts. In response to this challenge, requirements matrix was developed using two dimensions to determine deliverables from subcontractors. Figure 2, demonstrates the developed requirements matrix with horizontal axis representing uncertainty and the vertical reflects the level of complexity. The matrix suggest that requirements increase as the complexity and uncertainty increase. This was concluded from interviews where an example of a simple fencing contractors will be required to submit programmes in complex format. The matrix suggest different means of programme production that will subsequently add a level of complexity on planners of main contractors.

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Complexity	High Complex (many suppliers, highly constrained)	Integrated P6 Schedule with 4D Simulation/or 14 point DCMA check	Integrated P6 Schedule with 4D Simulation/14 point DCMA with Qualitative Risk Assessment	Integrated P6 Schedule with Quantitative Schedule Risk Analysis (QSRA), and 4D Simulation/14 point DCMA
	Moderate (single supplier)	Logically Linked Schedule (e.g. P6, MSP, Power Project)	Logically linked Schedule and Qualitative Risk Assessment/14 point DCMA	Logically linked Schedule with QSRA
	Low Complexity (simple quantity based delivery – low constraint)	Simple Bar Chart (e.g. Excel)	PERT Analysis (e.g. excel with 3 point duration)	Excel based schedule with Simulation schedule (e.g. @Risk)
	Low Uncertainty	Moderate Uncertainty	High Uncertainty	
		Uncertainty		

Figure 2: Subcontractors scheduling requirements matrix

The construction schedules are used as the basis for backwards calculations for generating engineering schedules. Calculations for engineering programmes are worked backwards from the construction commencement that is considered the required date for approved engineering. In other words, the latest date is established based on zero free floats to ensure that engineering does not hinder construction progress. Durations for engineering activities are computed after assigning resources based on availability to individual tasks and considering productivity rates. The constraints for engineering activities as identified earlier are resources and finish dates constraints, while the objectives predefined in earlier steps should be maintained.

Procurement tasks start after an adequate level of engineering development. Identifying the appropriate level of design development prior to progressing with procurement often involves conflicting objectives, where deciding to proceed with the preliminary design will result in high risk of budget overruns due to lack of details. Meanwhile, full completion of the design prior to releasing packages for procurement might affect project schedules. This trade-off can be resolved by a packaging strategy that breaks down the procurement into smaller packages. These packages are progressed along with design progress.

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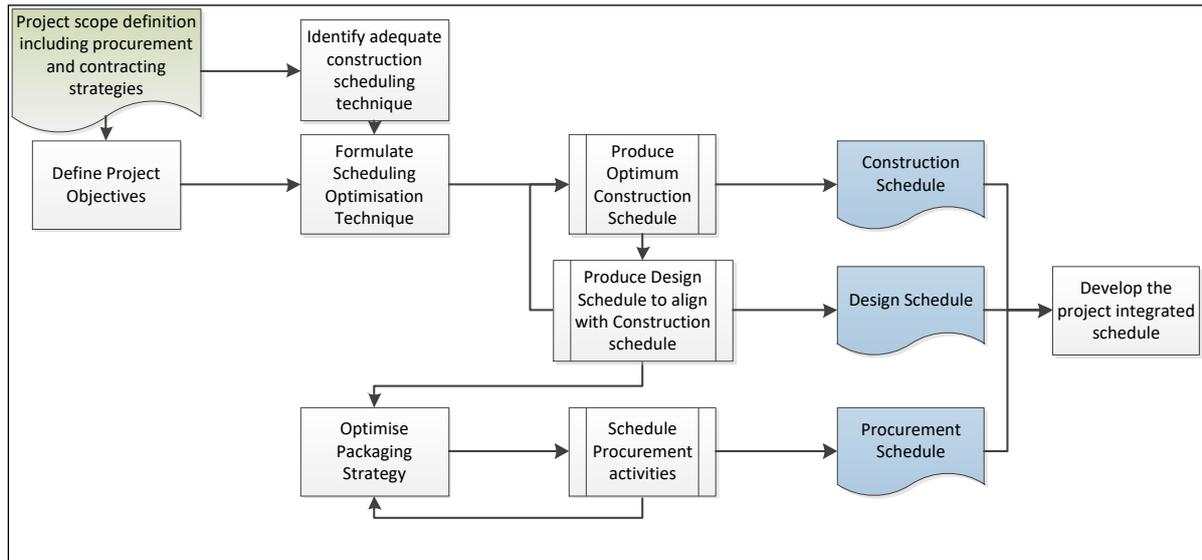


Figure 3: Scheduling development framework

The different components have to be integrated into a single schedule and logically linked. The level of detail of the integrated schedule depends upon the ability to establish a rational network and is preferred to be maintained as concise as possible. This can be achieved by identifying interfacing milestones amongst sub-schedules and ensuring their inclusion within the integrated programme. For example, a concrete activity has to be preceded by all engineering activities related to design, production drawings, and method statements. The end date of all the aforesaid engineering activities is considered the interfacing milestone with concreting. In addition, procurement of reinforcement is related to the production of workshop drawings and bar bending schedules, the completion of which is considered as an interface between engineering and procurement. Moreover, placing the reinforcement requires the delivery of material; this is an additional milestone for the interface between procurement and execution activities.

Conclusion

Integrated scheduling framework is developed in this research taking cognizance of three crucial fitness criteria thus: representations, programme objectives, and constraints. It was found that construction main components, i.e. engineering, procurement and construction, are different in nature and require a blend of scheduling techniques to ensure the development of the most realistic abstract model to simulate real-life.

It is acknowledged that the developed model is conceptual, which requires further validation through empirical testing. Future research potential is to investigate developing an integrated tool that will facilitate the implementation of the described framework within the industry. This will enable the validation and enhancement of the current framework.

Another potential future research area is to expand the current model to include dynamic scheduling, i.e. accounting for controlling programmes and accommodating current status to reschedule projects while considering the updated status.

Finally, this framework can be combined with Building Information Modelling (BIM). This is a potential area for combining BIM and machine learning algorithms to predict and forecast future project performance based on historical data.

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