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Scheduling and Cost Optimization for School Buildings in Public Sector

A Thesis Submitted in Partial Fulfilment of the Requirements for the
Master Degree in Engineering Management

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Thesis Discussion Committee Decision

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The Discussion Committee met on _____(day and date) in Hall no_____ (hall/ room no.)_____. Upon discussing the student whose details are stated above in public, the discussion committee recommends the following:

The student awarded grade _____ In the thesis subject_____

Without making any changes to the thesis

After making the modifications attached with this decision

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Abstract

Nowadays, globalization and growing competition in construction industry have created increasing challenges for project managers to deliver their projects on time and within allocated budget. The success of a construction project depends on scheduling, cost effectiveness and how firmly the project can be controlled. Inappropriate scheduling leads to completion delays and cost overruns.

The main aim of this thesis is to develop and use a scheduling and cost optimization model to overcome the challenging and competitive environment in school building construction in the public sector. Two well-established local contractors are selected to investigate their school construction scheduling practice for two school buildings in the Ministry of Works, Municipality Affairs and Urban Planning (MoWMAUP) in Bahrain. As a result, a new school scheduling model (SSM) has been developed which involves the following: 1) The logical relationships within each floor (horizontal constraints) and among the different floors (vertical constraints); 2) The vertical link between the structural core activities which have repetitive nature; 3) Work continuity and crew synchronization; 4) productivity factors and learning curve theory; and 5) Pre-determined deadline, work interruptions, and resource constraints.

Moreover, genetic algorithms technique (GA) is used along with SSM to reduce construction cost. GA is a unique optimization technique that is useful to examine an optimum or near optimum solution for any complicated problems consisting of large number of variables such as school buildings.

Optimization is used to select construction methods, number of crews, and works interruptions for each activity that results in an optimum schedule with minimum total construction cost. Furthermore, SSM illustrates graphical reports of the large schedule data to assist crew and project control throughout construction.

The application of SSM functions require a Visual Basic for Applications (VBA) macro that uses the language of Microsoft Project software. Later, a case study is carried out on school building construction in Bahrain to examine and prove its suitability. The consistency and suitability of SSM to the school building environment is proven through various optimization experiments.

Dedication

I dedicate my thesis to all my family and my close friends for their continuous support. A special feeling of gratefulness to my devoted parents and my son for their patience, and for providing me with strength to complete this work.

Acknowledgment

I thank all my family members and close friends for their constant support and patience during my studies in all my life. My gratitude and appreciation of this work supervision is for Prof. M. P. Saka for his continuous guidance and generous assistance. I extend this gratitude to Prof. Saad Suliman for his upkeep guidance in the Masters' Degree in Engineering Management.

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Chapter 1

Introduction

1.1 Background

1.2 Research Problem

1.3 Research Questions

1.4 Research Objectives

1.5 Importance of the Research

1.6 Limitations of the Research

1.7 Terminologies of the Research

Chapter 1

Introduction to the Study

This chapter introduces the need for studying the research topic selected.

1.1 Background

In the highly competitive environment of today's construction industry, project managers are facing increasing challenges to deliver cost-effective project in a timely manner. The success of a construction project depends heavily on how effective scheduling is and how firmly the project is controlled. Poor scheduling can easily result in completion delays and cost overruns. These in turn result in claims, counter claims, disagreements, and disputes (Arditi et al. 2002). Appropriate methods should be used in planning and scheduling of a project to minimize dependence on experience and intuition alone.

Currently, construction industry is facing major challenges as many projects suffer from time extension, cost overruns and, severe conflicts. There are many factors that can contribute to these common problems like the increasing complexity and the highly uncertain nature of modern construction projects, the increasing competition in the construction industry; and the growing demand for faster and less costly construction under increasing regulatory rules for safety and energy efficiency.

Planning is a necessary part of any successful construction project, where a detailed plan allows project managers to schedule the required work, track progress, and decide on corrective actions when unexpected events arise.

By proper planning and scheduling, contractors increase the possibility that a project can be completed within budget and time constraints, while reducing the chances of chaos breaking out (Mattila and Park 2003). The need for proper planning and scheduling of construction projects is crucial for all the parties involved.

Therefore, structured planning and scheduling is more essential for projects with repetitive nature such as highways, multiple housing units, and school buildings. The size of these projects is very large and includes construction and maintenance of infrastructure facilities.

In the public sector, the government is focusing more on providing a high level of education for its citizens; therefore, building schools is being a necessity with the increasing density of population in the country. Nowadays, increasing cost of building materials, equipment, work force and land in Kingdom of Bahrain has reinforced the need for school buildings. Because of the growing competition in the construction industry, considerable pressure has been applied on the public sector to deliver the schools faster and cheaper.

Hassanein and Moselhi (2004) characterized repetitive projects into two categories:

- a) Projects that are repetitive due to their linear geometrical layout (e.g., highway and pipeline projects); and

- b) Projects that are repetitive due to a uniform repetition of a unit work throughout the project (e.g., multiple similar houses and schools comprising typical floors) While school buildings belong to the second category, it is essential to distinguish between schools' buildings and multiple similar houses particularly from the scheduling perspective. Multiple similar houses, while representing a challenge due to repetition and size, consist mainly of individual units separated in space.

In this case it is possible for crews to work simultaneously at different units, and some crews can move horizontally from one unit to the other.

Repetitive projects are called Non-serial only when contain subprojects or mini-project of similar activities, but with independent starting and finishing dates (Ezeldin and Soliman 2009).

However, schools' buildings contain number of typical floors with identical activities that are repeated sequentially from one floor to the next. These repetitive activities are not moving in one direction but in two directions: a horizontal direction through the floor; and a vertical direction from one floor to the next. As a result, it is impossible to proceed with higher floors without completing the lower floors. The sequencing of activities is controlled by horizontal and vertical constraints.

The traditional process of planning and scheduling was done using network scheduling techniques and the most common is the critical path method (CPM). Because of the widespread use in the construction industry and in industrial engineering applications, CPM has gone through an evolution over the last 40 years, from arrow diagrams, the program

evaluation and review technique, and precedence diagrams to the current sophisticated commercial software used today (Mattila and Park 2003).

The repetitive projects are unique for their crew work continuity which is not the case in the traditional network scheduling methods such as CPM for scheduling construction projects” (Hyari, El Rayes & El-Mashaleh 2009). Crew or resources continuity means uninterrupted and unchanged or keeping continuity and consistency in the usage of resources moving from a unit to another (Zhang, Zou and Su 2013). Its advantages for project managers are best benefits from the learning curve effect for each crew and minimizing of the movement of crews throughout the units. Moreover, work interruption leads to an increased direct cost because of the idle crew time.

However, current Network techniques show major drawbacks when applied to scheduling present complicated projects of repetitive nature such as high-rise building construction. Therefore, there is a need for a better planning and scheduling tool that consider both, the horizontal and vertical constraints in school buildings construction.

1.2 Research Problem

Construction project management aims to satisfy and trade-off between three conflicting objectives which are time (schedule), cost, and performance (quality). One of the “most important aspects of project management” is the time and cost trade-off i.e. the less costs endured in resources allocated to an activity, more time is required to complete it. (Liao et. al, 2011)

Most of the government construction projects have not managed adequately over the past years, which lead to major cost overruns. For example, Malkiya Girls Primary and Intermediate School project, has suffered from time overruns, cost overruns, unmanageable risks, and low performance resulting in higher projects' overall cost.

Unfortunately, there are also examples in Kingdom of Bahrain where issues arising from schedule, cost and performance have led to the postponement of major vital construction projects such as the West Riffa, Muharraq and Alsalam Girls Primary Schools, Jidhafs Social Centre and many others.

Therefore, this research is carried out to introduce an effective scheduling model for schools' projects to optimize the total construction cost considering alternative construction methods for project activities, each having its duration and cost. This research has been motivated mainly by inadequate scheduling methods and ineffective optimization techniques as described in the following subsections.

1.2.1 Poor Scheduling Methods

Majority of the available scheduling programs tackle some but not all aspects of building project management. Most of the project management software systems, such as Microsoft Project and Primavera, for example, are based on the Critical Path Method (CPM). Despite of their popularity and wide use, CPM based techniques have been criticized widely in the literature for their inability to model repetitive projects (Harmelink 2001). Some of these limitations include the inability to schedule crews in a manner that maintains work continuity and the difficulty in representing the large number of activities in a legible manner (Vanhoucke 2006).

Many methodologies for planning and controlling linear and repetitive projects such as highways, multi-story building, and high-rise building have been developed over the years under the name of linear scheduling methods (LSM) (Damci, Arditi, & Polat, 2013). Those methods have been developed since the early 1970's for the scheduling and cost optimization of work with a repetitive nature.

Line-of-balance (LOB) is a variation of linear scheduling methods that allows the balancing of operations such that each activity is continuously performed. The major benefit of the LOB methodology is that it provides production rate and duration information in an easily interpreted graphics format (Yang and Ioannou 2004). It allows a smooth and efficient flow of resources, and requires less time and effort to produce than network schedules (Arditi et al. 2002).

Moreover, the LOB graph can illustrate the issues of the progress of an activity and identify possible issues that can arise in future. Apparently, LOB is considered a better tool for a project with repetitive activities compared to any other scheduling technique, because it allows the possibility to alter activities' rates of production.

However, available scheduling techniques for repetitive projects such as the LOB consider only sequential activities and have a one-dimensional formulation to maintain crew work continuity. Therefore, studies were performed to combine the benefits of the CPM and the LOB techniques, but these models demonstrate some shortfalls (Couto and Teixeira 2005) such as:

- Do not handle non-repetitive activities within the project such as the foundation works in a school building;
- Do not consider work interruptions, resource constraints, or cost optimization;
- Do not consider time and space dependency between activities which could result in undesirable time gap between activities and unnecessary idle time; and
- Do not consider learning curve effects or weather conditions impact on the production rate.

1.2.2 Mathematical Optimization Techniques Issues

As CPM techniques' are unable to consider resources and deadlines constraints, other techniques such as Time-Cost Trade-off (TCT), have been developed to tackle non-repetitive projects. By allocating additional resources to critical activities, the TCT technique attempts to increase their production rate and thus shorten the project duration (Reda 1990). However, application of TCT technique to school building projects results in variable production rates at different floors that may result to unfavorable crew-work interruption. Moreover, where a number of alternative construction methods are available for each activity, CPM techniques cannot implement TCT analysis (Hegazy and Wassef 2001).

1.3 Research Objectives

The objective of this research is to develop an efficient model that is capable of optimizing the time, cost, and resources involved in the construction cost of school buildings. The research has the following four objectives:

1. Study the unique characteristics of school buildings in Kingdom of Bahrain, as opposed to other linear projects, and determine the various considerations that affect scheduling decisions of school projects;
2. Develop a School Scheduling Model (SSM) that tackles the identified considerations through introducing a repetitive scheduling formulation that considers the horizontal relationships within each floor, as well as the vertical constraints imposed by the nature of school building construction;
3. Employ the genetic algorithms (GA) technique to develop a cost optimization model that is integrated into the new scheduling formulation; and
4. Develop a prototype computer system and validate its capabilities through a case study.

1.4 Research Methodology

The approach used in this research to achieve the objectives stated earlier comprises the following:

1. Review the theory and current developments that relate to school building project scheduling and cost optimization. Also analyze previous efforts for combining CPM with LOB to identify the important elements necessary to achieve full integration and further implementation in the proposed model;
2. Identify the factors that impact the duration and total construction cost of school projects and integrate them into the scheduling model;

3. Apply project management software (Microsoft Project) to calculate the start and finish time for the activities on the first repetitive floor;
4. Develop a scheduling model that defines the method of construction, number of crews, and work interruption to use in each repetitive activity so that the logical relationships within each floor and vertical constraints among floors are satisfied, the work continuity is maintained, the pre-defined deadline is met, and the total cost is minimized;
5. Integrate genetic algorithms (GA) technique into proposed model to optimize the total construction cost; and
6. Illustrate the model results into graphical representation that simplify the complicated school-scheduling findings.

1.5 Research outline

This thesis examines and discusses the application of scheduling and cost optimization in the construction of governmental school buildings in Kingdom of Bahrain.

The thesis is divided into the following six chapters:

- Chapter 1: includes an introduction, which identifies the factors that impact the schedule and total construction cost of school projects in order to integrate them into the scheduling model. In addition, it includes the research problem, objectives, methodology, outline and abbreviations of the research.
- Chapter 2: presents a literature review of available scheduling techniques for repetitive activities in current construction projects.

- Chapter 3: describes in detail the concept and formulation of the School Scheduling Model (SSM). The considerations for school scheduling are identified and analyzed. It presents the findings of the meetings held with representatives of construction firms. This chapter ends with discussing the development and integration of cost optimization calculations using GA' technique.
- Chapter 4: presents the implementation stage of the proposed model as prototype software, its main components, input, and output. Further experimentation to validate the model is carried out and results are discussed.
- Chapter 5: Contains the thesis conclusion and recommendations and extensions to current research in future studies.

1.6 Terminologies of the Research

1.6.1 Abbreviations of the Research

CPM	Critical Path Method
LOB	Line of Balance
TCT	Time Cost Trade-off
SSM	School scheduling Model
GA	Genetic algorithm
ADM	Arrow Diagram Method
PDM	Precedence Diagram Method
LSM	Linear Scheduling Method
CAP	Controlling Activity Path
RSM	Repetitive Scheduling Method
HVLS	Horizontal and Vertical Logic Scheduling
SCRC	Space-Constrained Resource-Constrained Scheduling System
AI	Artificial Intelligence
FL	Fuzzy Logic

NN	Neural Network
FNS	Fuzzy Network Scheduling
ANN	Artificial Neural Network
ND	Neural Dynamic
VBA	Visual Basic for Applications
ES	Easy Plan

1.6.2 Symbols of the Research

i	activity number
j	index to the construction method used in activity i ($j= 1,2,$ or 3)
k	floor number
L	the month number ($1,2,..., 12$) in which the activity is scheduled
Q_{ijk}	Quantity of work for activity i using method j at floor k
P_j	Production rate for the resources involved in method j according to the resource type (crew, sub-contractor) and their working hours per day

f_{kL}	productivity factor (0 to 1), depending on the working conditions at floor k during month Z
d_{ijk}	duration for activity i using method j at floor k
C_{ij}	sum of the cost per day for the resources involves in method j of activity i (depending on the resource type and its working hours per day)
C_{ijk}	Direct cost of activity i using method j at floor k
d_{sck}	is the duration for the structural core group at floor k
n	is the number of structural core activities
d_{ijk}	is the individual durations of the core activity I at floor k using construction method j
R_{sck}	the progress rate of the structural-core activities
T_L	is the deadline duration of the project
T_1	is the CPM duration of the first repetitive floor
F	is the number of floors
R	is the required progress rate to complete the project on time
T_{Fi}	is the total float for activity i
R_i	is the progress rate for activity i.

Cr_i	is the number of crews required to achieve production rate R_i
Cr_i	is the number of crews required to achieve production rate R_i
Cr_{ai}	Adjusted number of crews
R_{ai}	adjusted progress rate
SQI_n	The Solution Quality Index

Chapter 2

Literature Review

2.1 Inroduction

2.2 School Building Construction

Chapter 2

Literature Review

2.1 Introduction

This chapter provides an overview of the unique characteristics of school projects in Kingdom of Bahrain. In addition, this chapter presents a review of recent literature in traditional scheduling techniques for repetitive construction projects in general, and special scheduling techniques for school buildings in particular.

2.2 School Building Construction

School buildings comprise mainly of a number of typical floors with similar activities that are repeated sequentially from one floor to the other. These repetitive activities progress within the building in two directions:

- A horizontal direction through the floor and;
- A vertical direction from one floor to the next.

The sequencing of these activities is controlled by constraints between activities executed on different floors (vertical constraints). To incorporate these constraints in the schedule, the scheduling process must ensure the constraints are satisfactory for all activities on every floor. The scheduling model in repetitive construction projects produces a resource-driven schedule for repetitive units in the project that fulfils the “logical

precedence relationships, crew availability and crew work continuity requirements”. (Hyari , El- Rayes & El- Mashaleh 2009).

In general, school building construction is considered a special case of repetitive projects, which can be classified into two categories: linear (such as highways and pipelines) and nonlinear (such as schools projects and multiple-housing construction). While the first are repetitive due to their geometric layout, the second are repetitive as crews repeat the same task in all units. The difference between these two classes is that in nonlinear projects, the units are physical entities (e.g., floors in a school project) that can be in a single or multiple different locations. Therefore, once the work is completed in any unit, crews shift from that unit to the next. For instant, a painting crew working on a school would need to mobilize from one floor to the other. However, this is different in linear projects, where crews progress from one unit to the next during the project lifetime. For instant, a paving crew working on a highway would simply progress from one unit to the next without mobilization, unless a transverse obstruction exists (Hassanein and Moselhi 2004).

Within repetitive projects, crews (labor and equipment) move from one unit to the next and complete work that is prerequisite to other successor crews and equipment. The production system is frequently related to manufacturing assembly lines, which involve repetitive operations on products. In manufacturing, it is the product flowing across stationary labor and equipment whereas in repetitive projects, it is the labor and equipment that flow through the construction site (Yang and Ioannou, 2004).

The success of a construction project, particularly repetitive projects, depends heavily on how effective scheduling is and how firmly the project can be controlled. Poor scheduling can easily result in completion delays and cost overruns. These in turn result in claims, counter claims, disagreements, and disputes (Arditi et.al 2002).

The suitable methods should be used in scheduling a project and management decisions should not depend on experience alone. Therefore, a review of different scheduling techniques that were used to schedule construction projects is presented in the following sections.

2.3 Bar Chart Method

Bar Chart method is a graphical representation of the project schedule that was originated and developed by Henry L. Gantt during World War-1 (Mubarak 2005).

The duration of each activity is reflected by the length of a bar in accordance with the time scale of the chart (Figure 2.1). Unfortunately, this method is unable to show the inter-relationships between activities, thus failing to identify the critical activities, which basically control the project duration. This issue made modifying or updating a particular activity more difficult, and may cause additional changes in other related activities.

For small non-repetitive projects, however, a bar chart is simple to produce and understand and have universal appeal primarily due to its graphic and easily understandable format (Mubarak 2005).

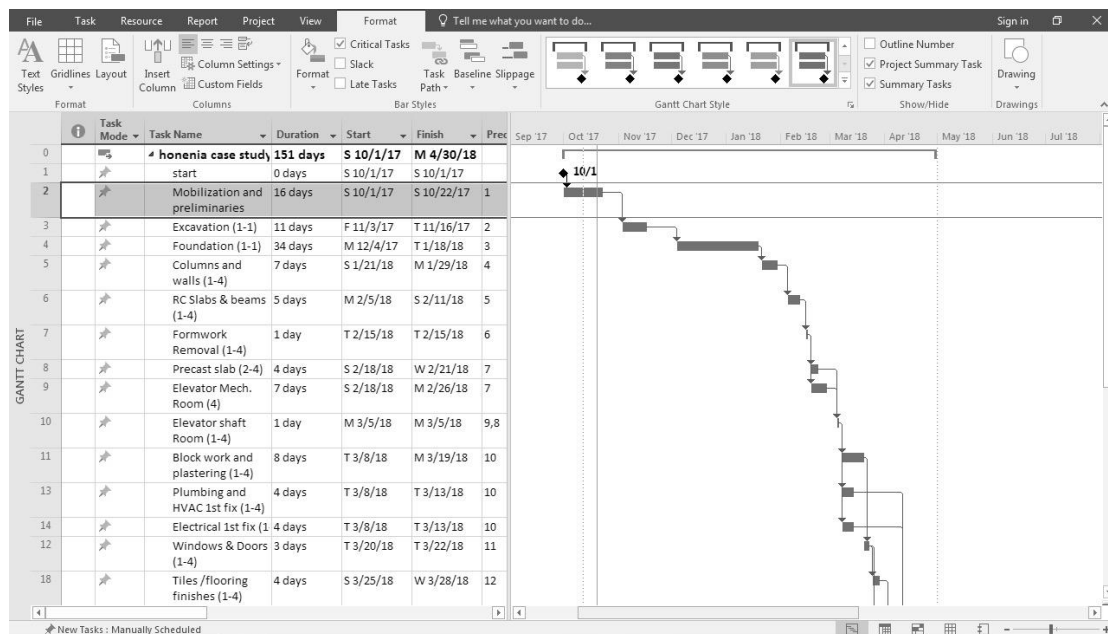


Figure 2.1: Sample of Bar Chart

2.4 Network Techniques

The Critical Path Method (CPM) is the best known and most used formal scheduling technique. A network diagram is a graphical representation of activities and their relationships.

As shown below the relationships between activities (Figure 2.2), these diagrams successfully reduce the deficiencies of bar charts. Network techniques clearly illustrate the critical activities that control the project duration.

There are mainly two types of network techniques used to reflect activities and their relationships. The first is arrow diagram method (ADM)

in where activities are represented by arrows and nodes connecting these arrows, with the nodes are considered events or milestones. The second type is activity on node diagram and known as precedence diagram method (PDM). In PDM nodes represent activities and connecting arrows represent the relationship among these activities. (Figure 2.2).

ADM can consider only one type of relationship namely Finish to Start whereas PDM can consider four different types of relationships namely, Finish to Start, Finish to Finish, Start to Start and Start to Finish (Nunnally, 1998).

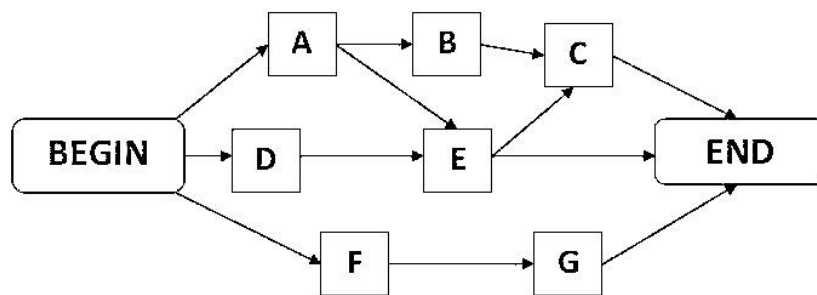


Figure 2.2: Sample Activity Network with Logical Relationships

Although those methods are common and used widely, they are having number of deficiencies. Hegazy (2003) listed these deficiencies as follows:

- CPM inputs are the project activities, their durations, and their dependency relationships. Accordingly, CPM calculations determine the start and finish time of the activities. Therefore, CPM algorithm is duration driven. Activities' durations are functions of the resources that are required to complete each activity. Consequently, The CPM formulation assumes that resources are

available and cannot be used to determine what resources are needed in order to meet the project deadline;

- Since CPM formulations deal with activities' durations, not resources, usually it results in large daily fluctuations in the total resources. Therefore, special resource-leveling efforts have to be done to reduce this fluctuation in resources; and
- CPM methods deal with activities' durations, but they do not deal with any aspects related to cost optimization of the project.

In repetitive construction, identical activity chains are performed many times. A CPM network requires an individual graphical element for each activity repetition, resulting in a very large network once activities are repeated many times. A typical CPM network for a repetitive construction project with three floors building, where the solid arrows in the figure represent logical relationships for the various activities within each floor, while the dashed arrows indicate sequence relationships among the consecutive floors (Figure 2.3).

As discussed earlier, the number of relationships needed to describe the network is significantly large, which makes it difficult to visualize and manage the project.

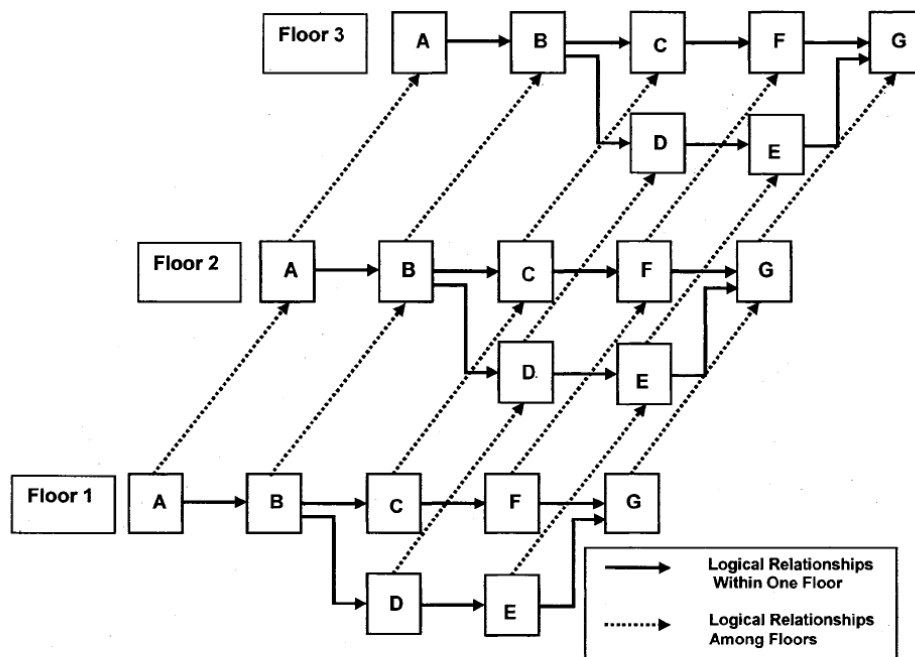


Figure 2.3: CPM network for repetitive Project

CPM based techniques' deficiencies to model repetitive projects have been widely recognized in the literature. Arditi et al. (2002) reported that CPM methods are not suitable for projects of a repetitive nature because repetitive activities usually have different production rates. This phenomenon of production rate may affect project performance by causing work stoppages, inefficient utilization of allocated resources, and excessive costs. Since there is no indication of production rates in CPM networks, the scheduler can never anticipate this situation during the development of a network, nor can it be detected in regular network analysis.

Moreover, Adeli and Karim (1997) have discussed the limitations of traditional network scheduling methods such as CPM as the following:

- Network methods do not guarantee continuity of work in time, which may result in crews being idle;

- Multiple-crew strategies are difficult to implement in network methods;
- The network diagram is not suitable for monitoring the progress of a project; and
- Network methods do not provide an efficient structure for the representation of repetitive tasks. All tasks are represented similarly, and there is no consideration of the location of work in the schedule.

2.5 Techniques for Scheduling Repetitive Projects

Due to the deficiencies and limitations of bar chart and network techniques while dealing with repetitive projects, other techniques were developed later, such as “linear scheduling methods.” (LSM).

LSM has detected various issues associated with linear scheduling, such as (Hegazy and Wassef 2001 and Arditi et al.2002):

- Difficulties to achieve a desired progress rate to meet project deadline;
- Inability to assure work continuity from one unit to the other;
- Inability to manage and synchronize resources;
- Inability to add proper work interruption to get a balance among the production rates of repetitive activities;
- Difficulties to sequence the execution of the work;
- Inability to illustrate the huge amount of data in a clear format.
- Does not consider learning curve effect;

- Does not consider non-repetitive activities within repetitive projects such as foundations in a school building.

2.5.1 Line-Of-Balance (LOB) Method

LOB is one of the earliest methods to schedule repetitive projects, which was invented by the Goodyear Company in the early 1940's and was further developed by the U.S. Navy in early 1950's for the programming and control of repetitive projects (Yang and Ioannou 2004). LOB was applied in the beginning to industrial manufacturing and production control in order to evaluate a production line flow rate of finished products.

Later in 1960's National Building Agency of the United Kingdom applied LOB in repetitive housing units (Lumsden 1968), where LOB technique is a simple graphical scheduling technique for serial repetitive activities and no network analysis was involved.

The LOB chart illustrates the planned start and finish time of each activity in each unit (Figure 2.4). The chart shows a LOB schedule for a serial network of three sequential activities with a buffer time between sequential activities. It also shows crew movement among different floors.

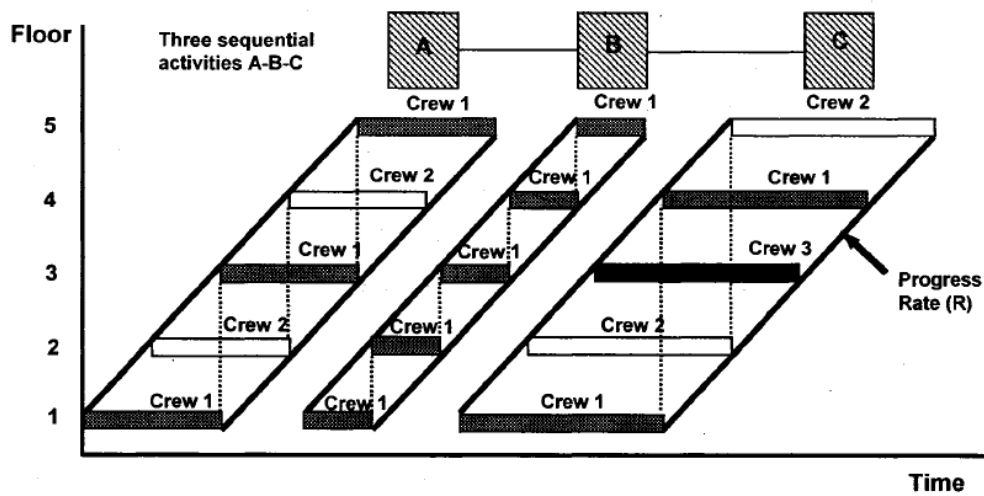


Figure 2.4: Graphical Presentation of LOB Schedule

For instance, activity A, has two crews employed for its execution; crew 1 is assigned first to floor 1 then moves to floors 3 and 5, while crew 2 is assigned to floor 2 then moves to floor 4. Schedule control in this method can be achieved by plotting the actual progress for each activity on the same chart, thus providing an overview of the project status at any point of time.

As suggested by Lumsden, each project has a "Natural Rhythm", and that any deviation from that rhythm would result in the resources being not fully utilized.

Therefore, the Lumsden formulation calculates the crews needed to achieve the required progress rate for each activity. However, the calculated number of crews must be rounded up to the next integer values causing variations in activities' progress rates. To achieve this natural

rhythm, the project manager must identify the construction methods and techniques that are balanced to a common rate of repetition.

The procedure for preparing LOB schedules can be presented in the following six steps:

1. Prepare a network diagram and calculate the completion date for the first repetitive unit.
2. Estimate the resources required to complete each activity.
3. Calculate the progress rate required to meet project deadline.
4. Calculate the theoretical number of crews for each activity that would achieve the required progress rate.
5. Calculate the actual progress rate based on the rounded-up number of crews.
6. Draw the line of balance by propagating the start and finish dates of the first unit activities using the actual progress rate.

Various techniques for improving LOB schedules that would result in more balanced lines (parallel progress rates); hence improving resource utilization and possibly reducing the project completion date. Such as:

- Changing activities' progress rate at intermediate points through the project;
- Laying-off and recalling crews at intermediate points through the project (introducing work interruption); and
- Overlapping some activities.

Al-Sarraj (1990) presented a mathematical model for LOB technique based on assumptions similar to those proposed by Lumsden. The model

calculates the start and the finish times for repetitive activities at each unit and produces two schedules:

1. Theoretical schedule based on the calculated progress rate that is needed to achieve project deadline without regard to crew numbers roundup; and
2. Actual schedule based on progress rates after crew numbers roundup.

However, LOB method only considers sequential activities and not consider issues arising from variable production rates, or provide a procedure to combine construction methods to get a natural rhythm.

2.5.2 CPM/LOB Methods

Traditionally, several efforts have attempted to combine the advantages of both CPM technique for critical analysis and LOB for linear scheduling.

Suhail and Neale (1994) developed their own procedure to put a formulation for determining the amount of crews needed to meet a given deadline. Their formulation incorporates the resource leveling principles and the activities' total float values to relax non-critical activities without affecting the project completion date. Despite of the obvious advantages of this methodology, it has a serious disadvantage since the formulation does not address the conflict arising from variation in progress rates due to crew round up nor addresses work continuity.

These disadvantages were later resolved by the formulation presented in (Hegazy and Wassef 2001) and are modified in this research to suit the environment of school buildings. In 2001, Harmelink and Rowings proposed the linear scheduling model (LSM) to provide a level of analytical capability to the linear scheduling process. Similar to CPM, it identifies the critical activities or the controlling activity path (CAP) through an upward and downward pass through the repetitive activities.

Harris and Loannou presented Repetitive Scheduling Method (RSM) in 1998 to establish controlling sequence using control points. The RSM illustrate a graphical schedule as an X Y plot of a series of production lines, each of which show a repetitive activity by using control points and the controlling sequence. Control points are the locations on each activity line where the activity changes from controlling to non-controlling, or vice versa and used to define the controlling sequence of activities, in a manner similar to the critical path in a CPM schedule, which in turn determines the project duration. This graphical methodology enables a project manager to control the work interruption period by arranging the resource production rate. Therefore, it can be useful for understanding RSM in easy coordinates considering the productivity of resources.

Although the RSM uses a new concept for analyzing a repetitive process, the project cost during interruption time and the organization of the crew group to minimize cost are not analyzed in the methodology (Kang et al. 2001)

2.5.3 Models Used for Repetitive Buildings

Horizontal and Vertical Logic Scheduling (HVLS) was proposed as a knowledge-based system by Thabet and Beliveau (1994). HVLS describe a structured procedure to incorporate horizontal and vertical constraints to schedule repetitive work in school building projects. Ten scheduling cases were defined for horizontal constraints and one case for vertical constraints. The system alters activities' durations to eliminate work interruptions while observing horizontal and vertical constraints. The scheduling decisions in these cases consider three activity parameters:

1. Work continuity to reduce idle waiting intervals of equipment and manpower, minimize extra effort associated with work interruptions, and maximize learning curve;
2. Convergence and divergence of flow lines (by comparing rate of production of successive activities); and
3. Vertical workflow direction to accommodate the nature of school projects which either upward (construction of the skeleton) or downward (finishing of external cladding).

In 1997, Thabet and Beliveau incorporated Horizontal and Vertical Logic Scheduling (HVLS) into SCRC a Space-Constrained Resource-Constrained Scheduling System for multi-story building projects. The system incorporates space-based scheduling techniques to consider the problem of limited space availability during the generation of the schedules. The system also incorporates scheduling procedures to account for resource constraints as well as any defined horizontal and vertical logic constraints associated with scheduling of multi-story buildings.

SCRC uses a parallel approach. At any time, all activities eligible for scheduling are considered together (i.e., in parallel). These activities are ranked into as a group according to heuristic criteria (i.e., activities with earliest-late-start date are scheduled first). The scheduling of each activity is performed in two consecutive stages:

1. In the first stage, horizontal and vertical constraints are defined and checked at critical floors. To ensure that the constraints are satisfactory at all floors, satisfaction of the constraints at these critical floors has to be verified. If they are found satisfactory, resource constraints are then checked to verify that no conflict between resource demand and availability exists.
2. In the second stage, activity space demand is compared to the available space in the associated work areas.

Even though the above models for school buildings has interesting features, the special considerations for horizontal and vertical relationships is lacking and cost optimization is not incorporated. Moreover, existing models do not adequately account for the impact of weather conditions and the learning curve on the productivity of the working crews.

2.6 Optimization Models

Due to the significance of cost optimization for school buildings, a literature review on optimization models is discussed in this section.

2.6.1 Mathematical Programming Techniques

Previously, mathematical models apply either linear or dynamic programming procedures to find optimal solutions for scheduling and optimization of repetitive projects. Selinger (1980) proposed a dynamic programming model for scheduling repetitive projects to reduce overall project duration. However, this model did not consider cost or work interruptions. Russell and Caselton (1988), who introduced a two-state variable with the objective of minimizing project duration, developed a modification of Selinger's model. The state variables represented sets of the activities' durations and interruptions. However, this model did not include cost in the optimization process.

A linear programming approach was proposed by Reda (1990) to minimize project direct cost assuming linear time-cost relationships and strong adherence to the continuity constraints (i.e., no interruptions were allowed). Moselhi and El-Rayes (1993) minimized project direct cost using a dynamic programming model that could determine optimal crew formation without considering work interruptions. Similarly, Senouci and Eldin (1996) developed a two-state variable to minimize total construction cost, considering both crew formations and work interruptions among limited non-serial activities.

However, the only optimization model could handle non-repetitive activities was the one developed by Senouci and Eldin (1996). Additionally, the models did not consider project deadline, crew synchronization, and resource constraints, simultaneously. In addition, the mathematical optimization techniques they used, such as linear and

dynamic programming, do not assure an optimal solution (Li and Love 1997).

2.6.2 Artificial Intelligence Techniques

Construction management problems are complex, ill structured, full of uncertainties and vagueness, and have inexact and incomplete information. Developing a mathematical model for solving such problems is difficult and expensive (Cheng and Ko 2003). The development in Artificial Intelligence (AI) technology has produced a new tool that are beneficial to be utilized for construction applications. AI-based optimization techniques can be used for scheduling optimization in large-size projects.

To work more productively and deal with increasing challenges has motivated many researchers to develop nontraditional problem-solving tools based on AI as: Fuzzy Logic (FL), Neural Network(NN), and Genetic Algorithms (GA) have been extensively explored in scheduling and optimizing construction projects. An introduction to these techniques and their applications in scheduling is discussed hereafter.

Fuzzy Logic: The term “Fuzzy” refers to the degree of fuzziness and relative significance and it tackles the impact of fuzziness on the solutions made by experts for complicated problems. Fuzzy logic theory was developed by Zadeh in 1965 to deal with uncertainties that are not statistical in nature. The concept of fuzzy sets theory differs from that of the conventional crisp sets mainly in the degree by which an object belongs to a set.

Objects are either included or excluded from the crisp set. However, in fuzzy set objects are described in such a way to allow gradual transition from being a member of a set to nonmember. Each object contains a degree of membership ranging from zero to one, where zero indicates non membership while one indicates full membership (Lorterapong and Moselhi 1996)

Project management goals are usually fuzzy in nature because some relevant information is imprecise and/or vague. Several researchers for construction project planning and scheduling have used fuzzy logic techniques. Various studies have documented the use of fuzzy logic for estimating the duration of project activities, by accounting for factors such as site conditions, weather, and labor performance, all of which are best expressed linguistically (Oliveros and Fayek 2005)

Lorterapong and Moselhi (1996) introduced fuzzy network scheduling method (FNS). The model attempts to facilitate the representation of imprecise activity duration, the calculation of scheduling parameters, and the interpretation of fuzzy results generated. In 2004, Bonnal et al. proposed a framework for addressing the resource constrained fuzzy project-scheduling problem.

In spite of the benefits of fuzzy logic, its use on linear and repetitive projects will complicate the problem as a large number of fuzzy parameters are expected to be involved.

Artificial Neural Network: Artificial Neural Network (ANN) is a parallel-distributed processor inspired by the architecture of human brain. It is made up of simple processing units (neurons) that perform

computations. It demonstrates the ability to learn, recall, and generalize from training patterns. Through their learn-by-example process, a neural network is able to automatically associate the causes with their related outcomes, without logical explanation. After being trained, an ANN is able to predict the outcomes of a completely new situation (Cheng and Ko 2003). A typical ANN consists of a group of processing elements organized into a sequence of layers usually with full connections between successive layers through connection weights (Figure 2.5).

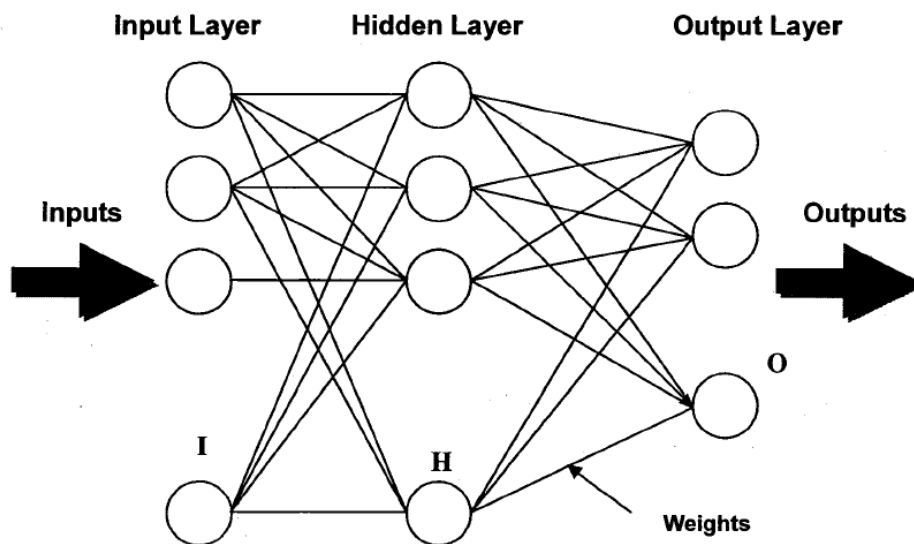


Figure 2.5: Three Layer Neural Network

Adeli and Karim (1997) to schedule and optimize construction projects developed a neural dynamic model (ND). ND's objective is to minimize construction cost. ND varies the construction duration to solve the cost duration trade-off problem and obtain a global optimum schedule and corresponding minimum direct cost. ND accommodates repetitive and non-repetitive activities alike. Additionally, it takes into consideration

work continuity constraints, multiple crew strategies, and the effect of job conditions on the performance of a crew such as weather conditions. ND, however does not address resource-constrained scheduling problems, which are important for construction projects.

Senouci and Adeli (2001) extended the model developed by Adeli and Karim (1997) to consider not only direct cost but also total cost minimization. The model performs resource leveling and resource constrained scheduling simultaneously.

Furthermore, it is capable of dealing with large size repetitive projects. However, the model dealt with continuous activity durations only and did not consider the case of discrete activities (Senouci and Eldin 2004).

Techniques based on Neural Networks have extensive capabilities for scheduling and optimizing repetitive projects. However, such techniques have been met with uncertainty from researchers and practitioners. ANNs that are suitable for optimization usually have complex formulation. Additionally, practitioners perceive ANNs as “black boxes” due to the ambiguity and their internal logic, thus limiting their usage (Hegazy and Wassef 2001).

Genetic Algorithms: Genetic Algorithms (GA) were developed as nontraditional optimization methods that simulate the natural evolutionary process of survival of the fittest. A GA is an optimization procedure that operates on a population of parents (possible solutions). Each population member (solution) is called a chromosome that consists of series of genes (binary or digital numbers) representing the values of the variables

associated with the solution. The fitness of each chromosome is a measurement of its performance, as defined by the objective function and the constraints (Senouci and Eldin 2004). In its simplest form, GA evolves the population until an optimum is reached. The evolutionary process involves cycles of generating and testing new offspring solutions, one of three operations. Each of these operations is described below (Goldberg 1989):

1. **Reproduction:** is the basic engine of Darwinian natural selection by the survival of the fittest. The goal of the reproduction process is that the parent solution with good fitness survives into the next generation. Each population member is assigned a probability of being selected as a parent based on its fitness.
2. **Crossover:** is a procedure in which an offspring (new solution) is generated from the marriage (exchange of information) of two parent solutions. In this manner, the crossover operation creates solutions that can be tested, and then will survive if they are more fit than weaker members in the populations (Figure 2.6.)
3. **Mutation:** generates a new offspring solution by introducing random changes in a parent solution.

GA is effective at global search. In addition, because of its simplistic implementation procedure, the GA is simple to hybridize with domain-dependent heuristics to make an effective implementation for specific problems. For these advantages, GA has received considerable attention regarding their potential as a novel optimization technique and have been used successfully to solve several engineering and construction

management problems (Cheng and Ko 2003), including time-cost tradeoff, resource leveling and resource allocation.

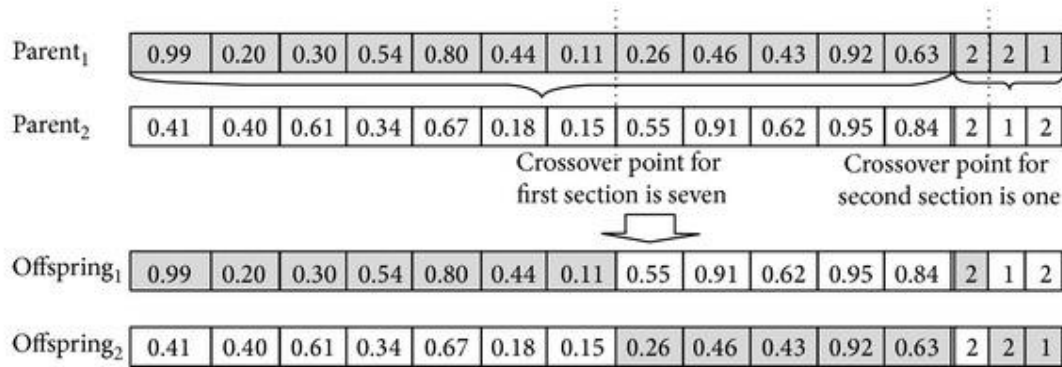


Figure 2.6: Sample of Crossover Operation

Hegazy (1999) used GA to search for near-optimum resource allocation and leveling simultaneously by introducing random priorities into selected tasks and monitoring their impact on the schedule. Leu and Yang (1999) proposed a genetic algorithm-based multi-criteria construction scheduling model that incorporates the time-cost trade-off model, resource-leveling model, and resource-limited model. The model aims to provide an optimal combination of construction durations, resource amounts, minimum direct project costs, and minimum project duration under the constraint of limited resources.

Zheng et al. (2004) utilized GA to develop a model for time-cost optimization. The model aims to optimize total cost and total duration simultaneously. The model establishes the best time-cost solution by utilizing previous information to adjust the search direction and exert a search pressure toward an ideal point.

In 2001, Hegazy and Wassef introduced a genetic algorithm-based model for scheduling and cost optimization of repetitive projects. The model objective is to minimize total construction cost comprising direct cost, indirect cost, interruption cost, as well as incentives and liquidated damages. The model attempts to perform time-cost trade-off analysis considering a specified deadline and alternative construction methods with their associated time and cost.

Although GAs have already been applied successfully to numerous areas in civil engineering and construction including time-cost trade-off analysis, resource leveling, and resource allocation of non-repetitive projects, they have not been applied extensively to repetitive projects, with the exception of Hegazy and Wassef (2001). Their model, however, focused on multi-unit projects and did not address the unique characteristic of repetitive floors of government school buildings, which is addressed in this research.

2.7 Conclusion

As discussed earlier, repetitive projects in general and school buildings specifically have a unique nature; accordingly, they require dedicated scheduling and management methods. In this chapter, various techniques used to schedule repetitive projects have been discussed, accordingly several conclusions can be deduced from the literature review:

1. Combining CPM method with a repetitive scheduling method (LOB) can enhance repetitive scheduling;

2. The available research efforts do not tackle the various considerations relevant to school building projects such as:
 - Crew synchronization and work continuity;
 - Horizontal and vertical constraints;
 - Non-repetitive activities;
 - Learning curve effects;
 - Environmental factors impact on production rates; and
 - Minimization of total construction cost which include direct costs, indirect costs, interruption costs, incentives and, liquidated damages.
3. A flexible scheduling model for school buildings that addresses all above considerations is needed; and
4. Artificial intelligence techniques such as fuzzy logic, neural network and genetic algorithms have emerged as powerful tools to solve construction management problems. For cost optimization of school buildings, genetic algorithms have a great potential for use.

Chapter 3

School buildings Scheduling Model

3.1 Introduction

3.2 Current School Building Scheduling Practice

3.3 Proposed School Building Scheduling Model
(SSM)

3.4 Cost Optimization Using Genetic Algorithms

3.5 Conclusion

Chapter 3

School Buildings Scheduling Model

3.1 Introduction

This chapter introduces the progress of the proposed School Buildings Scheduling Model (SSM) for scheduling and cost optimization of schools. SSM is intended to reflect a number of factors facing in the construction of school projects. Thus, several meetings were held with representatives of construction firms to identify their practical considerations for scheduling of school buildings to include them into the model.

SSM has been designed as a scheduling system with a cost optimization at its core. Detailed description of the scheduling model is discussed in section 3.3, while the cost optimization is described in section 3.4.

3.2 Current School Building Scheduling Practice

In this section, existing Scheduling practices for construction buildings are discussed to identify the practical considerations, requirements, and specifications for the proposed model. Thus, series of interviews were conducted with project managers and site engineers from two different contracting firms specialized in school building construction in Kingdom of Bahrain to discuss their scheduling practice. In addition, site visits were done to construction site in order to study how they are

progressing on site and to understand the unique characteristics of school building construction.

The main issues identified for those two projects are summarized as follows:

- Both repetitive and non-repetitive activities should be included in scheduling system corporate (i.e., excavation and foundations) into a single framework for school building scheduling;
- The quantities for the same activity at different floors might differ;
- Work continuity of crews should be flexible and not rigid constraint, hence, work interruption should be allowed whenever needed. Also, the length of work interruption might differ at different floors;
- Any activity might have more than one predecessors and successors. Thus, the ability to add relationships among activities at different floor becomes essential;
- The productivity rate of a working crew may change as work progresses.
- Once the operation is repeated, it will require shorter time needed to perform it, which is known as learning curve effect. Therefore, learning curve effect should be considered;
- Environmental impact on the productivity of working crews should be reflected;
- The progress of some activities on some floors controls the progress of other activities on different floors. These constraints must be considered and integrated to ensure work continuity; and
- The schedule must be easy to read and understand. Therefore, degree of detail in the schedule must be carefully considered.

Each of the two studied contractors provided a copy of their project schedule of one school project (See Appendix 1 & 2). The approach used by the two general contractors to schedule their school projects is similar where they use Microsoft Project Management software to represent project's activities with start and finish dates. The activities were entered manually in a sequential. The program enables the project managers to update the schedule based on information provided from site.

Contractor (A) uses a simple and practical approach to compare planned versus actual progress of each activity. Basically, he uses a table to compare planned and actual activities in each floor to indicate if an activity on a certain floor is completed on time or suffering a delay (Figure 3.1). The main advantage of this approach is its simple representation, which follows the shape of the building

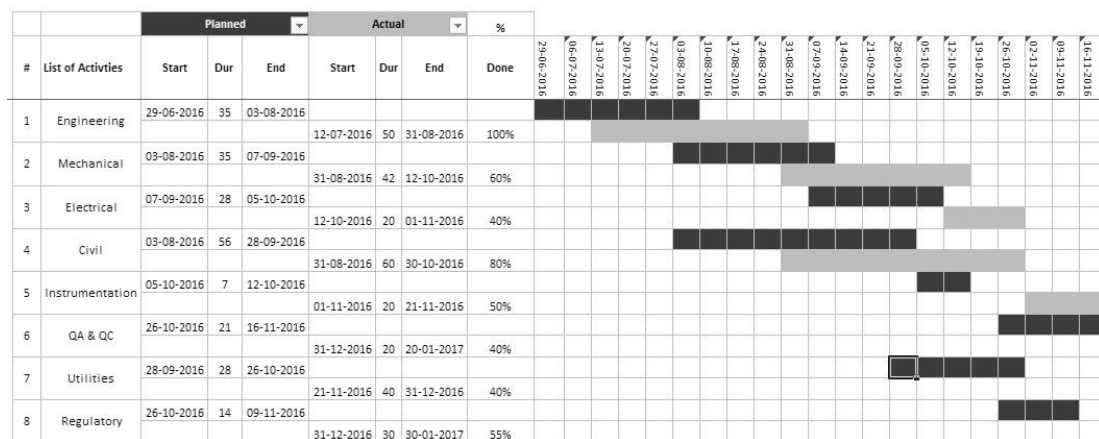


Figure 3.1: Contractor (A) to track activity progress

However, non-repetitive activities such as excavation and foundations are scheduled separately from the repetitive activities. All constraints are reflected into the activity times in the schedule.

With both contractors, activity times in the schedule are determined manually to maintain work continuity. It assumes that each activity follows a specific cycle time to complete the work in each floor. For example, the framing activity for a floor has to be completed in a 42 days. Similarly, the blinding activity for each floor has to be completed in a 1 days and so on. This approach, assumes that each crew will move from one floor to the other without idle time, given that the predecessor activity has followed its cycle time and has been completed.

Although the schedule is simple and easy to read, it does not show the constraints among the activities since it only uses numerical values, nor it shows the movement and the speed of crews. Furthermore, it is almost impossible to expect any delay before its occurrence, and if the delay occurs, it is very difficult to identify the reasons, the implications, or the appropriate corrective action to rectify the problem. Moreover, the scheduling technique does not consider construction cost or the resource optimization.

The site study and the discussions with the contractor's experts assisted in finding some of the difficulties usually encountered during the planning and scheduling of school projects. Additionally, the discussions helped to get their opinion on the best scheduling model alternatives for school projects and what are the difficulties encountered.

3.3 Proposed School Building Scheduling Model (SSM)

The proposed School building Scheduling Model (SSM) is a scheduling tool, specifically designed for the environment of schools. SSM calculates the number of crews required to meet the project deadline, under the following constraints: a) logical relationships within each floor (horizontal constraints); b) logical relationships among floors (vertical constraints); and c) work continuity constraints. SSM reflects a unique representation of the activities that form the building's structural-core, which need to be handled carefully to prevent scheduling errors.

Moreover, SSM allows the decision maker to add additional work constraints that reflect resource and/or work flow requirements.

The scheduling formulation of SSM includes five aspects, which are discussed in the following subsections:

1. Estimation of the durations and costs of individual activities;
2. Scheduling the building's structural-core activities;
3. CPM calculations for a single floor;
4. Crew synchronization to meet project deadline; and
5. Reflection of horizontal, vertical, and other constraints.

3.3.1 Estimating the Durations and Costs of Individual Activities

SSM allows activities to have up to 3 construction methods to provide different alternatives for cost and time optimization, those methods will be arranged from cheap-and-slow to fast-and expensive.

Consequently, each activity has various construction alternatives with their related resources, durations, and costs. For time and cost estimation, the following basic equations are used (Hegazy 2003):

$$\text{Activity duration} \dots\dots\dots d_{ijk} = \frac{Q_{ijk}}{P_j \times f_{kL}} \quad (3.1)$$

$$\text{Activity Cost} \dots\dots\dots C_{ijk} = d_{ijk} \times C_{ij} \quad (3.2)$$

Where:

i = Activity number

j = Index to the construction method used in activity i ($j= 1,2$, or 3)

k = Floor number and L represents the month number ($1,2,\dots, 12$) in which the activity is scheduled.

Q_{ijk} = Quantity of work for activity i using method j at floor k .

P_j = Production rate for the resources involved in method j according to the resource type (crew, sub-contractor) and their working hours per day.

f_{kL} =Productivity factor (0 to 1), depending on the working conditions at floor k during month.

d_{ijk} = Duration for activity i using method j at floor k

C_{ij} = Sum of the cost per day for the resources involves in method j of activity i (depending on the resource type and its working hours per day)

C_{ijk} = Direct cost of activity i using method j at floor k .

For instance, if the daily production rate of concreting crew is 300 cubic meter per day, and crew is assigned to carry out the columns at a specific floor that has a quantity of 600 cubic meter, given that the crew will work at 80% productivity (i.e., $f=0.8$) and the daily cost of such crew is BD 50,000. Using Equation 3.1, the duration of such activity will be $600/(300 \times 0.8) = 2.5$ days. Using Equation 3.2, the total cost of the activity becomes $BD\ 50,000 \times 2.5 = BD\ 125,000$.

As shown in Equation 3.1, the productivity factor (f) adjusts the duration estimate for an activity to account for other environmental aspects under which the work to be performed which include: 1) local weather conditions; 2) labor unrest; 3) space congestion; 4) level of management and supervision; 5) level of design change and rework; and 6) job uncertainty. Among all these factors, however, the weather has the largest impact on the value of the productivity factor.

The productivity of the structural work reaches its peak in summer mostly because of the good conditions and high temperatures. However, rain might stop the progress of the work.

Winter is the most difficult for a construction work where cold weather and high winds suspend work on sites because of safety reasons.

As a result of weather effects and other factors that impact productivity, SSM uses monthly seasonal productivity factor (f) that adjusts the time and cost estimates of activities. As shown in table 3.1, an activity that is scheduled for January will have its duration and cost increased by a factor of $1/0.9$ or 1.18, which is a 18% increase.

Month	Factor (f)	Month	Factor (f)
January	0.9	July	0.9
February	0.9	August	0.9
March	0.95	September	1.0
April	1.0	October	1.0
May	1.0	November	1.0
June (Ramadan)	0.85	December	1.0

Table 3.1: Seasonal Productivity Factors in Kingdom of Bahrain

3.3.2 Scheduling the Structural-Core Activities

The structural work has to be completed at any floor before any other work can start. Accordingly, SSM differentiates between two types of activities:

- Structural-core activities that form the school building structure; and
- Other activities that are not part of the structural-core, such as electrical, plumbing, painting, etc.

Mainly, structural-core activities are the columns, beams and slabs, in which, they have a specific relationship and have to proceed in a specific manner to avoid scheduling errors. For instance, Figure 3.2 shows an example of a linear schedule for the three activities along a 5-story building. The three activities are running in parallel and the figure shows a serious problem in the schedule. The columns of the second repetitive floor are scheduled to start at time Sc_2 before the slab of the first floor is completed at time Fs_1 . This breaks logical relationships that columns at the upper floors require the slabs below to be completed.

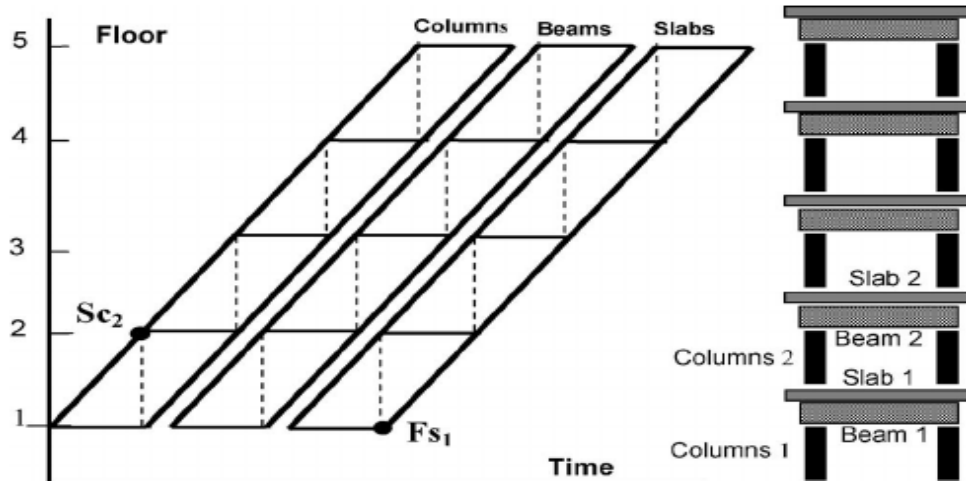


Figure 3.2: Improper Scheduling for structural core activities

In SSM to avoid this scheduling problem, structural-core activities are assigned one rate of production and considered as one group where duration is the sum of their individual durations, as follows:

$$d_{sck} = \sum_{i=1}^n d_{ijk} \dots \dots \dots (3.3)$$

Where:

d_{sck} = is the duration for the structural core group at floor k

n = is the number of structural core activities

d_{ijk} = is the individual durations of the core activity i at floor k using construction method j .

Accordingly, the correction of the schedule in Figure 3.2 is shown in Figure 3.3. The structural-core group is considered one activity that uses one crew (shaded bars). The work is progressed in sequence where the structural-core activity in an upper floor starts only after the completion of the whole group at the lower floor.

Accordingly, the progress rate R_{sck} of the structural-core group can be calculated as follows:

$$R_{sck} = \frac{1}{d_{sck}} \dots \dots \dots (3.4)$$

This way of arranging the structural core activities prevents scheduling errors in school buildings.

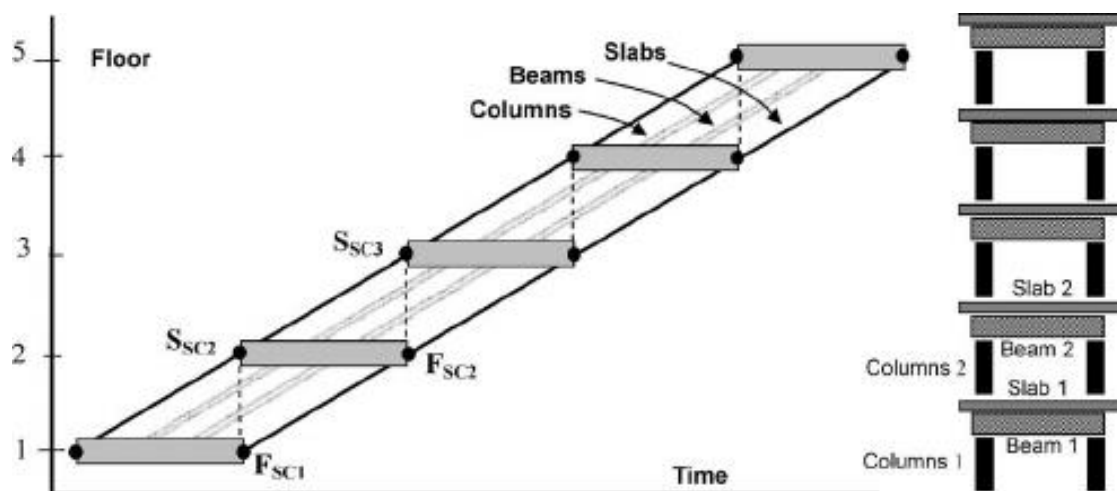


Figure 3.3: Corrected Schedule for structural core activities

3.3.3 CPM Calculations for a Single Floor

The CPM technique becomes essential to calculate the total duration and the activity times for a typical repetitive floor (early start, early finish, late start, late finish, total float, and free float) where each floor contains a network of activities. The CPM calculations use the activity's duration estimates associated with the method of construction being used for the activities. Although cheaper alternative is used to calculate the initial CPM for a single floor, the other estimates are used in the cost optimization model (described in section 3.4) to reduce project duration and to meet other constraints.

3.3.4 Crew Synchronization to Meet Project Deadline

Once the duration of the first repetitive floor T_1 is calculated from the previous step, the progress rate of the repetitive activities R that is required to meet the deadline can be calculated as follows (Hegazy 2003):

$$R = \frac{\text{Remaining Floors}}{\text{Remaining Time}} = \frac{F-1}{T_L - T_1} \quad \dots\dots\dots (3.5)$$

This equation can be described graphically as follows (Hegazy 2003):

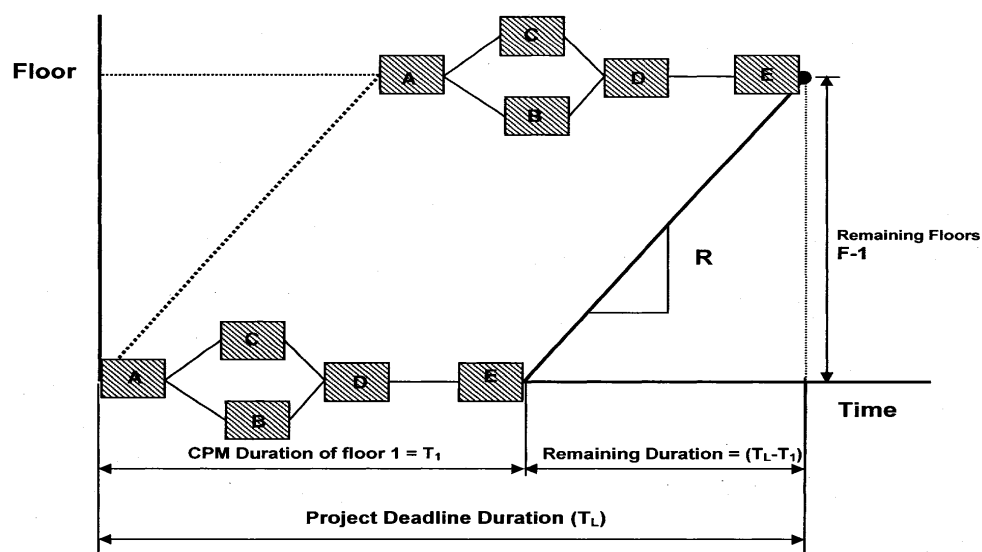


Figure 3.4: Desired Progress Rate

By calculating the desired progress rate R , it is possible to apply it on all critical activities in order to meet the project deadline. However, non-critical activities can be relaxed and given slower progress rates proportionate with their respective total float values (Suhail & Neale 1994).

Accordingly, the progress rate needed for any activity i can be calculated as:

$$R_i = \frac{F - 1}{(T_L - T_1) + T_{Fi}} \dots\dots\dots(3.6)$$

Where:

T_L = Deadline duration of the project

T_1 = CPM duration of the first repetitive floor

F = Number of floors

R = Required progress rate to complete the project on time

T_{Fi} = Total float for activity i

R_i = Progress rate for activity i .

Equation 3.6, is a general and considers CPM-based float calculations in the schedule development and can be applied to both critical and non-critical activities. For critical activities, total floats are zeroes and therefore equation 3.6 is reduced to Equation 3.5.

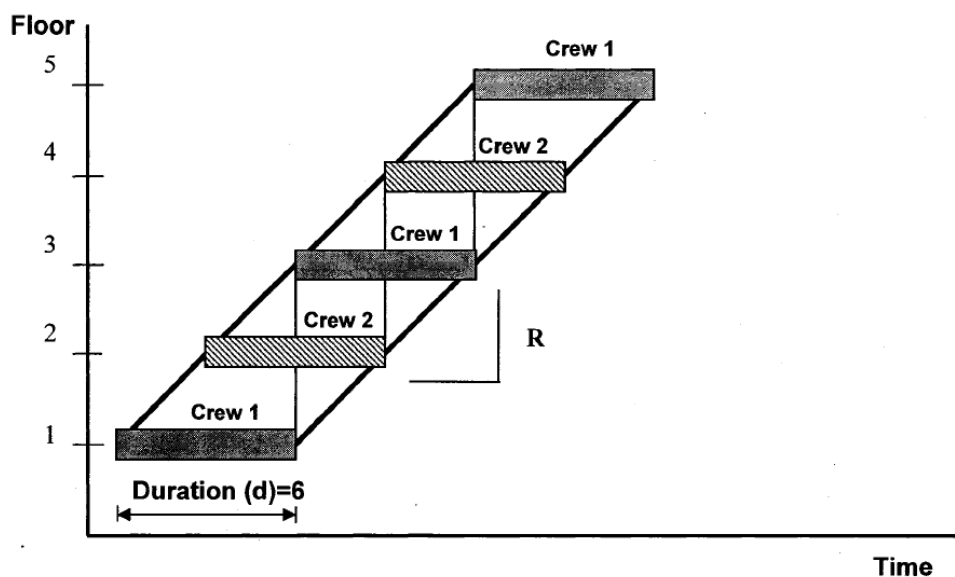


Figure 3.5: Crew Synchronization

Once the required progress rates for all repetitive activities have been calculated, the number of crews required to achieve those rates can be calculated, taking into consideration work continuity and crew synchronization as illustrated in Figure 3.5.

To determine the required crews for an activity i to achieve a certain progress R_i given the duration d_{ijk} that a crew takes to finish one floor without interruption (depending on the method of construction i used), is calculated as follows (Hegazy 2003):

$$Cr_i = R_i \times d_{ijk} \dots\dots\dots(3.7)$$

The number of crews Cr_i obtained from equation (3.7), mainly, makes critical activities to progress in parallel with a rate R_i to meet the project deadline.

For instance, on the 5-story building discussed previously, assume a critical activity with 6 days duration. Non-critical activity with 5 days duration, 0.2 floor/day rate for the critical activity and 0.16 floor/day rate for non-critical activity. By using equation 3.7 the number of crews required to complete critical activity is 1.2 crew and non-critical activity is 0.8 crew.

In most cases, the number of crews calculated using Equation 3.7 is not an integer value and needs to be adjusted and rounded up to the next integer. Moreover, sometimes the available crews are sometimes less than those needed are. Therefore, the actual number of crews Cr_{ai} must be limited to the maximum available:

$$Cr_{ai} = \text{Round Up } (Cr_i); Cr_{ai} \leq \text{Maximum Available Crews} \dots \dots \dots (3.8)$$

Accordingly, the actual progress rate of each activity R_{ai} needs to be adjusted based on the actual number of crews Cr_{ai} as follows:

$$R_{ai} = \frac{Cr_{ai}}{d_{ij}} \dots \dots \dots (3.9)$$

For instance, the critical activity that needs 1.2 crews will be rounded up using Equation 3.8 to become 2 crews. Also, the non-critical activity that needs 0.8 crew will be rounded up to 1 crew.

Once the number of crews is determined, the start and finish time of the crews working at different floors for each activity can be calculated. For instance, the 6 days’ critical activity that was decided to use 2 crews and its work continuity is maintained as shown in figure 3.5.

Moreover, changes made to the number of crews calculate in Equation 3.7 (due to rounding or resource limits) will not guarantee to meet the project deadlines, nor maintain work continuity, or crew synchronization as the revised crew numbers and progress rates in Equations 3.8 and 3.9 will change. Also, when resource limits are enforced, some activities will less number of crews than required, thus, causing delays. Therefore, scheduling constraints must be considered.

3.3.5 Scheduling under Constraints

SSM calculations objective is to schedule critical activities in a parallel way as much as possible to shorten project duration. However, due to the adjustments done in crew’s numbers and other constraints such as crew limits, and the adjustment in actual progress rates, this will break the

logical relationships, work continuity, crew synchronization, and deadline of the project. To reduce the impact of these constraints the variables of Equation 3.9 must be controlled (i.e., activity duration and number of crews) and the actual rate of an activity can be made closer to the desired rate.

A slow activity can be made faster by reducing its duration (i.e., selecting another construction method from the available alternatives to each activity) or using more crews. However, a fast activity can be made slower by selecting a slower construction or by introducing a suitable amount of work interruption at particular floors. Each of these measures has its effects on the project completion time and total construction cost, therefore, it is necessary for SSM to be more flexible to deal with all these options and then select the ones that optimize the schedule.

To reflect for the conditions for a school building, the following constraints have been considered in the scheduling formulations of SSM:

- Vertical constraints among the floors;
- Designed period of work interruption;
- Possibility of variation among repetitive floors;
- Learning Curve effect;
- Possibility of having constrained construction methods; and
- Other constraints.

Vertical Constraints among Floors: There are mainly two main types of constraints control the logical sequence of the activities in school building projects; horizontal constraints and vertical constraints. Horizontal constraints control the logical sequence between activities on the same floor. They are defined by the precedence links among the activities on each floor. Accordingly, any activity cannot be scheduled

unless all its preceding activities are scheduled. These constraints are used to calculate the duration for single floor using CPM technique, as discussed in section 3.3.3.

The second type of constraints is the vertical constraints, which is based on logical dependences among activities on different floors and associated with the vertical construction of school building projects. In this type of construction, the execution of some activities on some floors controls the execution of other activities on different floors. Therefore, the start or completion dates of an activity on each floor may become dependent on the controlling activity executed on a different floor and this vertical dependency between the two activities is defined as a vertical constraint.

The model of vertical constraints is illustrated in Figure 3.6 where it is assumed that activity B on the first floor cannot start before the completion of activity A on the fifth floor. Hence, the start of activity B on the first floor needs to be shifted from time t_1 to time t_2 .

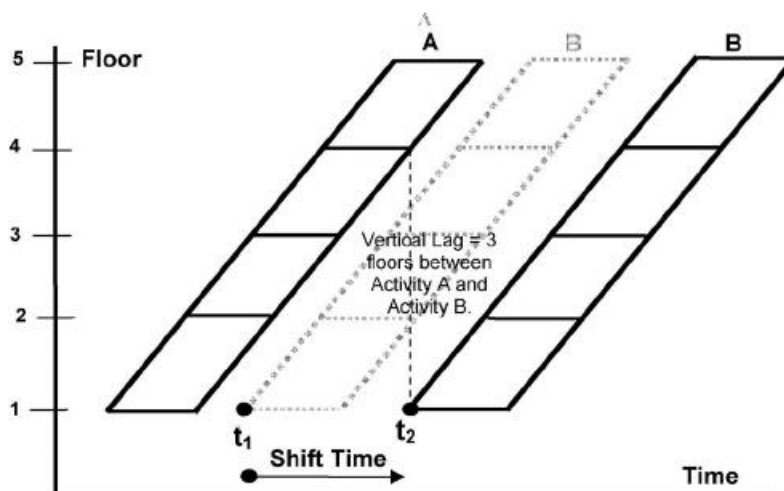


Figure 3.6: Example of Vertical Constraint

For instance, removal of formwork from each floor can only be done after slabs are completed for two additional floors (or as set by the design specifications). The concrete slabs must be allowed enough time to cure and reach its designed compressive strength before the formwork to be removed. Otherwise, the load of the upper slab is transferred to the lower slab and the contractor runs the risk of having the lower slab deflecting and damaging the structural strength of the building.

SSM is capable to accommodate any logical vertical constraints between floors to maintain the precedence relationship between activities. It allows the scheduler to include them into the project original schedule by specifying the constraints and the number of floors that should be maintained as a vertical lag between the two activities. Accordingly, SSM calculates the amount of schedule shift time to be applied to the start of activities (Figure 3.6).

Designed Work Interruption: SSM calculates the start and finish times for each activity at all floors to determine its duration, progress rate, crews and interruptions. An interruption in SSM is defined as the delay of the start of an activity from its calculated start based on its progress rate (R_{ai}).

Interruption is required is when one or more fast activities are stuck between slower ones (Figure 3.7). In this figure, an interruption (I_{ik}) is introduced to activity B at floor k. This strategy makes it possible to start the first part of activity B earlier than its original schedule. Hence, the following activity C is possible to start earlier.

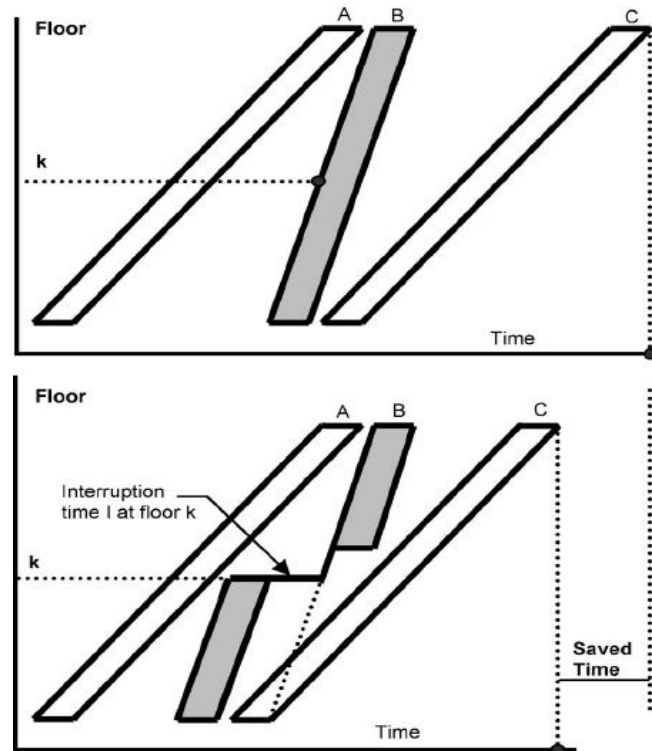


Figure 3.7: Schedule with Interruption

This strategy will reduce project duration but affects the continuity and learning effects of the project. However, this issue can be negligible when the number of floors is large and the interruptions are not excessively applied.

To include the interruption I_{ik} for an activity i at floor k , the original start times OS_i of the activity at floors from 1 to k are adjusted as follows:

$$S_{i1}=OS_{i1}-I_{ik}$$

$$S_{i2}=OS_{i2}-I_{ik}$$

$$S_{i3}=OS_{i3}-I_{ik}$$

$$S_{ik}=OS_{ik}-I_{ik}.....(3.10)$$

Equation 3.10 is illustrated in Figure 3.7 where activity B is shifted by l_{ik} , to allow activity B at floors from 1 to k to start earlier than its original start time which enables activity C to start before its original start and completed earlier than its original finish time. This strategy can achieve a reduction in the project duration.

Possibility of Variation among Repetitive Floors: construction of school buildings will have different shapes and designs; thus it is common to have variations among the floors. Therefore, identical floors should be considered to be “Standard” floors to simplify data entry and enter floor data once for all the standard floors. Special floors can then be entered separately. For example, the area of a building is reduced from the 3rd floor to the 5th floor. Thus, the duration and cost of the structural-core activities (and all other activities) is reduced. In SSM, this concept of reduced duration and cost can be applied to all repetitive activities.

For each activity, SSM uses the term “Standard Unit” to describe the typical duration and cost of that activity, and the term “Non-Standard Unit” to describe the duration and cost of any unit that differ from the standard. To identify non-standard durations and costs, allow the user to specify a percentage of the standard. Accordingly, the activity duration and cost of this non-standard unit is calculated automatically. This approach is also useful since if an activity has more than one standard method of construction, it will still have the same methods but with different durations and costs.

For instance, if the user assigns 100% for an activity at a non-standard floor, it means that this activity duration and cost will be the same as it is

at the standard floor. If the user assigns 80% for an activity at a non-standard unit, it means that the activity duration and cost will be 80% of the standard duration and cost for the same activity at the standard unit. This feature allows the user to account for the reduced/increased amount of work that might be required for the same activity as the construction progresses to the other floors.

Learning Curve Effect: Basically, the more times an operation is performed, the shorter will be the time needed to perform it. This phenomenon is called the learning curve effect. Accordingly, the time spent for the performance of the same operation decreases significantly in the first few units and narrows after a certain number of repetitions. The effect of the learning process is not considered in the traditionally linear relationship between time and the number of units produced, but in the ideal situation it should be incorporated into a schedule of school building construction in order to reflect the actual conditions.

The time required to perform identical activities successively and in the same conditions is expected to decrease to a certain value; hence, considering the learning effect in performing an activity is the same as admitting an increase in production rates from a certain number of repetitions, and at least during some subsequent repetitions. Therefore, it is possible to introduce this effect in repetitive construction scheduling methods, thus bringing about an expected efficiency increase after an initial learning period (Couto and Teixeira 2005).

The learning curve is illustrated graphically by indicating the amount of time, cost or number of man-hours needed for carrying out the

successive activities required. It emphasizes that time, cost and man-hours for accomplishing repetitive and subsequent tasks decreases in each repetition, according to an expected learning rate. Consequently, improvement in productivity can only be reached with more efficient construction processes.

Learning curve effect is included into SSM using the same Standard Unit feature discussed in the previous section. The user can assign 80% for an activity at a certain non-standard unit, to indicate that the activity duration or cost will be 80% of the cost and duration for the same activity at the standard unit due to improving performance or productivity of the crew performing the activity.

Possibility of Having Constrained Construction Methods: SSM allows activities to have up to 3 construction methods (from cheap and slow to fast and expensive) and hence each activity will have various construction alternatives with their related resources, durations, and costs. For instance, first method is to employ cheap sub-contractor who will work normal hours (8 hours/day). Second method is to pay the same sub-contractor premium to work over time (12 hours/day). This method will finish the activities faster than the first method (shorter duration), but will cost more. Third method is to use other expensive sub-contractor who has larger-size crews and more efficient machinery. This will finish the activities even faster than the previous methods, but will cost significantly more. Construction method selected for one activity might affect the selection of construction method for other activity.

For instance, although structural framing is divided into three activities; column, slab, and formwork removal, they have to be executed by the same crew (same sub-contractor). Accordingly, if construction method 1 is selected for columns, construction method 1 or 2 must be selected for slabs and formwork removal (since both methods are carried out by the same sub-contractor). While if construction method 3 is selected for columns (other sub-contractor) then construction method 3 must be selected for slabs and formwork removal.

3.4 Cost Optimization Using Genetic Algorithms

SSM generates schedules by amending the alternatives for construction methods, number of crews, and the amount of interruptions at any floor. Therefore, a cost optimization model becomes essential to recognize the optimum construction methods, number of crews, and interruptions, to meet schedule constraints. SSM model is basically an improvement of the model by Hegazy and Wassef (2001) to consider school building requirements. It involves objective function, optimization variables, and optimization constraints.

The main objective of SSM is to find, for each activity (repetitive and non-repetitive), the optimum construction method, number of crews, and work interruption periods, that: a) meet project; b) satisfy the logical relationships within each floor (horizontal constraints); c) satisfy the logical relationships among floors (vertical constraints); d) maintain work continuity; and e) minimize the total construction cost. Consequently, to enable the model to deal with the problem of large optimization size, the model uses Genetic Algorithms (GA), which can arrive at near-optimum solutions to large-scale problems.

3.4.1 Applying GA for School Building Scheduling and Cost optimization

The cost optimization is included in the present scheduling model using the GA technique, where hundreds of possible solutions to a problem can be generated and the most suitable is selected (the optimum or near optimum solution). Using the Visual Basic for Applications (VBA) macros available in MS Project, the optimization parameters are automatically set up. The steps to create a GA are as the following:

1. Formation of the solution representation (chromosome structure) which is made up of the problem variables;
2. Selection of the evaluation criteria (objective function),
3. Generation of an initial population of chromosomes (initial solutions),
4. Selection of an offspring generation mechanism (process to generate new potential solutions), and
5. Preparation of the procedure code to apply genetic operators to generate the next generation of solution strings.

The fitness of each string is evaluated by performing system analysis to compute the value of the objective function. If the solution violates any of the constraints, the value of the objective function is penalized (senouci and Eldin 2004).

3.4.2 Optimization Parameters

Objective Function: The objective function of the model is to minimize total construction cost, encompassing: 1) Direct cost; 2) Indirect cost; 3) Liquidated damages; and 4) Incentive for early completion.

Variables: the independent variables in SSM are: 1) the construction-method indicators for the activities, 2) number of crews for the activities, and 3) work interruptions at various floors. These are represented in the form of chromosome (string of all variables) (Figure 3.8). The set of values inside the genes (cells) of chromosome represent one possible solution to the problem.

Constraints: Along with proper ranges for the variables, the following constraints observed:

- Project duration should be less than or equal to the deadline duration.
- The number of crews is less than or equal to the number of floors.
- Structural core activities are properly scheduled.
- Conditional construction methods are respected.
- Vertical constraints are met.

For flexibility, any combination of optimization variables are possible, to reflect the project manager's objective.

- Attaining crew synchronization;
- Incorporating both repetitive and non-repetitive activities;
- Including learning curve and weather conditions impact on the working crews' productivity;
- Achieving work continuity;
- Meeting a project deadline;
- Schedule structural-core activities;
- Initiating interruption times to balance progress lines; and
- Including the vertical constraints and horizontal constraints without interrupting the logic relationships between activities

SSM cost optimization is related to minimum total construction cost including direct, indirect, penalties and incentives cost. The cost optimization includes alternative construction methods for repetitive and non-repetitive activities, each having its duration and direct cost. GA is used to reach the optimum construction methods, number of crews, and interruptions for each activity that results in a schedule with minimum total construction cost.

Chapter 4

Model Implementation: A Case Study

4.1 Introduction

4.2 Case Study

4.3 SSM Model

4.4 Conclusion

Chapter 4

Model Implementation: A Case Study

4.1 Introduction

Application of the proposed School Building Scheduling Model (SSM), which was discussed in chapter 3 will be presented in detail in this chapter. The capabilities and special features of SSM are demonstrated through an actual case study of a school building where a comparison will be made between the traditional scheduling method and the proposed SSM model in this section.

4.2 Case Study

After studying the scheduling practice for the two contracting firms as stated in section (3.2). The actual data for “Honeniya Intermediate School Building” were obtained to apply the SSM model and test its validity. Honeniya is a 4-story school building project, including the roof floor is discussed as a case study to validate the scheduling capabilities of the SSM prototype developed in this study. The ground floor will consist of main court yard, laboratories, cafeteria, offices, social rooms and multipurpose hall along with other services. While the 1st to 4th floors (70% of the ground floor area) consist of computer labs, art rooms and Information Technology rooms, class rooms. The 4th floor consist of teachers rooms. Four elevators serve the building.

The foundation type for this building consists of strip foundation with concrete framing structural system and consists of columns, beams and

slabs. The building façade consists of insulated block work, windows, and curtain walls (See Appendix 6).

The actual activities, their logical relationships, their durations and costs have been determined based on historical data of the existing Honeniya school project and from the main contractor. The data for the 22 main activities of the project are listed in Tables 4.1 and 4.2 as shown, the activities' descriptions indicate the floors in which each activity takes place.

The activities listed in Table 4.1 executed previously using the first construction method show in table 4.2 . Project Scheduling was done using traditional CPM method without considering optimization in cost or schedule (See Appendix 1). Honeniya School project considering the main activities listed in the tables below was completed in 12 months (250 working days) with BD 4.131 million (See Appendix 5).

Hoeniya School Project faced sever delay and has gone above allocated budget were additional funds had to be arranged to continue with the project. Due to improper planning of repetitive activities there was so many idle crews in some units and over allocation in other units. Also unexpected change requests from the Client and the Engineer due to shortfalls in the design or additional requirements has affected the progress of the project in terms of time and cost.

In this case study SSM model will be used to overcome the issues faced in Honeniya School project. However, SSM will be limited to the five (5) aspects mentioned in section 3.3.

Activity No.	Description	Depends on
1	Mobilization and preliminaries (1-1)	-
2	Excavation (1-1)	1
3	Foundation (1-1)	2
4	Columns and walls (1-4)	3
5	RC Slabs & beams (1-4)	4
6	Formwork Removal (1-4)	5
7	Precast slab (2-4)	6
8	Elevator Mech. Room (4)	6
9	Elevator shaft Room (1-4)	8
10	Block work and plastering (1-4)	9
11	Windows & Doors (1-4)	10
12	Plumbing and HVAC 1 st fix (1-4)	9
13	Electrical 1st fix (1-4)	9
14	Wood works (cabinets, counters, lockers, worktop, benches.) (1-4)	17
15	Metal works (kitchen cabinets, whiteboards, pin boards....)(1-4)	17
16	Gypsum and finishes (1-4)	11
17	Tiles /flooring finishes (1-4)	11
18	Painting (1-4)	14,15,16
19	Electrical final fix(1-4)	13
20	Plumbing and HVAC final fix (1-4)	12
21	Cleaning (1-4)	18,19,20
22	Demobilization (1-1)	21

Table 4.1: Activities and their dependencies

Act. No.	Description	Construction Method 1		Construction Method 2		Construction Method 3		Max. Crew No.
		Cost (BD)	Dur. (day)	Cost (BD)	Dur. (day)	Cost (BD)	Dur. (day)	
1	Mobilization and preliminaries (1-1)	5,300	16	-	-	-	-	1
2	Excavation (1-1)	28,100	21	32,150	14	38,580	11	1
3	Foundation (1-1)	138,160	34	186,000	28	192,400	23	1
4	Columns and walls (1-4)	25,610	11	33,290	8	35,510	7	1
5	RC Slabs & beams (1-4)	43,760	8	56,880	6	62,570	5	1
6	Formwork Removal (1-4)	-	1	-	1	-	1	1
7	Precast slab (2-4)	36,950	4	44,330	3	46,660	2	1
8	Elevator Mech. Room (4)	8,600	11	10,320	8	11,150	7	1
9	Elevator shaft Room (1-4)	2,890	3	3,360	2	3,500	1	2
10	Block work and plastering (1-4)	67,350	8	80,810	5	84,850	4	3
11	Windows & Doors (1-4)	47,540	4	52,540	3	56,000	2	2
12	Plumbing and HVAC 1 st fix (1-4)	60,000	5	72,000	4	75,600	3	3
13	Electrical 1st fix (1-4)	31,840	3	38,200	2	40,120	1	2
14	Wood works (cabinets, counters, lockers, worktop, benches..) (1-4)	31,900	4	38,280	2	40,200	1	3
15	Metal works (kitchen cabinets, whiteboards, pin boards....)(1-4)	38,270	4	45,920	2	48,250	1	3
16	Gypsum and finishes(1-4)	61,370	3	73,750	2	77,325	1	2
17	Tiles /flooring finishes (1-4)	75,200	7	90,240	5	95,000	4	3
18	Painting (1-4)	16,480	5	20,000	4	23,500	2	2
19	Electrical final fix(1-4)	63,680	3	76,400	2	80,250	1	3
20	Plumbing and HVAC final fix (1-4)	123,860	3	136,250	2	142,500	1	3
21	Cleaning (1-4)	4,500	4	5,000	3	-	-	1
22	Demobilization (1-1)	560	5	-	-	-	-	1

Table 4.2: Activities Costs and Durations

Some major constraints that are considered in the execution of the project are discussed below:

- a) Project needs to be completed within 6 months (125 working days) with total construction budget of BD 4.0 million. The indirect cost (field

related costs that are encountered during construction, but not associated to any specific activity) is BD 720 per day. Liquidated damage (Penalty should be paid to the owner if the general contractor fails to complete the work within the contract duration) is BD 1650 per day. Incentive (to be paid to the contractor if the work is completed earlier than completion date) is BD 800 per day.

- b) The productivity of crews is reduced in the months of summer due to severe weather conditions and shorter working hours as it is regulated by Ministry of Labor to work fewer hours in the months of July and August. Therefore, activities that are highly sensitive to bad weather and cause reduction in productivity are plastering, painting, structural framing, and block work. Moreover, in the month of Ramadan, which is the month that all Muslims start fasting and also work less hours according to the civil law in Bahrain.
- c) The school's floor area changes in the 1st - 4th floors, where the total area is reduced to almost 70% of the ground floor area. Consequently, the amount of work required to complete each activity on the upper floors differs from those required for the same activities on the lower floors.
- d) The main contractor identified three alternative construction methods for each activity with associated direct cost, crews, and duration. The first method (columns 3 and 4 in Table 4.2) is to appoint cheap sub-contractor who will work normal hours (8 hours/day). The second method (columns 5 and 6 in Table 4.2) is to pay the sub-contractor percentage to work overtime (12 hours/day). This method finishes the

activities faster than the first method (shorter duration), but will cost more. The third method (columns 7 and 8 in Table 4.2) is to use other expensive sub-contractor with larger crews and more efficient machinery. This will finish the activities even faster than the previous methods, but will cost significantly more.

- e) It is possible to use a combination of fast and slow subcontractors. However, the construction method selected for one activity might affect the selection of construction method for other activity. The conditional methods that will be applied to the case study at hand are summarized in Table 4.3.

IF	THEN
Construction Method 1 is selected for column	Use construction method 1or 2 for slab and formwork removal
Construction Method 3 is selected for column	Use construction method 3 for slab and formwork removal
Construction Method 1 is selected for slab	Use construction methods 1 or 2 for column and formwork removal
Construction Method 3 is selected for slab	Use construction method 3 for column and formwork removal
Construction Method 1 is selected for formwork removal	Use construction methods 1 or 2 for column and slab
Construction Method 3 is selected for formwork removal	Use construction method 3 for column and slab
Construction Method 1is selected for Elevator Room	Use construction methods 1 or 2 for Elevator Shafts
Construction Method 3 is selected for Elevator Room	Use construction methods 3 for Elevator Shafts
Construction Method 1is selected for Plum. & HVAC 1 st fix	Use construction methods 1 or 2 for Plum. & HVAC final fix
Construction Method 3 is selected for Plum. & HVAC 1 st fix	Use construction methods 3 for Plum. & HVAC final fix
Construction Method 1is selected for Elect. 1 st fix	Use construction methods 1 or 2 for Elect. final fix
Construction Method 3 is selected for Elect. 1 st fix	Use construction methods 3 for final fix

Table 4.3: Conditional Construction Methods

- f) The execution of some activities on some floors controls the execution of other activities on different floors. As a result, the start or completion dates of an activity on a particular floor will become dependent on the activity executed on a different floor.
- g) The installation of elevator rails, doors, and frames must follow the installation of motors and equipment in the elevator mechanical rooms on the roof floor. The installation of motors and control equipment in the elevator mechanical room on the roof floor cannot start before the slabs and formwork removal are completed on this floor.

The above constraints in the case study project provide examples of practical situations encountered in school building construction. The objective of the case study is to validate the developed SSM prototype, prove its capability to consider all these constraints and to meet project deadline with least cost.

4.3 SSM Model

EASY PLAN (EP) program is developed using the Visual Basic for Applications (VBA) language of Microsoft Project software. The program was developed by Prof. Tarek Hegazy in 2002 and updated in 2016 (See appendix 3). EP is a user-friendly interface to facilitate the SSM functions with special features are as the following:

- It works in line with a Microsoft Project file containing the CPM of a typical floor;
- Possibility to enter the number of repetitive floors, desired deadline duration, and other constraints;
- Possibility to alter the number of crews, method of construction, and interruption times for any activity to respect any project constraints;
- It can generate a Microsoft Project file with start and finish times of all activities;
- It contains a progress report option that generates a report that facilitates the recording of actual versus planned progress during project execution;
- It includes GA optimization; and
- It includes a color-coded liner-scheduling chart to present the optimized schedule and its crews' movements.

The above features make EP the most suitable program to be used in school building scheduling. The application of EP to the case study is discussed in detail in the following sub-sections.

4.3.1 Step 1: Project Information

The first step involves entering the project information in the main screen of EP program as discussed in section 4.2. In “Project Information” screen will show the start date, project deadline, working days, penalty and incentives, and other contracts provisions to be entered as shown in Figure 4.1. The figure shows how the program will calculate the project end date, project cost and duration.

EasyPlan ©Dr. Tarek Hegazy, 2002-2016
University of Waterloo, tarek@uwaterloo.ca

Tutorial

Project Information

Three Key Resources			Start Date: 1-Oct-17	
Code:	Limit:	Used:	Deadline (Days):	
L1	9.0	8.0	Penalty (\$/d):	1,650
L2	5.0		Incentive (\$/d):	800
L3	3.0		Indirect (\$/d):	720

Workdays: SA ☐ ☒ ☒ ☒ ☒ ☐ FR

Report Every (d): **5**
i / Period (%): **1.00**
Markup (%): **10.00**
Hold Back (%): **10.0**
Down Payment (%):
Suppliers credit (%):

No. of Activities: **22**

Project End Date: **07-Mar-18** Project Cost = **\$1,071,740**
Duration (days) = **114.0**

Resource limits are not exceeded.
Project meets deadline.

Figure 4.1: Project Information

4.3.2 Step 2: CPM for a Single Repetitive Floor

The second step involved entering the activities of a single floor and their relationships into EP program (Microsoft Project file with the VBA macros of EP). With respect to the school case study, the project activities' bar chart is shown in Figure 4.2 while the activities' CPM network of a single floor is shown in Figure 4.3. It is noted that the activities' durations in Figure 4.2 are those of the cheapest construction methods.

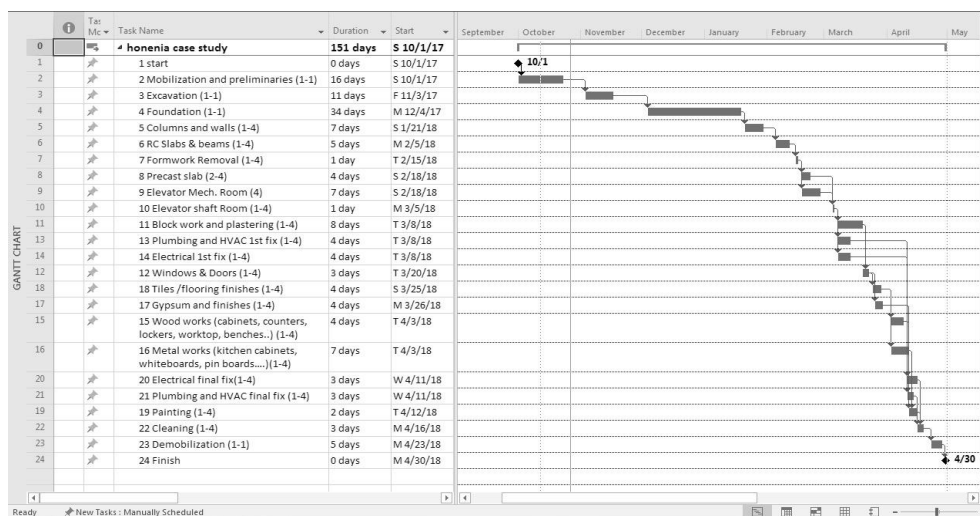


Figure 4.2: Project Activities

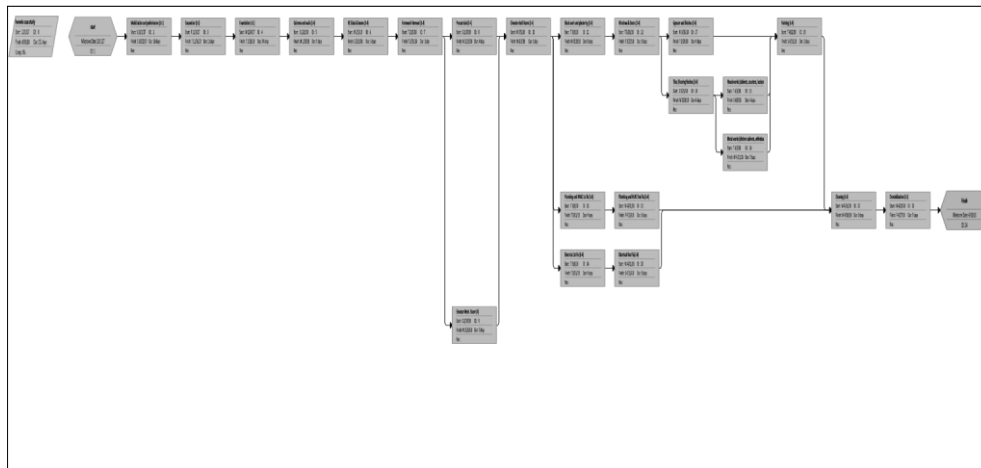


Figure 4.3: CPM Network of a Single floor

4.3.3 Step 3: Activities Details

The “Activities Details” screen covered in Tables 4.1 and 4.2, being entered including the three duration and cost estimates for each activity, the maximum number of crews to be used for each construction method, and productivity factor (Figure 4.4).

Activities & 3 Estimates

Options: Add Activity below current, Delete Current Activity, Estimates based on quantity and crew rates, Direct User-Input of cost, duration & resources

You may add few extra activities to avoid changes later. Do Not use Copy-Paste.

Activity	Description	Cheap Estimate			Moderate Estimate			Expensive Estimate			Productivity (0-1)		
		Cost1	Dur1	L5	Cost2	Dur2	L5	Cost3	Dur3	L5	Winter	Spring	Fall
1	Mobilization and preli	\$5,300	16.0	1.0	-	-	1.0	-	-	1.0	1.00	1.00	1.00
2	Excavation (1-1)	\$28,100	11.0	1.0	\$32,150	14.0	1.0	\$38,580	11.0	1.0	1.00	1.00	1.00
3	Foundation (1-1)	#####	34.0	1.0	#####	8.0	1.0	#####	23.0	1.0	1.00	1.00	1.00
4	Columns and walls	\$25,610	7.0	1.0	\$33,290	6.0	1.0	\$35,510	7.0	1.0	1.00	1.00	1.00
5	RC Slabs & beams	\$43,760	5.0	1.0	\$56,880	1.0	1.0	\$62,570	5.0	1.0	1.00	1.00	1.00
6	Formwork Removal	-	1.0	1.0	-	3.0	1.0	-	1.0	1.0	1.00	1.00	1.00
7	Precast slab (2-4)	\$36,950	4.0	1.0	\$44,330	8.0	1.0	\$46,660	2.0	1.0	1.00	1.00	1.00
8	Elevator Mech. Room	\$8,600	7.0	1.0	\$10,320	2.0	1.0	\$11,150	7.0	1.0	1.00	1.00	1.00
9	Elevator shaft Room	\$2,890	1.0	2.0	\$3,360	5.0	2.0	\$3,500	1.0	2.0	1.00	1.00	1.00
10	Block work and plaster	\$67,350	8.0	3.0	\$80,810	3.0	3.0	\$84,850	4.0	3.0	1.00	1.00	1.00
11	Windows & Doors	\$47,540	3.0	2.0	\$52,540	4.0	2.0	\$56,000	2.0	2.0	1.00	1.00	1.00
12	Plumbing and HVAC	\$60,000	4.0	3.0	\$72,000	2.0	3.0	\$75,600	3.0	3.0	1.00	1.00	1.00
13	Electrical 1st fix (1-4)	\$31,840	4.0	2.0	\$38,200	2.0	2.0	\$40,120	1.0	2.0	1.00	1.00	1.00
14	Wood works (cabinets)	\$31,900	4.0	3.0	\$38,280	2.0	3.0	\$40,200	1.0	3.0	1.00	1.00	1.00
15	Metal works (kitchen)	\$38,270	7.0	3.0	\$45,920	5.0	2.0	\$48,250	1.0	3.0	1.00	1.00	1.00
16	Gypsum and finishes	\$61,370	4.0	2.0	\$73,750	5.0	2.0	\$77,325	1.0	2.0	1.00	1.00	1.00
17	Tiles flooring finishes	\$75,200	4.0	3.0	\$90,240	5.0	3.0	\$95,000	4.0	3.0	1.00	1.00	1.00
18	Painting (1-4)	\$16,480	2.0	2.0	\$20,000	4.0	2.0	\$23,500	2.0	2.0	1.00	1.00	1.00
19	Electrical final fix (1-4)	\$63,680	3.0	3.0	\$76,400	2.0	3.0	\$80,250	1.0	3.0	1.00	1.00	1.00
20	Plumbing and HVAC	#####	3.0	3.0	#####	2.0	3.0	#####	1.0	3.0	1.00	1.00	1.00
21	Cleaning (1-4)	\$4,500	3.0	1.0	\$5,000	3.0	1.0	-	-	1.0	1.00	1.00	1.00
22	Demobilization (1-1)	\$560	5.0	1.0	-	-	1.0	-	-	1.0	1.00	1.00	1.00

Figure 4.4: Activity details and Estimate

4.3.4 Step 4: Activity Relationships and Scheduling Details

With the 22 activities of the project, the concrete structural-core is represented by the following activities: 1) Columns and walls; 2) Slabs and beams; 3) Formwork removal. EP considers the requirement of completing all structural activities on one floor before starting any other activities on this floor or upper floors. EP allows the users to incorporate the structural core activities, and use the network diagram to edit, change activity dependents as shown in Figure 4.5. Otherwise, schedule details to update and enter the predecessors and method used for each activity as shown in Figure 4.6. All other constraints that were identified during the planning stage, as per part (g) of the case study constraints, were entered to EP under screen “Conditional Methods”. As shown in Figure 4.6, the elevator shaft work (i.e., installation of elevator rails, doors, and frames) starts after the completion of the elevator mechanical room on the roof floor.

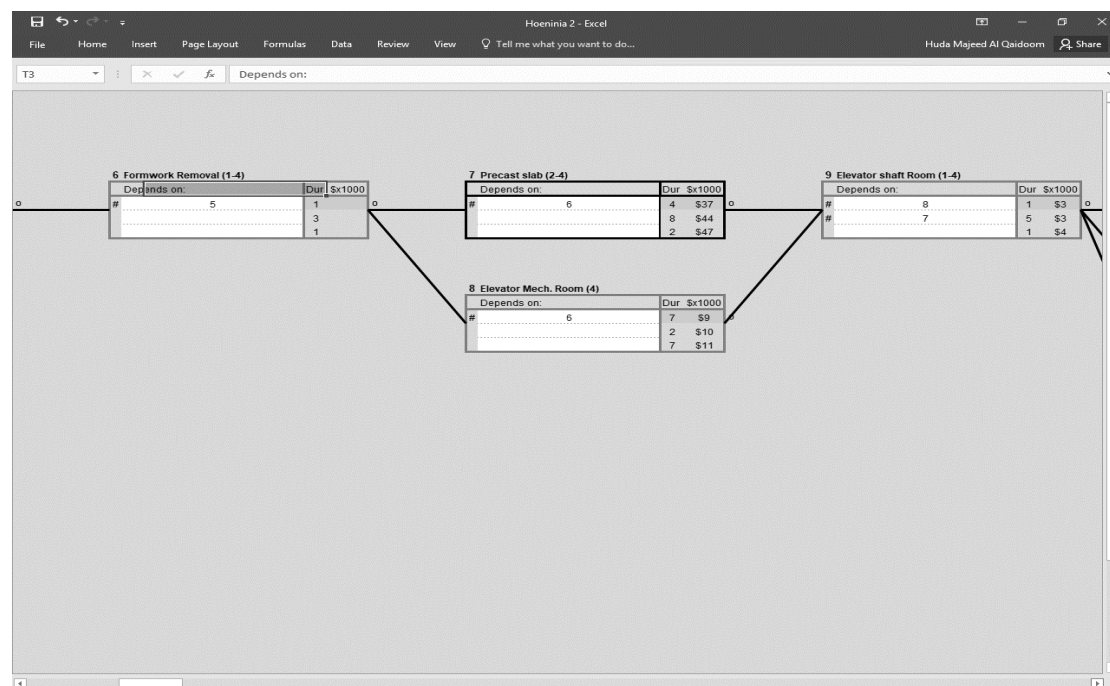


Figure 4.5: Activity Relations

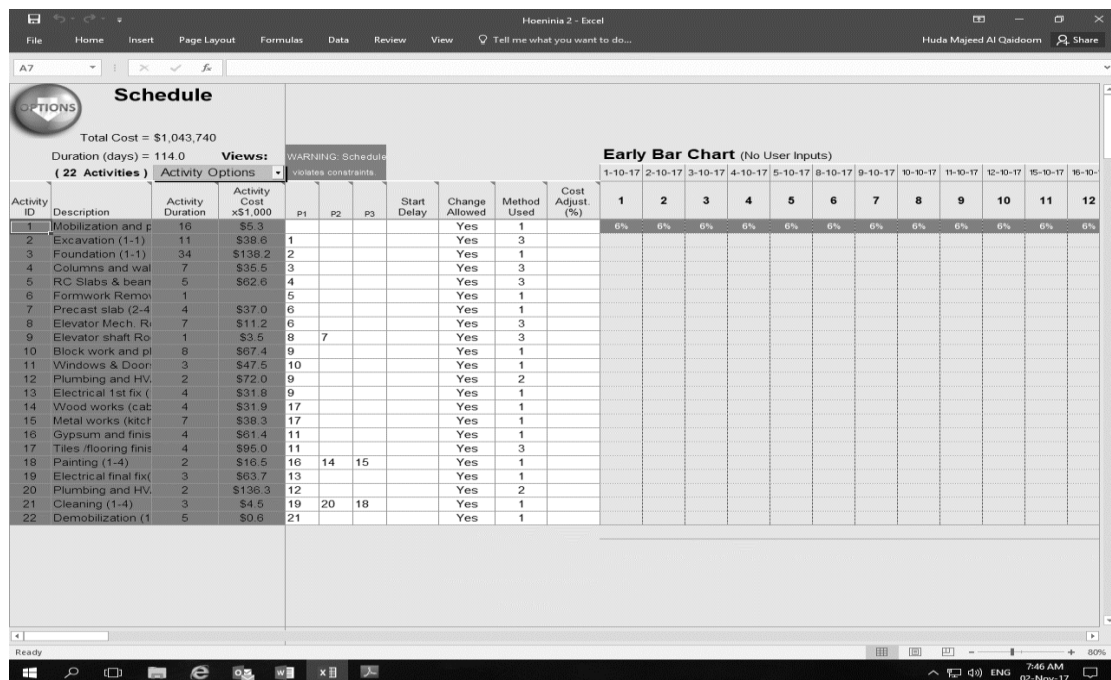


Figure 4.6: Schedule Details

As shown in Figure 4.6, there is warning mentioning that schedule violates constraints (Deadlines and Resources are exceeded), therefore, schedule has to optimized as shown on the coming sub-section.

4.3.5 Step 5: Optimizing Schedule

To optimize the schedule, select the optimize schedule option from the option list where the screen shown in Figure 4.7 will appear then Optimization (longer time) is selected to proceed. Number of cycles can be amended until the deadline duration is met. The program will introduce interruptions to delay some activities to avoid resource conflicts.

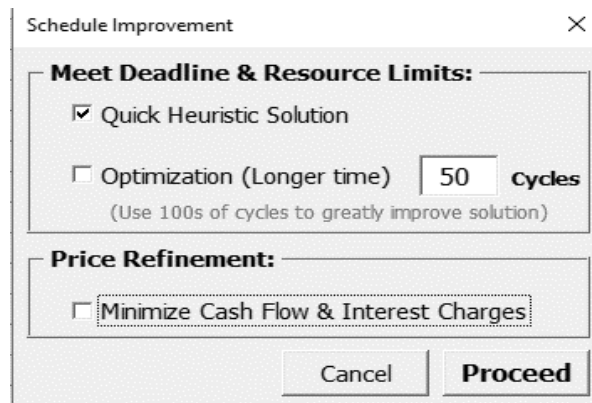


Figure 4.7: Schedule Improvement Screen

4.3.6 Step 6: Repetitive Schedule

EP is flexible enough to include any logical constraints between floors that might be essential to maintain the precedence relationship between activities. Open repetitive data screen and select each activity one-by-one and set its crew limit to proceed as show in Figure 4.8. The resulting schedule is shown in Figure 4.9. Notice the project deadline is 125 days with a total cost of BD 4.0 million. The conditional methods identified in table 4.3 can be entered in the screen shown in Figure 4.8.

Project Start: 1-Oct-17 - Note: To enter actual progress, export a MS Project, then, re-import it into a new EasyPlan project.

Repetitive Data

Repetitive-Activities | Conditional-Methods

Overall Repetitive Units: 4 Deadline: 120 Days

Mobilization and (1/22)

<< Previous Next >>

From Unit: 1 to Unit: 4

Standard Units:

	Duration (days)	Cost (\$)	Max. Crews	Selected Method:
Method1:	16	5300	0	1
Method2:	0	0	0	2
Method3:	0	0	0	3

Special Units:

Unit No. 1: 100 % of a standard unit.

Note: In EasyPlan, you cannot enter actual progress data for a repetitive schedule. To overcome this, export your repetitive schedule to a MS Project file, then, import that file to a new EasyPlan project.

Cancel Proceed

Figure 4.8: Repetitive Data

After proceeding with optimization, the schedule and cost optimization graph will appear as shown in Figure 4.9. There will be different options for arranging the resources (parallel, Shifted, ASAP and default) the most appropriate option can be selected.

In our Honeniya School project, the deadline of 125 days is not met, therefore we can change the crew arrangement or increase the number of crews where the project cost will increase. As shown in figure 4.9, the crews number, Methods and interruption time can be amended as discussed earlier. Accordingly, the specified conditions should be entered under which EP will optimize the schedule and the total cost of the project including the following:

- The optimization constraints of meeting deadline and resource limits being hard or soft (fixed or flexible) as shown in Figure 4.10. By

checking hard on the deadline box, the GA algorithm considers the solutions that meet the deadline. In addition, by checking hard on the resource limits, the GA algorithms will consider only the solutions that satisfy resource limits. If both constraints are set on soft, the GA algorithm tries to find the “best” solution that satisfies both constraints as shown in Figure 4.10;

- Whether or not the user desires to vary the number of crews;
- Whether or not the user wants to vary the construction methods;
- The limit for the number of interruption days the user would like to introduce to any activity;
- Finally, the number of GA processing cycles.

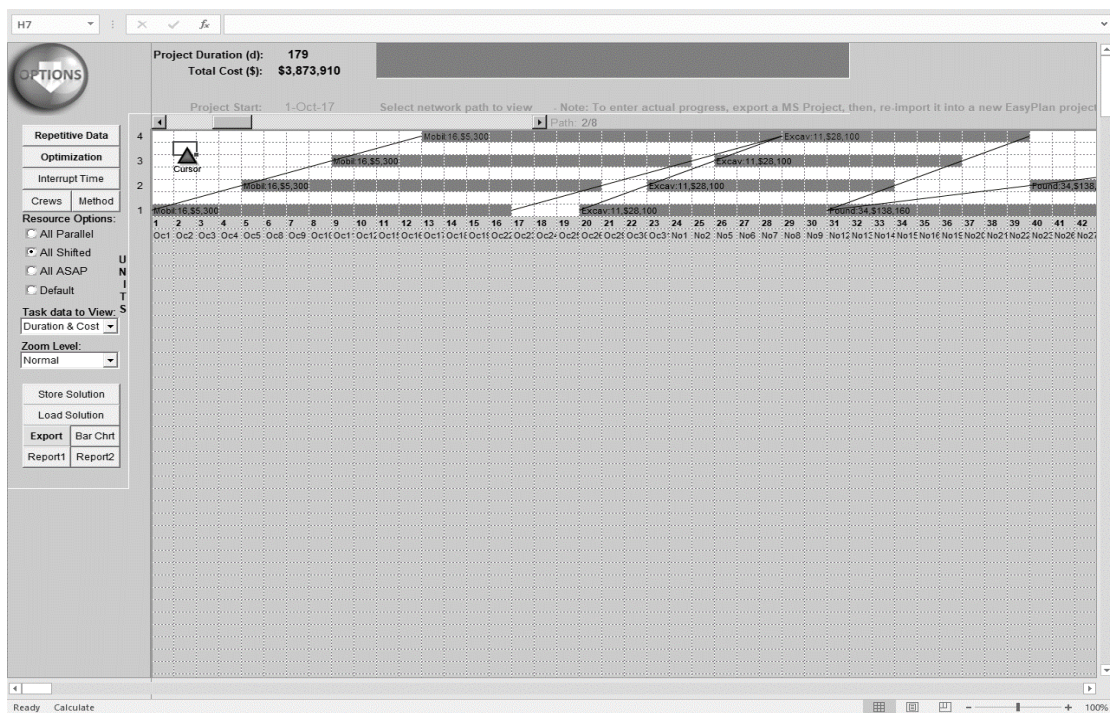


Figure 4.9: Optimization Schedule

For convenience, EP displays the LOB diagram of each individual path, one path at a time and uses color filled lines to show the movement of crews. The structural core activities are scheduled as one group of activities that has one productivity rate. This rate changes starting from the 1st floor then 4th floor due to the reduction in the amount of work, as explained previously.

The screenshot shows a Windows-style dialog box titled "UserForm1". It has a close button (X) in the top right corner. The dialog is divided into two main sections. The first section, "Optimization Constraints:", contains two rows of radio buttons. The first row is "Deadline:" with "Hard" and "Soft" options; "Soft" is selected. The second row is "Resource Limits:" with "Hard" and "Soft" options; "Soft" is selected. The second section, "Options:", contains three items: "Vary the No. of Crews:" with a checked checkbox, "Vary Construction Methods:" with a checked checkbox, and "Vary interruption within:" followed by a text box containing "0" and the word "days". Below these is "No. of processing cycles:" followed by a text box containing "100". At the bottom of the dialog are two buttons: "Cancel" and "OK".

Figure 4.10: Optimization Screen

4.3.7 Results and Discussion

EP activates the GA evolutionary algorithm to search for the best schedule that satisfies all the above-mentioned conditions. In the present case study, a number of experiments were conducted to reach best solution by altering the number of processing cycles as shown earlier in Figure 4.10. The results of optimization experiments and the time taken to get best solution are shown in Table 4.4.

The Solution Quality Index (SQI_n) for n cycles is calculated as follows:

$$SQI_n = \frac{\text{Least Cost of All cycles}}{\text{Least Cost using n cycle}} \dots\dots\dots(4.1)$$

Experiment No.	No. of Cycles	Duration (Day)	Cost (BD)	Solution Quality Index (SQI_n)
1	50	144	BD 4,075,900	0.9422
2	100	128	BD 4,011,120	0.9575
3	150	123	BD 3,927,950	0.9777
4	200	133	BD 4,007,300	0.9584
5	250	121	BD 3,840,690	1
6	300	120	BD 3,986,320	0.9634
7	50	170	BD 3,973,700	0.9665
8	100	138	BD 4,065,540	0.9447
9	150	121	BD 4,007,370	0.9584
10	200	125	BD 4,029,720	0.9530

Table 4.4: Optimization Results

As shown in table 4.4, EP was able to meet the deadline of 125 days by optimizing the schedule and budget of BD3.840 million by optimizing the cost in experiment number 5.

The least cost is achieved in the 5th experiment using 250 cycles and maximum number of cycles was 300 by using GA feature incorporated in EP.

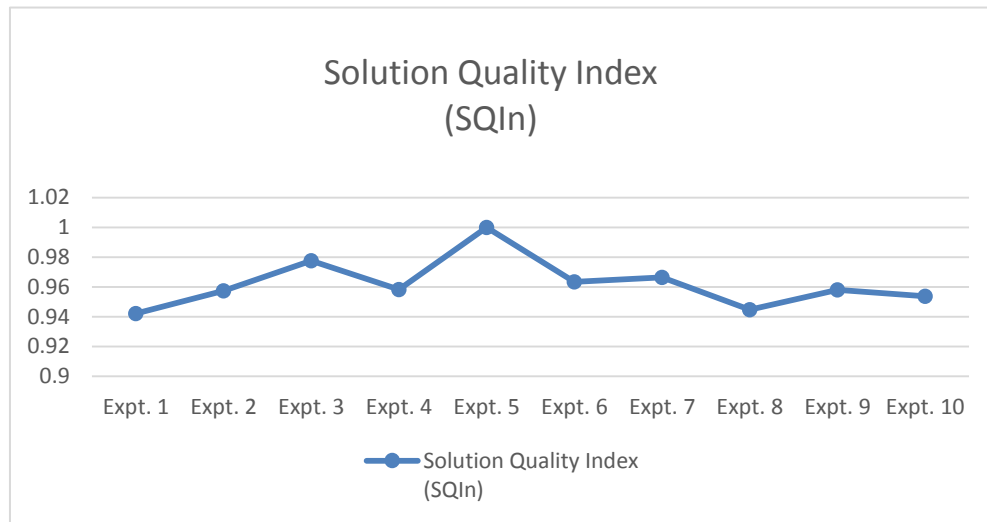


Figure 4.11: Solution Quality Index

As shown in Figure 4.11, the quality solution index increases as the number of processing cycles increases up to the 4th experiment (250 processing cycle) where EP reaches the least cost (i.e., best possible solution). Any more experiments by increasing the processing cycles will not improve the results and a near-optimum solution was reached using 250 processing cycles.

As shown in table 4.5, a comparison was done between the traditional CPM method used in the actual case study and the proposed SSM model in terms on project duration and cost. Where SSM model has reduced dramatically the duration of the project by less than %50 and the Cost of the project almost %8.

Method Used	Duration (Day)	Cost (BD)
CPM Method	250	BD 4,131,150
SSM Model	121	BD 3,840,690

Table 4.5: Comparison between CPM method and SSM model Results

4.3.8 Final Schedule Report

EP includes a progress report option that generates a spreadsheet report similar to the one used by the surveyed companies. The report facilitates the recording of actual versus planned progress during project execution.

Since we have modified the scheduling in planned progress in our case study, therefore only planned progress is reflected and the actual progress can be entered during the execution of the project as shown in Figure 4.12 and 4.13.

Activity Name	Demo Unit 1				Floor No.	Demo Unit 2			
	Cr.	1	Meth	1		Cr.	2	Meth	1
	St	Ma5	Fn	Ma11		St	Ma7	Fn	Ma13
	A.S.		A.F.			A.S.		A.F.	
Planned Start Time	Note					Note			
Actual Start Time (to be filled during construction)	Clea Unit 1				Crew to be used	Clea Unit 2			
	Cr.	1	Meth	1		Cr.	2	Meth	1
	St	Fe28	Fn	Ma4		St	Ma4	Fn	Ma6
	A.S.		A.F.			A.S.		A.F.	
	Note					Note			
	Planned Finish Time					Actual Finish Time (to be filled during construction)			

Figure 4.12: Details of the Schedule Report

	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
5					Demo		Unit 1			Demo		Unit 2			Demo		Unit 3		
6					Cr.		1 Meth	1		Cr.		2 Meth	1		Cr.		3 Meth	1	
7				Demobili	St	Ma5	Fn	Ma11		St	Ma7	Fn	Ma13		St	Ma8	Fn	Ma14	
8					A.S.		A.F.			A.S.		A.F.			A.S.		A.F.		
9					Note					Note					Note				
10					Clea		Unit 1			Clea		Unit 2			Clea		Unit 3		
11					Cr.		1 Meth	1		Cr.		2 Meth	1		Cr.		1 Meth	1	
12				Cleaning	St	Fe28	Fn	Ma4		St	Ma4	Fn	Ma6		St	Ma5	Fn	Ma7	
13					A.S.		A.F.			A.S.		A.F.			A.S.		A.F.		
14					Note					Note					Note				
15					Plum		Unit 1			Plum		Unit 2			Plum		Unit 3		
16					Cr.		1 Meth	2		Cr.		1 Meth	2		Cr.		1 Meth	2	
17				Plumbing	St	Ja28	Fn	Ja29		St	Ja30	Fn	Ja31		St	Fe1	Fn	Fe4	
18					A.S.		A.F.			A.S.		A.F.			A.S.		A.F.		
19					Note					Note					Note				
20					Elec		Unit 1			Elec		Unit 2			Elec		Unit 3		
21					Cr.		1 Meth	1		Cr.		1 Meth	1		Cr.		1 Meth	1	
22				Electric	St	Fe4	Fn	Fe6		St	Fe7	Fn	Fe11		St	Fe12	Fn	Fe14	
23					A.S.		A.F.			A.S.		A.F.			A.S.		A.F.		
24					Note					Note					Note				

Figure 4.13: Schedule Report

As shown in Figure 4.11 & 4.12, the schedule report identifies the following (for each activity at all floors):

- The planned start and finish times;
- Method of construction;
- Which crew will perform this activity; and
- The actual start and finish times to be filled during the construction.

Such report is very beneficial for construction companies since it shows the movement of crews within the overall plan. It enables the project manager to monitor the project and detect any delay. Moreover, it is very simple to understand and use. (See Appendix 4)

4.4 Conclusion

As discussed in this chapter, proposed scheduling and cost optimization SSM model was used to implement an actual case study of a government school building. SSM allows project managers to include the vertical and horizontal constraints encountered during the planning stage into an optimum schedule of the project. Moreover, the graphical representation of the schedule enables the project managers to monitor the crews' movements and the work progress during the project construction stage with a clear and efficient approach.

Chapter 5

Conclusion

5.1 Conclusion

5.2 Future Research

Chapter 5

Conclusion

5.1 Conclusion

The objective of this research is to develop an efficient model that is capable of optimizing the time, cost, and resources involved in the construction cost of school buildings. In order to achieve this, the unique characteristics and various considerations that affect scheduling decisions of school buildings in kingdom of Bahrain were studied to develop the School Scheduling Model (SSM). SSM tackles those considerations through introducing a repetitive scheduling formulation that considers the horizontal relationships within each floor, as well as the vertical constraints imposed by the nature of school building construction. It also has a cost optimization at its core using (GA) technique. SSM has been established with remarkable capabilities as:

- It considers the necessity of scheduling the structural-core activities as one group of activities that has one rate of production to avoid scheduling errors;
- It is flexible enough to include vertical constraints between floors which are dictated by the work sequence among the activities;
- It reflects the impact of weather conditions on crews' productivity;
- It considers non-repetitive activities while respecting the network logic for each repetitive activity;
- It can be used to find the near-global solution for large size projects;

- It optimizes the construction methods, number of crews, and work interruptions for each activity that result in minimum total construction cost; and
- It is represented in a clear graphical representation with a small degree of detail in the schedule to avoid having a jungle of lines that are difficult to understand. The model displays the repetitive schedule of each path and uses colors to reflect the crews' movement.

To validate the model, an actual case study of a government school building was used. SSM model has dramatically reduced the duration and the cost of the project with a better utilization of available crews. The results of the optimization experiments proved the suitability of the model to school building projects for the public sector in Kingdom of Bahrain.

5.2 Future Research

SSM model proved its suitability to school building projects by considering various aspects that affect scheduling decisions of school buildings. However, this model can be improved and investigated in future research using the following considerations:

- Applying the model to a real life future project from beginning to end, and comparing the planned versus the actual progress of that project;
- SSM can be integrated with a cost estimating system to provide realistic assessment of the time and cost associated with each method of construction;
- The current limitation in SSM such as three predecessors and the successors can be avoided by future studies;

- Also the current type of logical relationship (finish-to-start relationship) can be extended to include other types of relationships;
- The schedule report can be separated for each sub-contractor to include only the portion of work to be executed by this particular sub-contractor.

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Appendices

ملخص الرسالة

في الوقت الحاضر أدت العولمة وتنامي المنافسة في صناعة البناء إلى زيادة التحديات أمام مديري المشاريع من أجل تنفيذ مشاريعهم في الوقت المحدد وفي حدود الميزانية المخصصة. ويعتمد نجاح مشروع البناء على الجدولة، وفعالية التكلفة، ومدى إمكانية التحكم في المشروع بحزم ، و الجدول الزمني غير الملائم سيؤدي إلى تأخير في الإنجاز وتجاوز التكلفة المرصودة للمشروع. الهدف الرئيسي من هذه الأطروحة هو وضع جدولة ونموذج أمثل للتكلفة لاستخدامها للتغلب على البيئة الصعبة والتنافسية في بناء المدارس وخاصة في القطاع العام ، لذلك تم اختيار اثنين من المقاولين المحليين ذوي خبرة لدراسة آخر الممارسات في جدولة المدارس لمدرستين في وزارة الأشغال وشؤون البلديات والتخطيط العمراني.

ونتيجة لذلك تم تطوير نموذج جدولة بناء المدارس الجديد (SSM) الذي ينطوي على ما يلي: (1) العلاقات المنطقية داخل كل طابق (بما فيها القيود الأفقية) وبين الطوابق المختلفة (بما فيها القيود العمودية). (2) الربط الرأسي بين الأعمال الأساسية الهيكلية التي لها طبيعة متكررة؛ (3) استمرارية العمل وتزامن عمل الطاقم. (4) عوامل الإنتاجية ونظرية منحنى التعلم. (5) الموعد النهائي المحدد مسبقاً، وانقطاع العمل، وقيود الموارد.

وعلاوة على ذلك يتم استخدام تقنية الخوارزميات الجينية (GA) جنباً إلى جنب مع نموذج جدولة بناء المدارس الجديد (SSM) للحد من تكلفة البناء. تقنية الخوارزميات الجينية (GA) هو تقنية فريدة من نوعها ومفيدة لدراسة الحل الأمثل الأكثر مثالية لأي مشاكل معقدة تتكون من عدد كبير من المتغيرات مثل المباني المدرسية المتعددة الطوابق.

يتم استخدام التحسين لتحديد طرق البناء، وعدد من طواقم العمل، وانقطاعات أعمال الإنشاء لكل عمل مما يؤدي إلى الجدول الزمني الأمثل مع الحد الأدنى من تكلفة البناء الإجمالية. وعلاوة على ذلك يعرض نموذج جدولة بناء المدارس الجديد (SSM) تقارير بيانية عن بيانات الجداول الزمنية وخاصة لمشاريع الكبيرة والمعقدة للمساعدة في مراقبة طواقم العمل والمشاريع في جميع مراحل البناء.

سيطلب النموذج تطبيق في الأساسيات البصرية (VBA) يستخدم لغة برنامج ميكروسوفت بروجيكت (Microsoft Project).

وخيراً سيتم إجراء دراسة حالة بناء مبنى مدرسة حكومية لفحص وإثبات ملاءمة النموذج المقترح لتحسين الجودة في بيئة مبنى المدرسة من خلال تجارب التحسين المختلفة.

جامعة البحرين

قسم الهندسة الميكانيكية

كلية الهندسة



تحسين جدولة وتكلفة المباني المدرسية في القطاع العام

بحث لاستكمال متطلبات الحصول على درجة (الماجستير) في برنامج الإدارة الهندسية

إعداد

هدى مجيد جعفر القيدوم

الرقم الجامعي:

٢٠٠٣٨١٣٠

إشراف

محمد بولات ساكا

(أستاذ)

جامعة البحرين

مملكة البحرين

ديسمبر ٢٠١٧