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Optimal crew routing for linear repetitive projects using graph theory and entropy maximization metric

Ahmed Gouda

THE AMERICAN UNIVERSITY IN CAIRO

School of Sciences and Engineering

OPTIMAL CREW ROUTING FOR LINEAR REPETITIVE PROJECTS USING GRAPH THEORY AND ENTROPY MAXIMIZATION METRIC

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By

Eng. Ahmed Gouda Mohamed

Under the supervision of:

Dr. Ossama Hosny

Professor, Construction and Architecture Engineering Department

The American University in Cairo, Egypt

Dr. Khaled Nassar

Associate Professor, Construction and Architecture Engineering Department

The American University in Cairo, Egypt

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DEDICATIONS

I dedicate my thesis work to my family, to my father, to my beloved mother, to my beautiful wife and my daughter, for their love, understanding, encouragement, and support.

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First and foremost I would like to thank Allah for his gracefulness for providing me the enough patience, courage and wisdom for finishing my masters.

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ABSTRACT

Construction projects that contain several identical or similar units are usually known as repetitive or linear projects. Repetitive projects are regarded as a wide umbrella that includes various categories of construction projects and represents a considerable portion of the construction industry, and contain uniform repetition of work. CPM has been proved to be inefficient in scheduling linear projects because CPM does not address two key aspects, which are maintaining crew work continuity, and achieving a constant rate of progress to meet a given deadline. Line-of-balance (LOB) is a linear scheduling methodology that produces a work schedule in which resource allocation is automatically performed to provide a continuous and uninterrupted use of resource. The fundamental principles of LOB have several shortfalls that raise many concerns about LOB, which need to be attuned and improved in order to suit the nature of construction projects. Hence, this thesis proposes a hybrid approach for scheduling linear projects that stresses on the limitation of LOB scheduling technique. To meet the physical limitation of resources in linear projects, this study presents a flexible optimization model for resolving resource constraint dilemma in linear scheduling problems .The proposed model utilizes a MATLAB code as the searching algorithm to automate the model formulation. The novelty of this model is supplementing a new optimization engine and a decision supporting system that formulate the optimal

crews routing between different activities in different units and guarantee the optimal crew distribution for cost efficiency. This model investigates the mechanics of allocating a multi- task skilled workforce between different activities in different units that can lead to increased productivity, flexibility, and work continuity; besides, this model has the capability of accurately identifying the critical path in linear projects. Furthermore, to avoid day-to-day fluctuation in resource demands, this study encompasses a simulation model for handling the resource leveling in linear construction projects. The proposed model was implemented using crystal ball ribbon based on an entropy maximization metric. The entropy-maximization method accounts for such possibility of allowing activity duration to be stretched or crunched relying on activity type without affecting total completion date of a project and provides more optimized resource allocation solutions. A case study for a 4-km sewage pipeline is used to demonstrate the capability of the proposed models, which illustrates the implementation of the proposed models in construction projects.

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CHAPTER- 1

INTRODUCTION

This chapter starts with a general overview on the current scheduling techniques for multi repetitive projects. Then, it highlights the problem statement, need for the research, scope, objectives and outcomes of the thesis. The chapter also tackles the use of the line of balance (LOB) in scheduling repetitive construction project and discusses the resource leveling approaches applied in linear construction projects.

1.1 Background

It’s crucial, but hard, to separate good process from good outcomes. Often it’s assumed that any good outcome, must reflect a good managerial process and vice versa. Implementation of any construction project involves unique environments, challenges, and project management needs that have to integrate to achieve a successful outcome. Construction management had undergone a significant ratio of project failure and overrun over the last years. The underlying reasons beyond the failure in construction projects are inappropriate methods used in planning construction projects, mismanagement of resources, and lack of efficient project management tool (Russell and Radtke, 1991).

There are different examples of projects that succeeded in meeting perception of success, but failed to meet the project management success. An example of this projects is the Sydney Opera House that is arguably one of the most well-known and fascinating buildings in the world in its functional and architectural design. Yet, from a project management perspective, it was a spectacular failure. The construction of the project initiated in 1959, it was planned to be completed in 1963 with an estimated cost of $7 million. However, it was completed in 1973 for over $100 million (a cost overrun of 1300% and a schedule overrun of 250%). Another example is the project constructed when a paper manufacturing company with five plants across North America decided to increase its manufacturing capacity by embarking on a de-bottlenecking program. The project estimated completion period was 18 months at a cost of $26 million. The project eventually spanned five years with an extra $40 million as a result of mismanaging the project (Enos and Rogers, 2002).

Formulation of a project scheduling is not only perceived as a simple matter of pointing out the sequence and timing of activities within a project, but also it has to cope with a number of constraints and simultaneous considerations of several issues. Time, cost and targeted quality are considered the most essential concerns and considerations that have to be taken into consideration in any construction project to ensure the feasibility of a construction project process throughout its whole lifecycle.

To maintain this objective, the development of a practical and doable schedule approach in terms of time, cost, and resource utilization for the project is a key of concern. Several tools and techniques are used for scheduling of construction projects, these methods include network diagrams, bar charts, matrix schedules, check lists, linear scheduling methods and others. Linear scheduling methods are concerned with the planning and scheduling of repetitive projects, which are characterized by sequential activities that are repeated for substantial number of times.

Repetitive projects are regarded as a wide umbrella that includes various categories of construction projects that consist of a series of repetitive activities. One main objectives in scheduling repetitive projects is the capability of ensuring the continuation of work without any interruptions. Interruptions or idle time is the duration where a resource completes a task and being hold up without performing a new task till the complete of the predecessor task .Accordingly, repetitive activities should be scheduled in a way to omit or reduce interruption time. Linear projects are sub-divided into two types, which are horizontal projects as highways tunnels and pipeline networks, and vertical ones such as high rise buildings.

A survey was conducted by Russell and Radtke (1991) to identify the factors that contribute to failure of construction projects. These factors include underbidding, insufficient cash flow, external difficulties, and lack of experience in estimating and monitoring costs. These factors indicate lack of proper project management, which is in part due to the drawbacks associated with critical path method (CPM). One of the major drawbacks of using the CPM technique for repetitive projects is the complexity to represent and to visualize different relationships between repetitive activities. Moreover, the CPM network technique does not address two key aspects, which are maintaining crew work continuity, and achieving a rate of progress to meet a desired deadline. Maintaining the crew work continuity in linear projects is considered a main objective to permit the crews to move from one site to the next without any interruption (Lumsden 1968 and Laramee 1983). CPM is inappropriate for repetitive scheduling as it rules out the requirement of creating work continuity to obtain maximum crew utilization (Selinger, 1980). In addition, CPM is a time based scheduling approach not a resource based one, as resources availability is assumed to be unlimited during scheduling any construction project (Lutz and Halpin 1994).

Many attempts have been proceeded to develop scheduling methods and tools for planning and scheduling linear repetitive construction projects. The most common methods are as follows.

1. Line of Balance (LOB).
2. Vertical Production Method (VPM)

3. Linear Scheduling Method (LSM)

4. Repetitive Scheduling Method (RSM).

This research will focus on and tackle one of the abovementioned linear scheduling techniques, which is LOB. The drawbacks of LOB in scheduling repetitive projects will be highlighted. A framework adopts into LOB scheduling technique to enhance its efficiency as a linear scheduling tool.

1.2 Line of Balance

The LOB scheduling technique is deliberated as an effective scheduling technique for planning and scheduling linear projects. It was originally derived from the manufacturing industry and was developed by the U.S. Navy department for the programming and controlling of repetitive projects in the early 1950s (Neale and Neale 1989). Afterwards, it was later developed by the National Building Agency in the United Kingdom for repetitive housing projects to show that LOB is a resource-oriented scheduling methodology and to announce that a schedule approach that was based on resource utilization from the scratch is more realistic than activity dominated scheduling (Trimble, 1984).

LOB is a display of the project's profile and its situation by representing the cumulative completions of activities associated with a level of planned units' number at a given point in time. LOB shows the delays in the schedule that requires a deviation from the planned schedule due to the actual unforeseen progress of activities in a graphical way, and enables the assessment of this deviation (Khisty 1970). Repetitive projects are composed of a series of repetitive activities that need crews working and moving from one unit to another. These crews are required to repeat the same work in different areas in the project. Line of Balance (LOB) ensures the ability of maintaining resources working continuously without any interruption.

Consequently, LOB in scheduling repetitive activities is a way that reduces interruption and idle time of resources, and incorporates resource constraints into the schedule.

Many attempts have been established to combine benefits of CPM as a duration driven scheduling method and benefits of LOB as a resource driven scheduling technique in scheduling linear repetitive construction projects, where both logic dependency and resource continuity constraints are taken into account during scheduling process. (Suhail and Neale, 1994, Hegazy and Wassef, 2001, Ammar and Mohieldin, 2002, Ammar, 2003, Ammar, 2012, and Jung et al, 2013).

This thesis is aiming to introduce a new schedule framework for planning and scheduling multi repetitive projects where LOB scheduling tool will be utilized. First and foremost, it discusses the key aspects of LOB technique in scheduling repetitive projects, and highlights different concepts imbedded into LOB to improve its performance in scheduling linear construction projects. The thesis also provides a new ideology for maintaining crew circulation to optimize its number, and tackles the dilemma of resource leveling in repetitive construction projects. Finally, an approach to level resources utilization is developed in a manner to minimize its daily usage and smoothing its fluctuation with different production rates.

1.3 Statement of the problem

Despite the long history and expanding use of LOB in planning and scheduling linear projects, the literature indicates that LOB has a number of limitations that raise concerns about its use in the construction industry. The reasons for the limitation of LOB in scheduling linear projects are described as follows.

1.3.1 Limitation in LOB

1. In LOB scheduling technique, a single unit project is scheduled with its activities and those activities are repeated gradually with the number of desired repetitive units. This may result in rendering the process with same production rates and all activities could become critical with no float, which is required for relaxing the production rate in case of resource limitation.
2. A limitation of this methodology is that it assumes that production rates are linear and constant. To account for practical assumption, the amount of work within a repetitive activity along the entire units is identical and productivity of resources is constant. Due to the stochastic nature of construction processes, the assumption that production rates of construction project activities and tasks are linear may be erroneous and unrealistic (O'Brien, 1985; Russell and Wong ,1993; Yang, 2002).
3. Despite being an essential tool for project scheduling, LOB technique is inadequate in identifying criticalness and floats; thus, LOB method has to be developed to single out critical, non-critical repetitive activities, and floats to precisely detect the critical activities and path in LOB (Arditi et al, 2002).
4. From a resource utilization context, the assumption of linear, constant production rates hinder LOB in restricting each activity to be attained by the same crew in a linear sequential manner and eliminating the likehood of allocating resources among entire project units (Yang, 2002).
5. Construction projects involve circumstances that mandate the use of visual color coded diagrams or graphs for crews various circulations to facilitate pointing out each crew cycle, mapping out it's overlapping between different activities and to easily figure out concurrent activities at same periods (Arditi & Albulak, 1986).

1.3.2 Leveling of Resources in LOB

Resource planning and management is a key aspect for successfulness and profitability of any construction project (Karaa and Nasr 1986). Resource limitations should be taken into account, otherwise schedules will be conducted in an erroneous way (Hinze, 2004). Resource leveling in linear scheduling projects continues to grasp the motivation of researchers who expand its capabilities and applications. Linear scheduling methods rely mainly on resource allocation but do not implement any leveling on resources. Some researchers have been analyzing the problem of single-resource leveling in linear schedules (Georgy 2008; Lucko 2011), but known of the above-mentioned researches have taken into consideration the following parameters:

1. Among the well-documented factors that contribute to the difficulty of providing more improvement in resource usage, is the absence of different allocation or movement of crews between different activities in different units that is not previously considered during resource leveling in linear scheduling.
2. In addition, previous research do not consider the stretching or crunching of an activity duration in LOB to reach different and optimum crew sizes, they only considered activities with constant durations and crew sizes.
3. In this thesis, resource leveling in LOB scheduling technique is seamlessly extended to be implemented by applying entropy maximization metric using a simulation model.

In this thesis, a developed framework will be adopted into LOB scheduling technique, where the single unit project will be broken down into sub-activities with different floats before performing LOB calculation, which assist in relaxing sub-activities production rates. Afterwards, LOB deals with this sub-activities as a multi repetitive project, where each repetitive activity will be split down into equal repetitive sub-activities with different production rates, and consequently different number of crews are required. This method will assist LOB scheduling technique to have the tendency to incorporate a new concept for crew allocation from one activity to another in different units not only in a vertical linear direction, but also in all directions (upwards, downward, left and right) with no interruption between crews, which aims to find the optimum use of crews' number within repetitive activity. In addition, the visualization of crew circulation is enhanced and is presented using a color graphics for each crew route to easily identify crew number and its movement; besides, each crew movement is presented in a graph like a time scaled bar chart with its specified color to facilitate the process of pointing out the crew circulation within different units and to observe its starting and finishing dates.

Moreover, in this thesis, a new manner for single resource leveling of repetitive activities is implemented, where the number of crews required to perform a repetitive activity is the main purpose; besides, the possibility of ensuring different resource allocation during leveling between different activities in different units. Moreover, this research will take into account the likelihood of stretching or crunching duration of repetitive activities, as an approach to have an extensive enhancement in the resource histogram profile based on several conditions.

1.4 Objectives and Scope

The main challenges of this research stem from the desire to create an innovative framework and scheduling approach that overcome shortfalls of LOB in scheduling linear projects. This schedule approach will better handle schedule and resource constraints like project deadline, resource limit, minimizing indirect cost; besides it will adequately identify the critical path, which is difficult to be forecasted in LOB. The following are the major objectives of this research:

- Identifying the practical areas of potential enhancement that can improve the LOB scheduling tool by accounting for the breaking down of activities into sub-activities in order to formulate more efficient linear schedules
- Supplementing the repetitive scheduling literature with a new optimization model and an algorithm that can provide different and optimal crews routing between different activities in different units and serve as a decision support system for crew's circulation, and guarantee the optimal crew distribution for cost efficiency.
- Minimizing indirect costs by decreasing maximization in daily resource usage and allowing for using multi-task skilled crews between different activities in different units in repetitive projects; in addition to the new representation of different crews paths using Crews Diagramming Approach.
- Conducting a new resource leveling technique based on a simulation model that can capture the resource leveling dilemma by permitting for activity duration stretching and crunching, in which activity durations can be differentiated along the repeated units to ensure enhancing and smoothing resource fluctuations over time.

1.5 Research Methodology

The following steps are undertaken to achieve the research objectives:

Step-1. An extensive review of LOB drawbacks in scheduling linear repetitive projects is carried out in order to examine the existing LOB procedures and to identify its limitations.

Step-2. An optimization model is conducted by creating an algorithm on MATLAB using Sparse Matrix, Graph theory, and structural array. This model is considered a decision making tool to opt most optimum path and formulation for each crew and to allocate crews within activities in different units.

Step-3. A Crew Diagramming approach is rendered as a layout to map crews various routing from one site to another, and to figure out overlapping of crew circulation between different activities in various units.

Step-4. A spreadsheet simulation model is performed where the entropy-maximization metric will be used for leveling resources which allows for activity stretching and crunching to provide different resource allocation solutions and to achieve better resource leveling profile using Crystal Ball Ribbon software.

Step-5. Validation: A Case Study is used in order to validate the abovementioned and demonstrate its functionality and usefulness in scheduling multiple repetitive projects.

The case study shows the development of a new representation of crews' movement and routing while maintaining resource continuity and availability.

The case study shows the ability of LOB to accurately define the critical path.

The case study overviews an obvious enhancement and smoothness in resource usage profile.

1.6 Layout of the Thesis.

This thesis consists of five chapters. Chapter 1 – Introduction that introduces the research study and gives a generic overview of the thesis problem statement, research scope and objectives. Furthermore, it discusses the research methodology applied to reach the main objective of this thesis.

Chapter 2 – Literature Review tackles an extensive review for the previous researches that cover different concepts and challenges of line of balance (LOB) in scheduling repetitive projects; besides it introduces different approaches used for resource leveling in linear repetitive construction projects, entropy theory and graph theory.

Chapter 3 – Research Methodology and model development demonstrates the methodology and the interference between the research themes.

Chapter 4 – Verification and Validation implements a hypothetical case study for a repetitive project of a sewage pipe line installation in order to illustrate the proposed framework. In addition, it tackles and analyzes the results obtained from the applied case study.

Chapter 5 – Conclusions and Recommendations highlights the summary, conclusions, limitations, and recommendations of this research.

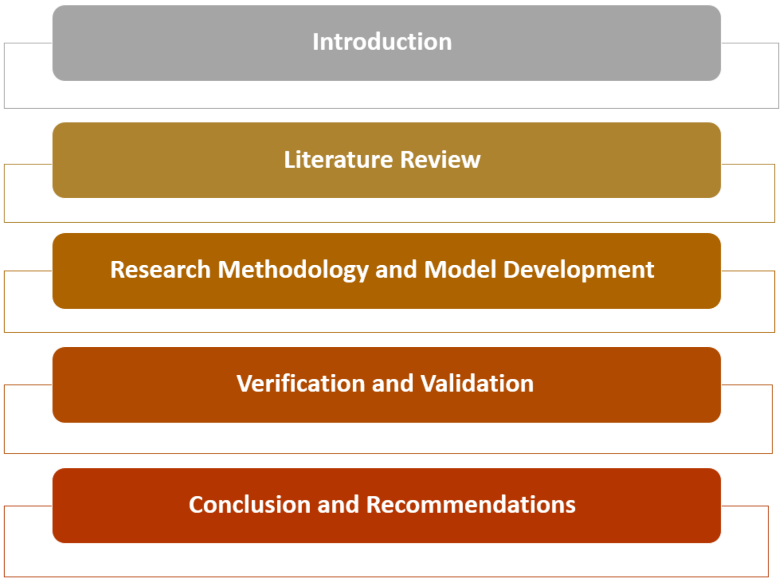


Figure 1.1: Thesis Organizational Chart

CHAPTER -2

LITERATURE REVIEW

One of the main purposes of this research is to support and to guide planners in precisely planning, scheduling and monitoring construction projects that are characterized by sequential repetitive activities**.** Hence**,** this literature review evaluates and discusses the pertinent theory and previous research conducted in the fields of LOB scheduling. Afterwards, it focuses broadly on overviewing previous research endeavors associated with enhancing LOB scheduling technique and its resource leveling. Finally, the chapter previews various efforts done in the field of implementing entropy maximization and graph theory in construction industry.

In this chapter, several topics will be introduced and discussed in details. The key topics, in which the chapter will focus on, could be divided into six main sections as follows:

1. Basic concept of LOB in repetitive projects.
2. Challenges and enhancement to improve LOB scheduling technique.
3. CPM and LOB integration Methodology.
4. Leveling in linear repetitive schedule Projects
5. Entropy Maximization Theory
6. Graph Theory

2.1 Line-of-Balance

This section demonstrates the Line of balance technique in depth, where it firstly begins with a historical review about Line of Balance. Then, it tackles the procedures undertaken to perform a Line of Balance calculations. Thenceforward, it deliberates the implementation of LOB in construction industry showing different challenges and enhancements proceeded to improve LOB technique. Finally, a generic summary about LOB and its relationship with this study will be emphasized.

2.1.1 Historical Review about LOB

The LOB methodology was originally introduced by the members of a group headed by George E. Fouch. During 1941, the Goodyear Tire & Rubber Company monitored production rate using LOB technique. LOB was developed by the US Navy in the early 1950s, as it was applied to the production planning and scheduling of the huge Navy mobilization program of World War ll. LOB has been implemented to industrial manufacturing and production adjustment to evaluate a production line flow rate of completed products and has been expanding across a whole spectrum of activities ranging from research and development through job shop and process flow operations. The line-of-balance technique is based on an assumption that the rate of production for an activity is uniform, where time is plotted on the horizontal axis and units of an activity is plotted on the vertical axis. The production rate of an activity is the slope of the production line (Johnston 1981).

Research have showed that LOB scheduling technique is more precise than CPM in scheduling linear construction projects. CPM has been criticized extensively in the literature for their inability to schedule repetitive projects (Selinger, 1980; Reda, 1990; and Russell and Wong, 1993). The size of the network of a CPM schedule for a repetitive project is relatively huge which lead to miscommunication among construction management team. Furthermore, CPM was designed for minimizing project duration rather than concerning with resource constraints of repetitive projects. LOB scheduling technique was claimed to have the tendency to conduct a crew circulation from one unit to another with less interruption or idle time for workers and equipment (Arditi et al, 2002)

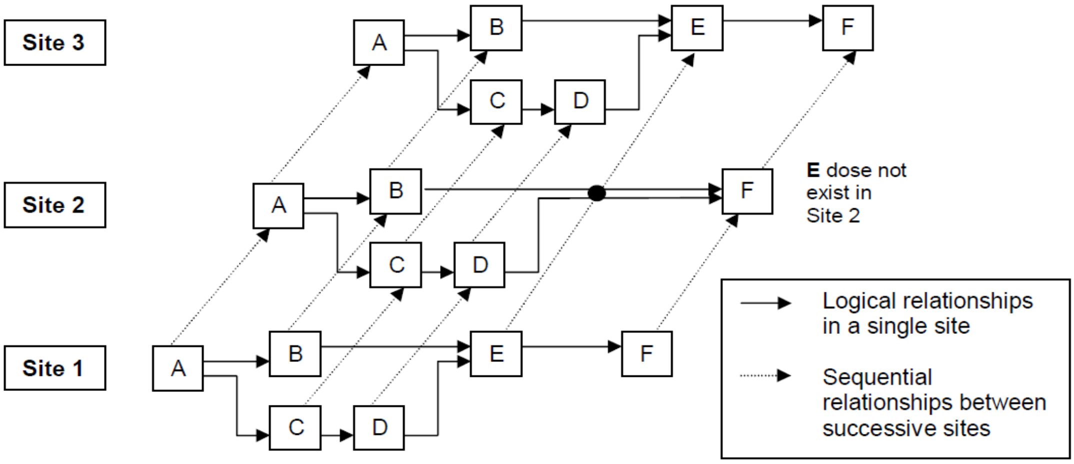


Figure 2.1: CPM Representation of repetitive Networks with Multiple-Distributed Sites (Hakeem, 2001).

2.1.2 Basic Procedures undertaken to perform LOB.

LOB scheduling technique depends on a required number of units that have to be completed and delivered in a specific period of time. The production rate of each activity, and its duration relies mainly on the targeted rate of delivery and are expected not to be less than this target rate (Lumsden, 1968). The rate of outcome that a crew of optimum size will be able to generate is called the ‘‘natural rhythm’’ of the activity. Any rate of outcome that varies from a multiple of the natural rhythm will result in the existence of an idle time for resources. Psarros (1987) has developed an algorithm to conduct the number of needed crews by an activity such that the rate of outcome, a multiple of the natural rhythm is as close to the target rate of delivery of the project as much as possible (Psarros, 1987).

The number of crews required to perform a repetitive activity and the actual rate of output are calculated to plot the LOB diagram, where the number of repetitive units are drawn against time. Two oblique or parallel lines, whose slope is equal to the actual rate of outcome represents the start and finish date of each activity in all unit from the first one to the last one, as it is calculated as follows (Lumsden, 1968).

$M = Qj - Qi / Tj - Ti$, $I < J$……………………………………………………….(1).

Where M is the rate of production (unit of production per unit of time); Qi, Qj equal number of units started; Ti, Tj equal time elapsed between the start of the project and the start of I and J units. The slope of line of balance connecting finish time of repetitive activities in each unit is equal to m. If the duration of the activity is known and the actual rate of outcome is limited to a multiple of natural rhythm, then the equation will be (Lumsden, 1968).

$Q = P/d$……………………………………………………………………….. (2).

Where P is the number of crews of an activity and d is the duration of an activity in one unit. The starting time of an activity is calculated as follows:

$Ti = T1 + (1/m) * (Qi-1)$……………………………………………………… (3).

Where ti is the starting time of an activity in i- th unit; t1 is the starting time of an activity in the first unit; m is the rate of production and Qi is the number of units produced (Lumsden, 1968).

2.1.3 Challenges and enhancements to improve LOB for Construction Industry

LOB scheduling technique have been implemented in the construction industry as a planning and scheduling technique in Finland in the 1980s (Harris and McCaffer, 1989), in which it is considered a scheduling methods that permits the balancing of construction projects and ensures activities to be performed continuously. The major benefit of the LOB techniques is providing production rate and duration of each repetitive activity in an easily graphical format. The LOB graph also allows the detecting of delays with the progress of an activity and permits the likelihood of production rate of different repetitive activities to deviate. Moreover, the LOB lets on the movement of resources and its flow in a smooth and efficient manner with less time consumed (Arditi and Albulak 1986).

LOB permits the adjustment of the production rate of activities to maximize resource utilization by eliminating idle time. This process of monitoring production rate is known as “balancing production rates.” LOB provides means of selecting crew size in order to minimize inefficiency and waste in resource usage. Furthermore, balancing production rates keeps all activities working at the same pace which may minimize project duration (Lutz 1990).

An early attempt was developed to schedule repetitive construction projects using LOB techniques with a computer application called “System for Repetitive Unit Scheduling” (SYRUS). It was developed to assist planners in scheduling linear projects in the construction industry. It is a menu driven application that relies on mixing both network and LOB techniques. This application failed to deal with many dilemmas encountered during scheduling projects (Arditi and Psarros 1987).

LOB computer applications were developed to enhance inefficiencies of the LOB technique and to improve its application. Hegazi et al (1993) proposed a computer program called BAL to schedule and to control linear projects with uniform sequential activities. This program is regarded as a user-friendly software that has the ability to generate schedules based on calendar and working days, and to come up with the desired rate based on the specified deadline. Moreover, this program previews possible updates for meeting deadlines and presents the resource usage throughout the project life cycle (Hegazi et al, 1993).

Senouci and El-din (1996) developed a non-serial dynamic programming technique for the scheduling linear projects with non-serial sequential activities. This method applies time/cost trade-off for linear projects, and manipulates the project durations and its costs efficiently. Furthermore, this technique overviews different crew formations, production rates and lag durations (Senouci and El-din, 1996).

Wang and Huang (1998) introduced a new scheduling approach that tackles the disadvantages of LOB to control the interval times. This method started with applying multistage linear scheduling method (MLS) based on the multistage decision making concept. The MLS overcomes the dilemma of LOB to monitor the interval times between activities in repetitive projects. In this approach, interval times are regarded as a function of the total number of repeated units, difference in time between the construction of adjacent activities and the order of activities. This method reduces the total project duration without reducing the duration of each activity at each unit (Wang and Huang, 1998).

Arditi et al (2002) proposed a computerized system for the implementation of LOB to imitate the concepts of a multi-level LOB diagram and to generate flexible unit network for scheduling high-rise buildings. Although RUSS and ALISS showed enhancement in satisfying deadline constraints in resources, they do have some shortcoming, as they do not guarantee the optimal crew distribution. Moreover, they neglect the distribution of production rates in the decision-making process, and the opting of consecutive activities with same production rates is not allowed because the algorithms only choose one activity in each iteration (Arditi et al, 2002).

Tokdemir et al (2003) maintained a computerized system of LOB called ALISS, which have the capability of accelerating the project for a specified deadline or milestone by increasing the number of crews of selected activities (Tokdemir et al, 2003).

Agrama (2011) introduced a spreadsheet algorithm, where LOB based scheduling technique was used. This novel model identifies start and finish times in an easy analytical way. It maintained crew work continuity without allowing any interruption, and achieving logical constraints and relationships between consecutive activities. In this study, non-typical activities were assumed, in which activity durations can be varied along the repeated units. The model was presented in three steps: first was the spreadsheet data; second was the model calculations; whereas third was LOB diagram (Agrama, 2011).

2.1.4 Concept of 'Criticalness in LOB

There is a huge difference between the concept of criticalness in LOB and the concept of criticalness in CPM network. This difference was proved by identifying the controlling activity path in case of using repetitive scheduling method (Harmelink and Rowings, 1998). LOB technique do not have the ability to identify criticalness and floats, so LOB method should be developed to single out critical, non-critical activities, and floats to accurately detect the criticalness in LOB. LOB is well known by having different production rates for activities, so the critical activities identified after LOB calculation may or may not coincide with the critical activities identified after analyzing the CPM network. The critical path in the LOB analysis may become noncritical if the production rate of an individual activity is changed by changing the number of crews required by an activity due to resource constraints (Arditi et al, 2002).

Arditi, et al. (2001) claimed that at least one critical path occurs while using CPM, and activities which are located on this critical path should be started and finished with their assigned dates in order not postpone the project completion date. On the other hand, the LOB scheduling methods criticality was relied on time and resources, unlike CPM which was only relied on time. As a result of the different rates of production of individual activities, critical activities in the CPM network may or may not agree with the critical activities in the LOB schedule as shown in figure 2.2.

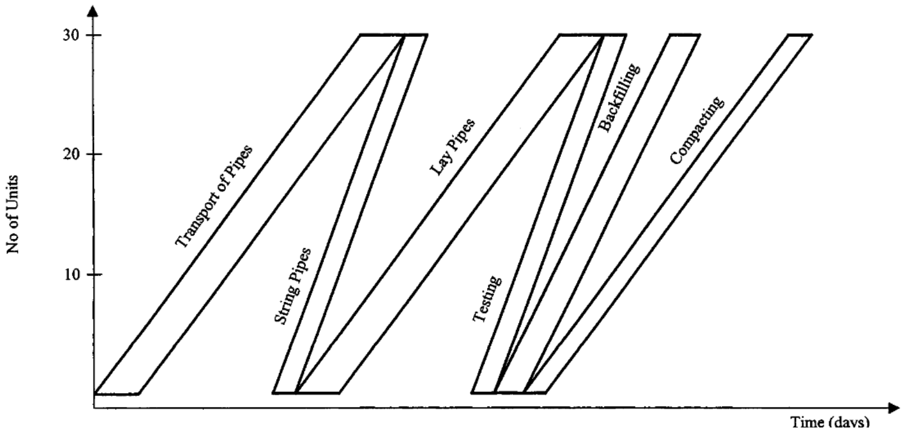


Figure 2.2: Example of critical path in LOB (Arditi et al, 2002).

2.1.5 Learning Curve Effect on LOB.

In LOB the relationship between time and the number of units produced is assumed linear with a constant rate of production over time, which opposes the real circumstances as the more times an operation is performed, the shorter will be the time required to perform it. This phenomenon is called the learning curve effect. The effect of the learning is incorporated into a repetitive project schedule to reflect the real circumstances of the project (Arditi et al. 1999).

The learning trend cannot be directly implemented in the LOB method because the LOB requires the consistency in the rate of production of each activity during repetitive unit construction. Therefore, the learning rate of each activity should be done and then converted into man-hour estimates. The activity durations in each unit has to be calculated individually because the rate of production of each activity will not be constant. The resulting production curves will plotted be in a LOB format which represent the start and finish times of each activity in a non-parallel lines as shown in figure 2.3 (Arditi et al. 2002).

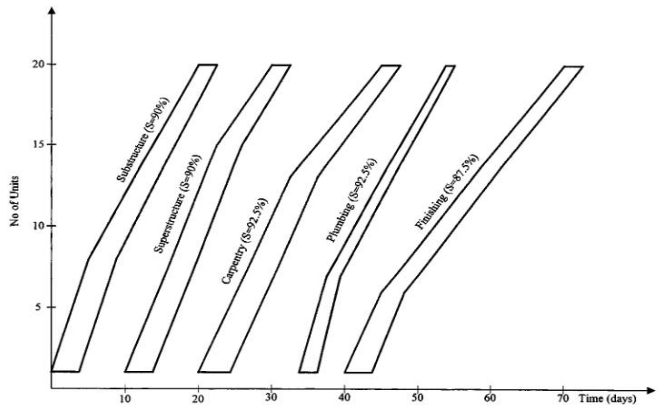


Figure 2.3: Example of LOB scheduling with learning curve effect (Arditi et al, 2002).

2.1.6 CPM and Line of Balance integration Methodology.

LOB is regarded as a resource controlling tool that conduct a balanced resource utilization in an efficient way. The major benefit of LOB scheduling technique is the visualization of production rate and duration of the repetitive activities in an ease graphical format with the applicability of controlling the progress rate to meet project duration deadlines, with preserving work continuity of resources (Yang and Ioannou 2004).

Many efforts have been attempted to integrate the benefits of CPM and LOB techniques as a new generation of planning and scheduling structures. The CPM/ LOB appears to be more convenient because it has advantages of a graphical basis and a mathematical one, where (1) resource allocation is done due having a deadline, (2) the determination of a critical path is easy like CPM, (3) Its application results in smoothing the fluctuation of resources usage, (4) it guarantees work continuity in linear projects, (5) finally CPM/LOB allows more than one crew to be assigned to an activity concurrently (Suhail and Neale ,1994).

2.1.6.1 Calculation procedures of integrated CPM and LOB

The process of integrating CPM with LOB is composed of four steps which are as Follows:

Step-one is LOB calculations which initiate with formulating a strategy for meeting a project deadline through a desired rate of delivery.

Rd= N-1/Tp-T1+Tf, Where N= number of repetitive units, Tp is the desired Completion date of the whole project, T1 is the completion date of one single unit, and Tf is the total float of noncritical activities to reduce the number of crews employed and to relax production rate of an activity (Suhail and Neale 1994).

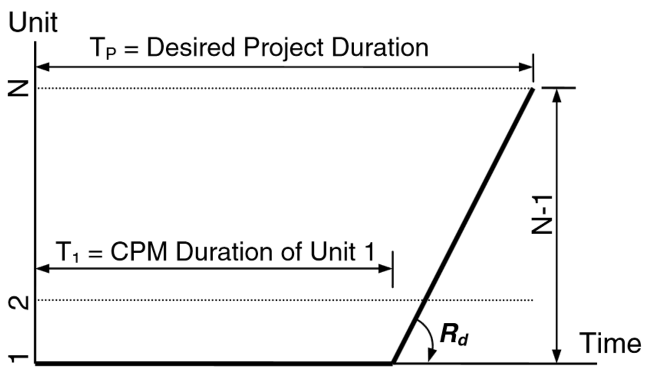


Figure 2.4: Desired Project rate of delivery (Ammar, 2012).

Then, the number of crews (Cdi) needed to maintain the desired rate of delivery of activity i can be calculated as follows:

- Cdi= di * Rdi, where di is the duration of an activity in one single unit
- Actual number of crews to be used (Cai) will be Cdi rounded up.
- Rai= Cai / di .Where Cai is the actual number of crew needed to perform a specific repetitive activity, and Rai is the actual rate of progress of an activity

Step -two is calculating the duration from the start of an activity in first unit till the finish of the same activity in last unit , in which ST_{iN} = start time of last unit; ST_{i1} = start time of first unit; and Di= duration along all units of activity i. Di =di + $ST_{iN} - ST_{i1}$ = di+ (N−1) / Ra.

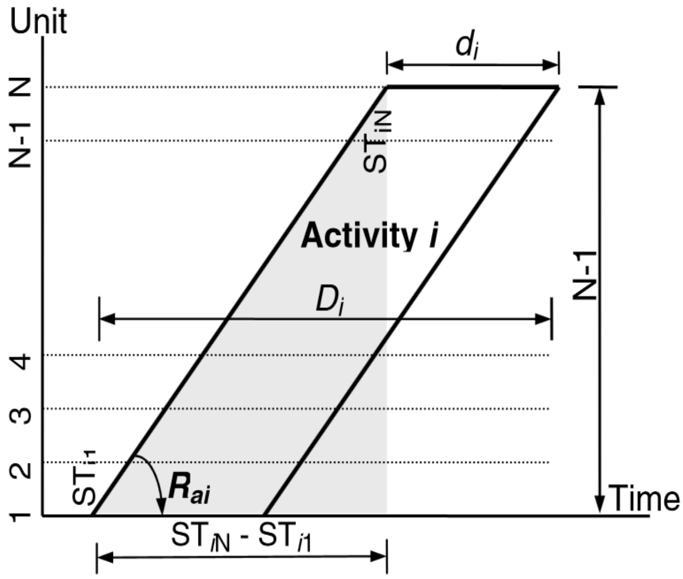


Figure 2.5: Duration of a repetitive activity along all units (Ammar, 2012).

Step-three is specifying logical relationships using overlapping activities by comparing the actual progress rate of predecessor and successor activities. If the actual progress rate of Predecessor is greater than actual progress rate of successor, then a start to start relationship will be applied plus buffer time. If the actual progress rate of Predecessor is less than actual progress rate of successor, then a finish to finish relationship will be applied plus buffer time. Finally, if the actual progress rate of Predecessor is equal to actual progress rate of successor, then a start to start relationship will be applied plus buffer time (Ammar, 2012).

The fourth step is performing a time scheduling calculations using CPM. Forward pass calculations are conducted to determine early timings of activities, whereas late timings of activities are determined in the backward pass calculations.

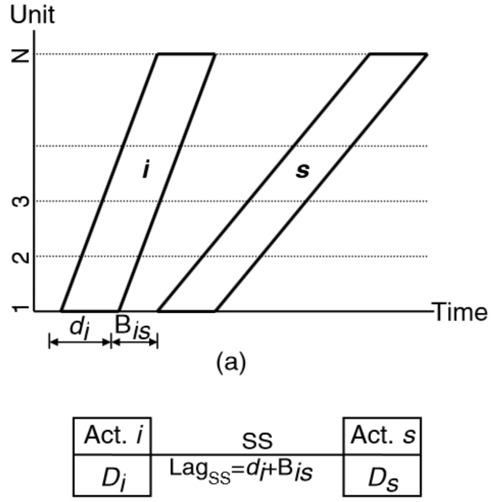


Figure 2.6: SS Relationship between Activities (Ammar, 2012).

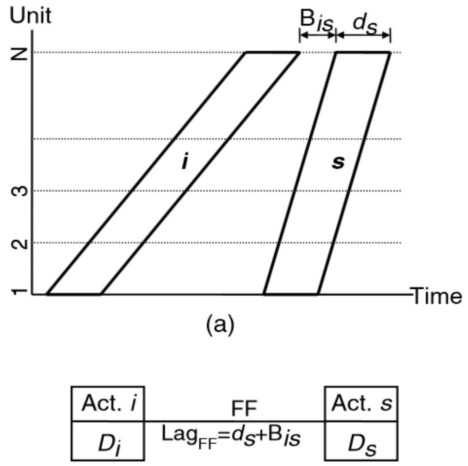


Figure 2.7: FF Relationship between Activities. (Ammar, 2012).

2.1.6.2 Previous research effort of integrated CPM and LOB

Suhail and Neale (1994) developed a model that determine the number of crews needed to meet a project duration deadline. The model presents a formulation for determining crews required to meet the project due date. Activities' total float are utilized to relax non-critical activities without influencing the total project duration. However, the model works well only when the calculated number of crews is not rounded to integer numbers and the crews' availability is not considered.

Hegazy and Wassef (2001) developed a model to minimize total construction cost (direct cost, indirect cost, interruption cost, incentives and liquidated damages) using integrating LOB and CPM method. The model uses genetic algorithms to outcome the optimum construction methods, number of crews, and interruptions for each repetitive activity. Nevertheless, the model performs time-cost trade-off analysis considering a project deadline. One its defects is limitation of the number of predecessors and successors for each activity to three only.

Ammar and Mohieldin (2002) developed a CPM-based repetitive scheduling model that utilizes the benefits of CPM to schedule repetitive activities in an easy non graphical approach. This model accounts for only the most significant resource for each activity.

Ammar (2003) developed a model for determining different types of floats for non-serial repetitive activities, in which the time float and rate float are extended to repetitive activities. Float analysis is performed in a manner similar to CPM analysis, without the need for graphical presentation. The analysis was based on a repetitive scheduling method, which utilizes CPM network of a typical unit, and overlapping between activities are used to model repetitive activities. A constant activity production rate is assumed and resource continuity is maintained.

Ammar (2012) proposed an integrated CPM and LOB model to schedule repetitive projects in an easy non graphical way, considering both logic dependency and resource continuity constraints. Overlapping activities of a single typical unit are used to indicate duration and logical relationships of repetitive activities. The proposed model consists of four steps. In the first step, LOB calculations are performed to ensure resource continuity. In the second step, activity duration of repetitive units is calculated. In the third step, overlapping activities are used to show logical relationships between repetitive activities. Finally, CPM is performed to specify activities' starting dates, finishing dates and floats.

Jung etal (2013) proposed a study that examined the simplified CPM/LOB methodology in construction scheduling planning and controlling to achieve accurate schedules. This study improves scheduling calculations of CPM/LOB to simplify existing scheduling method, straightforward design of the discharge procedure and enhances its applicability through CPM/LOB to provide CPM scheduling repetitive for the use of project resources (Jung etal, 2013).

Reza etal (2014) presented a methodology to enhance CPM/LOB scheduling method for deadline constraint satisfaction. A heuristic approach called "heuristic line of balance (HLOB) is introduced for scheduling projects with serial activities, which is composed of four heuristic rules and their combination in addition to seeking CPM/LOB initial calculation. Furthermore, the search-based heuristic line of balance (SHLOB) algorithm is presented in case extending the project size. Eventually, a LOB model in the form of integer nonlinear programming is implemented for verify proposed models (Reza etal, 2014).

2.2 Resource Management in repetitive projects.

2.2.1 Introduction.

Management of resources is considered a crucial key that should be taken into account for competitiveness and profitability in developing reliable and accurate construction schedules (Karaa and Nasr, 1986). One of the main reasons beyond the delay in construction projects is not well considering resource management during planning phase; besides, the resource availability, resource allocation and resource fluctuation are not taken into consideration that increase the probability of delaying the completion date of the project. Thus, resource limitations should not be ignored, in order not to generate unrealistic schedule (Hinze, 2004).

There are two categories of project scheduling, resource-constrained and time-constrained. Resource constraints in repetitive construction projects are composed of two types, resource availability constraints and resource continuity constraints. Resource availability constraints represent the limitations in the number of crew available for performing a specific repetitive activities. Resource continuity constraints stipulate the requirement of crew's movement and circulation in a consistent way without being interrupted. On the other hand, time-constraint resembles the completion of the project in the specified and desired duration.

Resource leveling is regarded as the one of the approaches used for the management of resources. Resource leveling in linear repetitive construction is required to maintain the encountered constraints during the project construction lifecycle. Resource leveling deals with minimizing fluctuations in resource utilization depending on the total float of non -critical activities without changing project duration (Son and Skibniewski 1999; Leu et al. 2000; Hegazy and Ersahin 2001; Senouci and Adeli 2001; Doulabi et al. 2011; Hariga and El-Sayegh 2011).

2.2.2 Previous research in the field of resource management of linear projects.

For linear construction projects, it has been known that resource utilization is important in improving work efficiency. However, few existing scheduling techniques can satisfy needs for solving such issues. Hence, this section will show several attempts that have been developed to tackle this dilemma.

Senouci and Naji (2006) implemented a computerized system for scheduling non- serial linear projects and optimizing total cost of the project using a genetic algorithm model. This model minimized the project total cost by comprising direct cost, indirect cost, and interruption cost. This system determined the optimum crew formations and reduced interruption days to decrease overall project cost (Senouci and Naji, 2006).

Hyari and El rayes (2006) introduced a computation model that include three computational modules which are scheduling, optimization, and ranking modules. (1) The scheduling module used a resource-driven scheduling algorithm to conduct practical schedules for repetitive construction projects, (2) The optimization module used a multi objective genetic algorithm to generate doable construction plans and to establish optimal tradeoffs between project duration and crew work continuity. (3) Finally the ranking module used a multi attribute utility theory to rank the produced plans to ease the selection and execution of the best plan for the project (Hyari and El rayes, 2006).

Liu and Wang (2007) established an optimization novel model for resolving linear scheduling dilemmas involving different objectives and resource assignment tasks. The proposed model adopted constraint programming (CP) as the searching algorithm for model formulation to create the flexibility for optimizing total cost and project duration. Additionally, the concept of outsourcing resources is used to enhance project performance (Liu and wang.2007).

In light of resource-constrained problem in repetitive projects, Hsie etal (2009) implemented a scheduling model to find the optimal set of production rates for crews in different time periods to remedy the issue of having the same production rate along the entire periods. This model took into consideration limited availability of resources and addressed work continuity while maintaining lead-time and lead-distance between operations. In this model, the optimization problem was solved using an evolutionary strategy algorithm (Hsie etal, 2009).

Gafy (2011) proposed an Ant Colony Optimization model based on the foraging behavior of ants to allocate resources in repetitive construction schedules that are constrained by an activity precedence and multiple resource limitations. The algorithm is used to optimally assign resources to repetitive activities to minimize interruption days (Gafy, 2011).

A proposed optimization model was maintained to integrate single/multiple-skilled crews to enhance work performance. Constraint programming (CP) was used to improve the efficiency of problem solving by handling sophisticated combinatorial scheduling issues and by engaging several heuristic rules. The CP-based optimization model minimized project duration considering the usage of both single-skilled and multi-skilled crews (Liu and Wang, 2012).

2.2.3 Leveling in Linear repetitive schedule Projects

This section tackles the resource leveling in linear repetitive schedules in depth, in which it discusses notable effort and different approaches done for leveling linear projects, which are subdivided into three approaches: Heuristic approaches, Optimization approaches and Metaheuristic approaches.

2.2.4 Heuristic approaches used for leveling Resources.

A proposed model was developed to tackle the important activities for multiresource leveling in linear construction project schedules. The model generates a linear project schedule and applies multiresource leveling that uses a resource weight and causes a deviation in daily resource utilization, and conducts a combined resource leveling histogram. In spite of the main contribution of this model in leveling resources, it was based on critical path method (CPM) calculations as it uses free floats instead of using the production rates of the activities, and uses a modified version of the minimum moment algorithm that does not produce better leveling than the original algorithm developed by Harris in 1978 (Dubey, 1993).

Minimum Moment algorithm is regarded as one of the most crucial techniques used for leveling resources, which was developed by Harris (1978). In Minimum Moment algorithm, activities are assumed to be uninterrupted, and once an activity starts, it continues till it is completed. Moreover, the technique assumes that the resource utilization is constant over the activity duration and only one activity can be move at a single time. In this leveling technique, the non-critical activities are only leveled by shifting respecting their total float durations. The main concept behind this algorithm is concentrated on an improvement factor which is considered the only discussion maker to moving any activity with its float. The improvement factor is calculated for all activities, and the activity with the largest improvement factor has the highest priority to be shifted within its float.

A multi heuristic hybrid model was introduced that combines the local optimizer with simulated annealing to remedy resource leveling problems. This model allows the probability of splitting activities to make it near optimum to real construction projects. The results shows that these heuristic models generate viable remedies for the resource leveling dilemmas in repetitive construction projects (Son and Skibniewski, 1999).

A developed model modified the two-stage procedure for single resource leveling which was developed by Liu (1999) to solve the multiresource leveling problem. The first stage deals with resource allocation and scheduling using a heuristic algorithm. The second stage uses the results of the first stage for multiresource leveling through simulated annealing. This model has the advantage of handling multiresource leveling, as it runs the multiresource leveling procedure only if different resource allocation alternatives generate the same project duration. Moreover, this model reveals that the resource leveling may not provide any improvement in resource usage, because it assumes a linear relationship between crew size and productivity, whereas this relationship is actually not linear due to the principle of optimum crew size (Yen's ,2005)

The resource leveling problem of linear repetitive projects was described as a constraint satisfaction problem where a constraint programming (CP) technique was used by Tang etal (2014) to remedy the resource leveling dilemma. A two-stage scheduling system for resource leveling of linear construction projects was created, which uses the rate float of the activity to obtain a more optimal schedule (Tang etal, 2014).

2.2.5 Optimization approaches used for leveling Resources.

Mattila and Abraham (1998) implemented an integer linear programming model by assigning weights while combining the multiple resources for multiresource leveling. This model relies on the linear scheduling model that was developed by Harmelink and Rowings (1998). The model provides an algorithm to determine the controlling activities of a project (same as critical activities in CPM), non-controlling activities (same as noncritical activities in CPM), rate floats, and activity floats. The model has the ability to find an optimum solution using integer linear programming, however it may be inefficient on large-scale projects with many variables as it will be hard to find the optimal solution. This model do not calculate the start/finish times of the activities and generate the linear schedule diagram and resource histograms automatically. In this model, the linear schedule diagram and resource histograms have to be manually generated by the scheduler before and after multiresource leveling is performed (Mattila and Abraham, 1998).

An automated optimization model was implemented which uses dynamic programming formulation and incorporates a scheduling algorithm and an interruption algorithm to follow the generation of interruptions during scheduling. This transforms the consideration of interruption in optimizing resource utilization, from an unbounded dilemma to a doable one (El-Rayes etal, 2001)

Finally, Hariga and El-Sayegh (2011) developed an optimization model for resource leveling that permits activity splitting and minimizes its associated costs. The objective of the model is to level resources to provide a tradeoff between the extra cost of acquiring and releasing resources versus the extra cost of activity splitting. The model can be used to determine the level where splitting an activity is beneficial and recommended (Hariga and El-Sayegh, 2011).

2.2.6 Metaheuristic approaches used for leveling Resources.

Further studies have been conducted for resource leveling in linear projects. A model was introduced that considered the need of an activity in its entirety for resource adjustments. The limitation of the controlling path was eliminated in the optimization process and the concept of changing buffer was introduced to realize high flexibility. Simultaneously, a genetic algorithm was used for solving the model. The possibility of obtaining optimal solutions could be improved because solving was based on many initial feasible solutions. However, this approach still has some limitations. The schedule quality of the genetic-algorithm-based model could not be guaranteed owing to the characteristics of the genetic algorithm (Georgy, 2008).

A new methodology of modeling linear schedules was implemented using singularity functions, which have been used for identifying criticality of an activity and performing the float analyses. The model extracts one flexible equation for the complete resource profile of a schedule, including any changes in the resource production rates of activities. A subsequent equation describes the first moment of area of the resource profile. Minimizing the moment of daily resource usage is the objective function for leveling the resource profile. A genetic algorithm with inverse ranking is performed to conduct successive iterations. Chromosomes contain different permutations resource rates at which the activities can be performed.

Probabilistic reproduction, crossover, and mutation steps. The calculations illustrate the precise of singularity functions in generating a model that integrates the linear schedule with its resource profile and facilitates the overall optimization process (Lucko etal, 2011).

A genetic algorithm (GA)-based multiresource leveling model was developed for linear repetitive projects scheduled using LOB. The model shows that the production rate and an activity duration are controlled by the resource that requires the longest duration in completing a unit. Once the LOB schedule is created, resource leveling is performed according to the principle of optimum crew size that makes use of a utility data curve and shows the suffering in the productivity rate if the crew size is different than the optimum crew size. The principle of natural rhythm is implemented that permits shifting the start dates of an activity forward or backward at different units of production by changing the number of crews employed. The activity duration and the precedence relationships between activities do not change during performing of leveling process. (Damci etal, 2013).

A backward-forward hybrid genetic algorithm (BFHGA) was presented for producing an optimal scheduling of a resource-constrained multi project scheduling problem (RCMPSP). This approach combines complementary strengths of the backward-forward scheduling method, genetic algorithms, and simulated annealing to remedy resource-constrained multi project scheduling problem (Sonmez and Uysal, 2014).

2.3 Entropy Maximization

This section introduces the concept of entropy as a measure of a system smoothness and degree of spontaneity and shows its implementation in construction industry. This section begins with defining the theory of entropy in physics. Afterward, this section points out the preceding application of entropy theory in construction industry.

2.3.1 State of the Art.

Entropy, in physics, is a measure of the unavailability of a system's energy to do work, and it is central to the second law of thermodynamics which deals with physical processes and the degree of spontaneity in their occurrence (spontaneous changes occur with an increase in entropy). Entropy is a measure of smoothness and changes of the different systems and it has been associated with the amount of order, disorder and the amount of wasted energy in the transformation from one state to another. Entropy relations provide the means for expressing the total amount of disorder (SD) and order (SO) in the system (Landsberg, 1984).

SD = CD / CI

SO = 1− CO / CI

Where CD is the disorder capacity of the system, CI is the information capacity and CO is the order capacity of the system. Entropy (Hx) is also defined as the product of the probability distribution (PX) of a variable x, times the natural logarithm of the inverse of that probability distribution Eq.

Hx = PX ln (1/px)

$$H(p_1, p_2, \ldots, p_n) \leqslant H(1/n, 1/n, \ldots, 1/n) \quad iff \;\; p_i = 1/n$$
$$\forall\, i = 1, 2, \ldots, n$$

There are two main properties of entropy that are associated with subadditivity and maximality. Subadditivity concept is a function's property which means that the function's value for the sum of two elements is less than or equal to the sum of the function's values for each element (Landsberg, 1984)

In entropy terms, if a system consists of two subdomains having n and m components, the total system entropy is less than or equal to the sum of the subdomains' entropy.

Whereas, the concept of maximality implies that the entropy function, (H p1, p2...pn), takes the greatest value when all results have equal probabilities.

H (v11 ,v12, ... , v1 m ,v21 , ... ,v2 m , ... , V n1 , ... ,Vn m)

$$\leqslant H\left(\sum_{i=1}^{n} v_{i1}, \sum_{i=1}^{n} v_{i2}, \ldots, \sum_{i=1}^{n} v_{im}\right) + H\left(\sum_{i=1}^{m} v_{1j}, \sum_{i=1}^{m} v_{2j}, \ldots, \sum_{i=1}^{m} v_{nj}\right)$$

2.3.2 The Application of Entropy Theory in Construction Management.

The concept of entropy has not only been tackled in physics and chemistry, it has also been implemented in construction management. The concept of the long-term entropy and profitability change of public construction firms was introduced in the United States. This concept showed that a firm's entropy is the weighted sum of related and unrelated diversification that can be expressed on the basis of the standard entropy equation, which is defined as the sales share of the business segment of the industry group's total sales. The major outcome of this research was formulating a linkage between entropy and profitability (Choi and Russell, 2005).

A fuzzy and entropy-based mathematical model was developed to solve the weighting dilemma of in overall cash-flow of the project. The model was applied in multi project cash flow diagram, which acts as a decision making tool for investing in a new construction project (Tang et al, 2006).

An optimum model was established for the design scheme of construction relying on the concept of entropy. This model was applied on indices of different schemes to build up a non-fuzzy judgment mathematical matrix to calculate entropy, then these indices were implemented in calculating entropy weight. Afterwards, the attribute matrix can be calculated to point out the ideal point (Ruan et al, 2009).

A new method for resource allocation and scheduling of resource-constrained construction projects was pointed out using entropy measurement. The entropy is considered an indicator of a project's ability to progress out orders and change into a chaotic condition to predict a project's progress approach. The entropy was used based on the resource assignments per activity (required vs. assigned resource units) (Christodoulou et al, 2009).

Another model proposed the use of entropy principal properties which are sub-additivity and maximality to revisit the minimum moment method for resource leveling. The entropy-maximization method presented permits the stretching of an activity and provides resource allocation solutions to enhance the overall resource usage fluctuation (Christodoulou et al, 2010).

2.4 Graph Theory.

2.4.1 State of the Art.

General speaking, a Graph theory is the study of graphs, which are mathematical structures used to model pairwise relations between objects. A "graph" in this context is made up of "vertices" or "nodes" and lines called edges that connect them. A graph may be undirected, meaning that there is no distinction between the two vertices associated with each edge, or its edges may be directed from one vertex to another

Graph Theory started with Leonhard Euler in his study of the Bridges of Konigsberg problem (Dickson, 2006). The city of Konigsberg was located on the Pregel River in Prussia. The river divided the city into four separate landmasses, where these four regions were linked by seven bridges as shown in figure 2.8. Dwellers of the city asked if it were possible to leave home, cross each of the seven bridges exactly once, and return home. Leonhard Euler (1707-1783) thought about this problem and the method he used to solve this issue is the graph theory. Since Euler solved this problem in Graph Theory, it has become one of the most crucial areas of applied mathematics. Graph Theory is cross-disciplinary between Math, Computer Science, Electrical Engineering and Operations Research (Dickson, 2006).

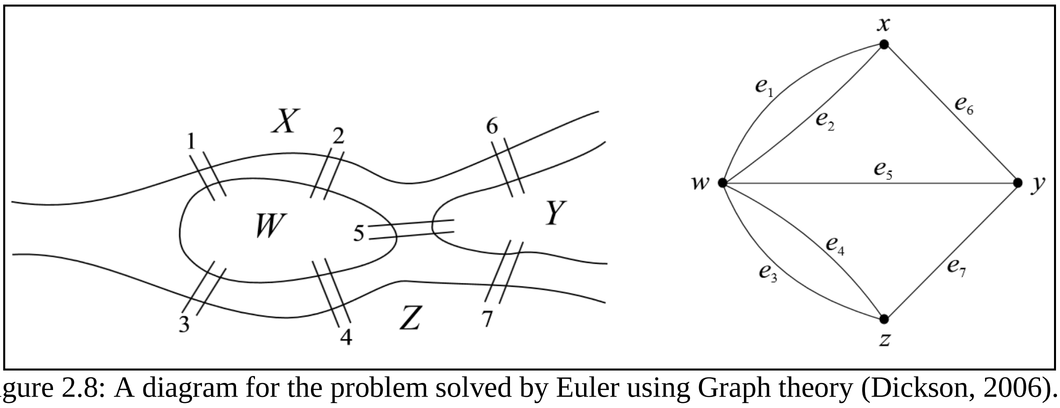


Figure 2.8: A diagram for the problem solved by Euler using Graph theory (Dickson, 2006).

The key to Euler's solution was in a very simple abstraction of the puzzle. Each land masses in the city of Konigsberg is represented as a vertex and each bridge is imitated as an edge connecting the vertices corresponding to the land masses. A graph was drawn that encodes the necessary information. The problem reduces to ending a "closed walk" in the graph which traverses each edge exactly once (Dickson, 2006).

2.4.2 Graph theory and Sparse Matrices.

Graph theory is a fundamental tool in sparse matrix techniques. A graph G is defined as the pair G= (V, E) where V is the set of vertices V= {v1, v2... Vn} and E is the set of edges between vertices .e. E= {e1, e2... ek} consists of pairs ek= (vi, vj) where Vi and vj are elements of V (Dickson, 2006).

The adjacency graph of a sparse matrix is a graph G= (V, E) whose N vertices in V represent the N unknowns. Its edges represent the binary relations established by the equations in the following manner: There is an edge from vertex i to vertex j when aij not equal 0. This edge will therefore represent the binary relation “equation i involves unknown j.” We assume that equation i will always involve unknown i, i.e. there is a loop at each vertex as shown in figure 2.9 (Dickson, 2006).

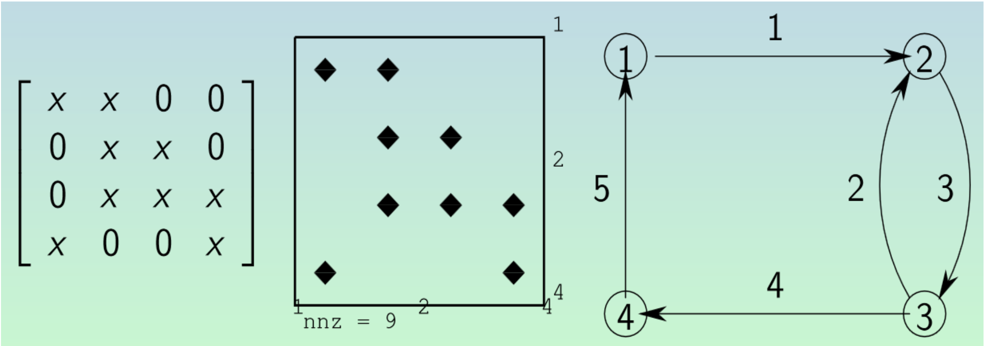


Figure 2.9: The adjacency graph of a sparse matrix (Dickson, 2006).

When a matrix has symmetric non zero pattern, i.e. when a Ij and A ji are always non zero at the same time, then the graph is undirected. Undirected graphs can be represented with non-oriented edges (Dickson, 2006).

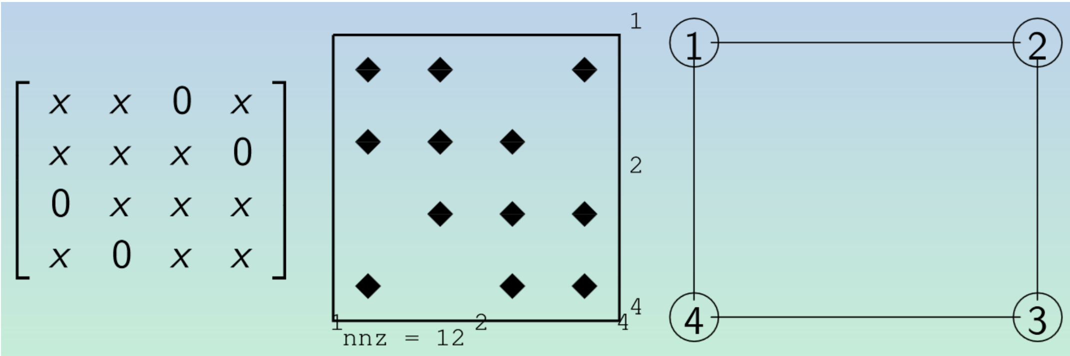


Figure 2.10: Undirected graphs with non-oriented edges (Dickson, 2006).

Principle of sparse matrix techniques: Store only the non- zero elements of A and try to minimize computations and storage.

The following part shows list of problems and situations, in which the Graph Theory can be implemented (Dickson, 2006).

1- **Optimization Problems using Graphs theory:** Graph theory treats problems of optimization like a road network that attempt to maximize the flow along that network while minimizing costs.

2- **Topological Graph Theory**: Defining methods that imbed graphs into topological spaces, where certain properties are maintained. For example, it can identify the probability of drawing a graph on a plane in such a way so that no two edge cross like the case of the bridges of Konigsberg graph.

3- **Graph Coloring**: This part tackles the identification of numbers of colors needed to color each vertex (or edge) of a graph so that no two adjacent vertices have the same color.

4- **Algebraic Graph Theory**: Is the application of abstract algebra (sometimes associated with matrix groups) to graph theory. Many results can be proved about graphs when using matrices and other algebraic properties.

2.5 Discussion of literature findings.

Many approaches have been developed to remedy the dilemmas of scheduling repetitive projects since 1960. The Line-Of-Balance technique (LOB) was introduced to the construction industry as one of the major linear scheduling graphical techniques. Many researchers have adopted the concept of LOB, and focused on balancing crew production and maintaining continuity of work flow. After the advent of the personal computer and the improvement in computing capabilities, many mathematic approaches have been established to solve repetitive project scheduling problems. Sophisticated mathematic models and algorithms were developed to optimize resources required and to smoothen the fluctuation of resources profile. Advancement of these models was established to mathematically model complicated and realistic construction operations.

While reviewing the literature, it has been realized that none of the above mentioned research have tackled the unrealistic assumptions of LOB that assumes constancy in production rates of each repetitive activity. Moreover**,** Considerable research has been developed to ensure work productivity and continuity. However, most of these studies neglect the flexibility of altering crew movement between different activities in different unit simultaneously. Besides, the availability of using multi-task skilled crews in linear construction projects between different activities in different units. Therefore, there is a need for developing a tool that tracks and monitors the above-mentioned drawbacks in a dynamic manner by ensuring the possibility of having different production rates within an activity. Besides, there is a need for applying a multi-task skilled crew between different activities in different units. Moreover, there is a need for an algorithm that changes linear crews routing and provides several and different formulation for crews' circulation to generate optimal crews' allocation for resolving resource constraints problems; besides this algorithm precisely identifies the critical path in linear projects. Furthermore, the daily resource usage needs to be minimized by using the concept of stretching or crunching of activities duration with varying duration in linear projects based on activity type and the location of the project.

Table 2.1- Summary for the above -mentioned research efforts developed for scheduling and managing repetitive Projects.

Reference	Technique	Considerations	Comments
Models of Line of Balance Scheduling			
Arditi and Psarros 1987	Computerized System (SYRUS)	Integrating both network system and LOB technique to schedule linear projects.	Linear scheduling projects
Hegazi et al, 1993	Computerized System (BAL)	Generate schedule based on calendars and working days to conduct desired rates based on deadlines.	Linear scheduling projects
Senouci and El-din ,1996	Non serial dynamic programming	A time cost tradeoff analytical model for linear projects.	Non- Serial linear projects.
Wang and Huang ,1998	MLS decision making tool	Monitoring and controlling interval times between activities in repetitive projects.	Multi stage linear scheduling
Arditi et al , 2002	Computerized System (RUSS)	Imitate the concept of multi-level LOB diagram to satisfy deadline constraints in resources.	Scheduling high rise buildings.
Tokdemir et al, 2006	Computerized System (ALISS)	Accelerating the project for specified deadline or milestone.	Linear scheduling projects
Agrama, 2011	Spreadsheet Algorithm.	Define relationship controlling start time of activities at first unit to maintain resource without interruption.	Non- Typical linear project.
CPM/LOB - Models			

Suhail and Neale ,1994	CPM/LOB Model.	Determining number of crews to meet desired project duration where total float relax non-critical activities.	Crew availability not considered
Hegazy and Wassef ,2001	CPM/LOB & Genetic algorithm.	Minimizing direct, in-direct, interruption costs and liquefied damages using G.A and CPM/LOB.	Predecessor and successor are only three
Ammar & Mohieldin,2002	CPM/LOB Model.	CPM based repetitive schedule model for significant resources only, not multiple ones.	Non-graphical approach
Ammar ,2003	CPM/LOB Model.	Determining different types of floats for non-serial repetitive projects.	Constant production rate
Ammar ,2012	CPM/LOB Model.	Overlapping between activities are utilized to indicate duration and logic relationship between activities.	Non-graphical approach
Jung etal, 2013	CPM/LOB Model.	Identifying The FS relationship formula derivation and application of the simplified CPM/LOB method.	Using FS relationship only
Reza etal, 2014	Heuristic Lien of Balance Model.	Lob model in the form of integer non-linear programming is used for deadline constraint satisfaction.	Deadline constraint Satisfaction
Models of Resource Optimization in Linear Projects			
Senouci and Naji, 2006.	Genetic Algorithm.	Determining optimal number of crews to reduce overall project cost.	Non-serial repetitive projects
Hyari and El rayes, 2006.	Computational Model.	-Using resource algorithm. -Multi objective G.A for tradeoff analysis	Linear scheduling projects
Liu and wang.2007.	Constraints Programming Algorithm.	Optimizing total cost and project duration	Linear scheduling projects
Chang and Huang, 2009.	Evolutionary strategy Algorithm.	Finding optimal set of production rates.	Consider Resource Limitation
Gafy, 2011.	Anty Colony.	Allocate resources to reduce duration and interruption days.	Consider Multiple Resource Limitation
Liu and Wang, 2012.	Constraints Programming Algorithm.	Integrate single/multiple skilled crews to enhance work continuity.	Engaging several heuristic ways
Models of Resource Leveling in Linear Projects			
1. Heuristic Approaches.			

Harris ,1978	Min. Moment Algorithm.	Shifting non-critical activates based on total float using an improvement factor.	Not applied in linear projects
Dubey, 1993	Modified Min. Moment Algorithm.	Multi resource leveling depending on resource weight.	Multi resource linear projects
Son and Skibniewski, 1999	Multi Heuristic Hybrid Model	Combining local optimizer with simulated annealing depending on splitting of activities.	Leveling Linear projects
Yen's , 2005	Modified Two Stage Method	Using a heuristic algorithm to allocate resources, and then leveled using simulated annealing.	Multi resource linear projects
Tang etal ,2014	Constraint Satisfaction Problem	Two stage scheduling system for leveling resources using rate float of activities.	Leveling Linear projects
2. Optimization Approaches.			
Mattila & Abraham, 1998	Integer Linear Programming Model	Detect controlling activities by assigning weights while combining the multiple resources	Leveling Linear projects
El-Rayes et al, 2001	Dynamic Programming Formulation	Considering interruption in optimizing resource utilization.	Leveling Linear projects
Hariga and el-Sayegh, 2011	Mixed binary integer programming	- Minimizes he costs of shutdown - Restarting an activity if it is split - Minimize costs resulting from the variations of the resource usage.	Leveling Linear projects
3. Meta-Heuristic Approaches.			
George,2008	Genetic Algorithm	Introducing concept if changing buffer to achieve high flexibility in resource leveling.	Leveling Linear projects
Lucko et al, 2011.	Singularity Function.	Integrating linear schedule with resource profile through minimizing moment of resources.	Leveling Linear projects
Damci et al, 2013.	Genetic Algorithm	Resource leveling is performed using optimum crew and natural rhythm principals.	Multi resource linear projects

Sonmez and Uysal, 2014.	Backward-Forward Hybrid G.A	Integrating forward and backward calculations with simulation annealing.	Resource constraint multi project scheduling problem
The Theory of Entropy			
Choi and Russell, 2005	Mathematical Model	The concept of the long-term entropy and profitability	Profitability analysis
Tang et al, 2006	A fuzzy and entropy-based mathematical model	Solve weighting problem of in overall cash-flow of the project	Cash-flow analysis
Ruan et al, 2009	Non-fuzzy judgment mathematical matrix	Established the design scheme of construction project depending on the concept of entropy	Decision making tool
Christodoulou et al, 2009	Mathematical Model	Resource allocation and scheduling of resource-constrained construction projects was pointed out using entropy measurement	Resource allocation
Christodoulou et al, 2009	Mathematical Model	Using sub-additivity and maximality principles to revisit the minimum moment method for resource leveling	Resource leveling

CHAPTER 3 – RESEARCH METHODOLOGY AND MODEL DEVELOPMENT

In order to achieve the research main targets and objectives, which were demonstrated in chapter one, a clear research methodology have to identified and stated. Therefore, this chapter highlights the proposed research methodology for achieving the main scopes of this thesis.

3.1 Introduction

In this chapter, the research methodology is declared and discussed in details. The chapter initiates with stating the main research problem and listing the research scope and objectives. Subsequently, the research methodology is proposed to single out the main scheme that have to be followed to pinpoint the research main objectives. This chapter will discuss the following main topics:

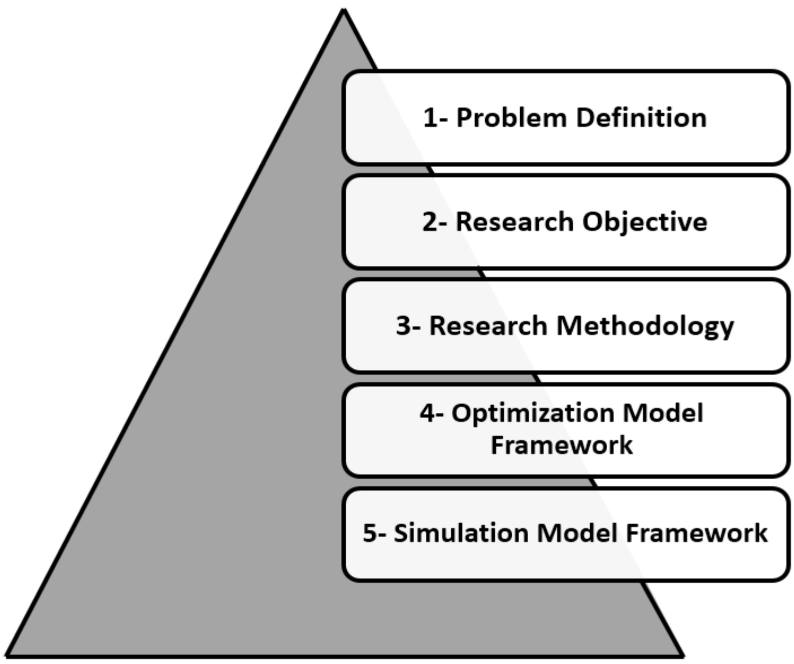


Figure 3.1: Steps of achieving Research Methodology Framework

Thusly, the above-mentioned points are deliberated deeply with a main target of attaining the research objectives.

- **Based on the literature review represented in Chapter 2, five areas in which the current LOB scheduling technique needs improvements are identified.**

1. Enhancing and providing a hybrid schedule approach for managing and monitoring repetitive construction projects in case of time and resources.
2. Clearly identifying critical and non-critical activities in LOB.
   - Accurately identify the critical path of a linear construction project.
3. Developing a decision support tool for minimizing resource usage required to attain a repetitive activity by altering the crews' itinerary.
   - The feasibility of applying multi-task skilled crews between different activities in different units to execute a repetitive construction project.
4. Improving the visualization of crews' movement and overviewing their circulation among repetitive activities.
5. Improving the resource leveling in LOB scheduling technique.

The aforementioned points are the key areas that require enhancement, in addition to the areas highlighted in Chapter 2. It is essential to figure out that resolving the dilemma in these fields needs a careful and a precise accounting for all the areas combined and necessitates a departure from traditional LOB technique. The following sections include a full description of these areas of enhancement, followed by the presenting and analyzing a scheduling scheme for repetitive projects that can address these needed improvements in a collective manner.

3.2 Areas Requiring Enhancement.

3.2.1 A developed schedule approach for managing and manipulating repetitive construction projects.

Often, linear construction projects involve circumstances that mandate the occurrence of a float or non-critical repetitive activities to accommodate the dilemma associated with resource constraints in construction projects. In LOB scheduling technique, the production rate of a repetitive activity is assumed to be constant along the entire number of units of a repetitive project, where the quantity of work within this repetitive activity is identical and productivity of resources is steady. Furthermore, LOB scheduling technique is generally incapable to portray the repetitive activities as partly critical, mainly because of the assumption that each repetitive activity is a single undivided parallelogram with a specific duration. This hypothesis is unrealistic as the repetitive activity is composed of sub-activities or stations as a result of breaking down of an activity, which may have different production rates, and may acquire different crew's usage due to the probability of having a float that relax the sub-activities production rate.

Figure 3.2 illustrates a simple case study of a repetitive construction project that is composed of three repetitive activities I, J and K respectively. CPM calculations of the three activities in the single unit is implemented that show the criticality of the three activities with no total float, which consequently lead to the similarity and constancy in the work performed and crews productivity rate of the three activities along the repetitive units as shown on LOB diagram.

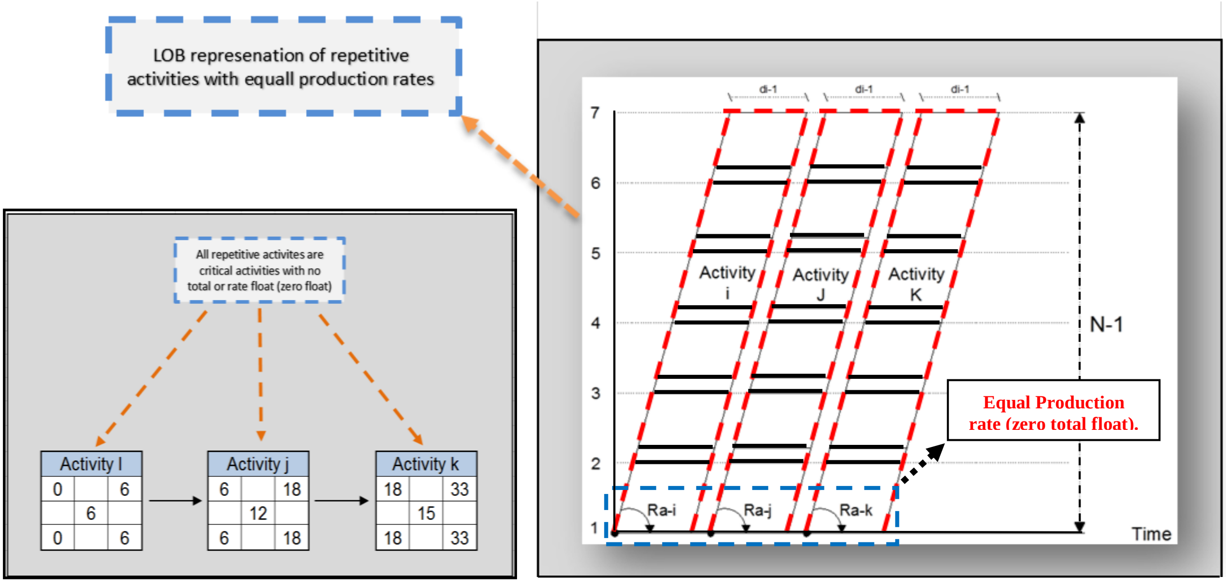


Figure 3.2: Traditional LOB scheduling technique

3.2.2. Clearly identifying the critical path of linear construction projects.

There is an obvious variety between the concept of criticalness in the LOB scheduling technique and the concept of criticalness in CPM networks. LOB scheduling technique do not have the ability to identify the accurate criticalness and floats; hence, an improvement in LOB scheduling techniques should be developed to point out critical, non-critical activities, and floats to precisely identify the critical path in LOB.

3.2.3. Minimizing the maximum number of crews utilized to perform a repetitive activity by changing their routing.

In LOB scheduling technique, each individual repetitive activity is considered as a single longitudinal bar where its length is equal to the number of units in the project. Besides, each individual linear activity has its own number of crews that are required to repeat the same work in different sectors and to perform this repetitive activity along the number of units of the project. Moreover, the relationship between crews in an individual activity is a linear vertical relationship only (Linear nature since one crew follows another sequentially), as there is no any route or path for crews circulation inside a repetitive activity. LOB scheduling technique assumes that the rate of production for an activity is uniform where the amount work attained by crews in any individual repetitive activity is equal and constant. This assumption may be unrealistic in real life construction projects due to the occurrence of unforeseen conditions and force majeure that may confront any construction project leading to amending the production rate in a specific unit. Consequently, this results in the appearance of an ideal time between crews and eventually interrupts the crews work continuity and extends the total project duration.

Figure 3.3 shows a linear project composed of three repetitive activities. Each repetitive activity need two crews to be achieved, in which each crew linearly pursue another in a vertical sequence. The total number of crews required to complete these three repetitive activities will be six different crews (two per each activity). As well as , LOB do not have the capability to execute different tasks by applying multi-task skilled crews that can maneuver and can circulate between different activities in different units to improve productivity and to reduce indirect costs.

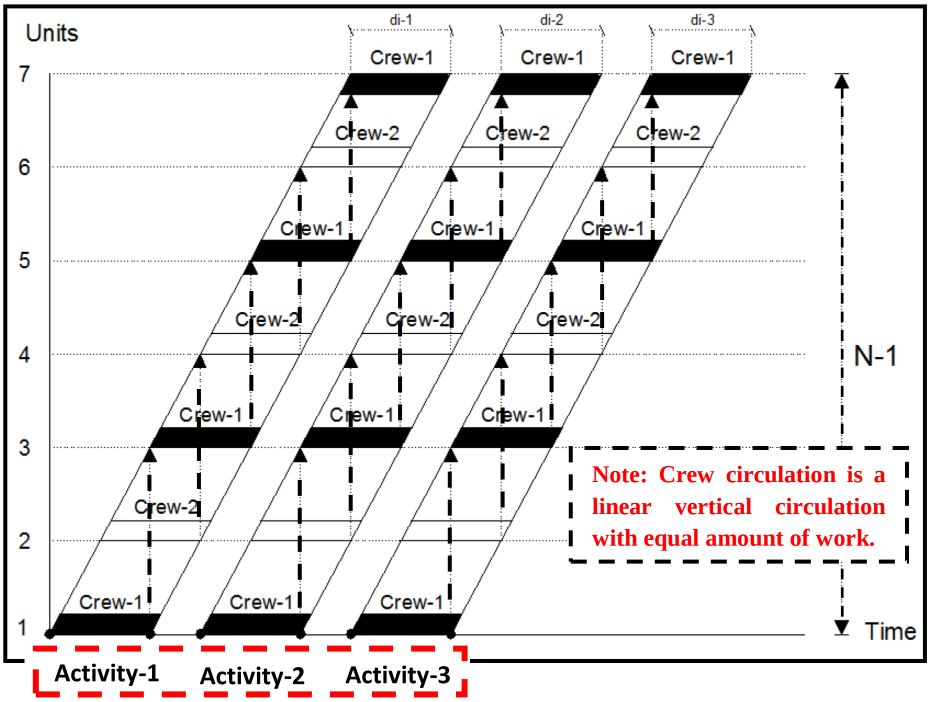


Figure 3.3: Crew Circulation in LOB scheduling technique

3.2.4. Enhancing the resource leveling in LOB scheduling technique.

The majority of linear construction projects are significantly impacted by circumstances that involve a resolving tool for resource limitation problems. For resource-constrained projects, the backward pass calculation may proceed incorrect total floats calculations because the sequence of some activities depends not only on the logical relationships but also on resource dependencies (Kim and de la Garza 2003). One of the key issues with existing LOB techniques is the fact that each repetitive activity is regarded as a single parallelogram having a constant production rate. While the literature describes several techniques that have been developed in order to remedy resource limitation dilemmas, none of the techniques has been devoted to consider the principle of stretching or crunching activities duration (depending on activity type) to get a better resource fluctuation profile and to comply with actual situations.

3.3. The Proposed Representation of LOB Scheduling Technique.

The following subsections tackle the measurable procedures undertaken to enhance the representation of a project and activity progress in LOB, which addresses the areas of required improvement in an ease, practical approach and within a consolidated framework.

3.3.1. The Representation of Activities in LOB after Breaking-down Activities.

Since the representation of activities and their durations are the basic parameters for schedule calculations; hence, the precise representation of the activities would remedy many issues accompanied with the abovementioned limitation of LOB. In contrary to the traditional manner of overviewing activities as parallelogram that span a specific number of units and period of time, repetitive activity is represented as a number of separate sectors or stations, but connected time sectors that add up to the total duration of the repetitive activity. For example, an activity of any linear project with a three kilometer distance and a duration of six days is broken down into three equal separate time station or sector with and a length of one kilometer and a duration of two days.

This method permits the representation of any logical relationship between the broken-down activities using only a Finish-to-Start (FS) relationship. The breaking down of activities into separate equal stations or sectors provides more accurate calculations that result in creating a partly critical and non-critical activities, unlike the traditional representation of activity, and consequently generate a more precise critical path.

On converting the above-mentioned methodology into LOB calculations, each activity is decomposed into separate sub-activities with different production rates due to the creation of critical and non-critical sub-activities within a repetitive activity. Accordingly, this reflects the stochastic nature of construction processes and do not account for practical assumption of having constant production dates while using LOB scheduling technique.

3.3.2. Proof of the concept

To illustrate the feasibility of the abovementioned ideology in providing better representation and analysis than the traditional LOB, the following simple case study evaluates the applicability of the concept. The simple example is composed of three different activities, each with a three kilometer distance. Nevertheless, these three activities are broken-down into separate sectors, each with a one kilometer distance and equal durations. The breaking down of activities results in increasing ability to represent the internal relationships between the activities, which consequently creates partly critical and non-critical sectors with an activity. The breaking down of activities is rendered into a LOB format, which emanates in breaking down an activity into sub activities with different production rates (activity relaxation as a result of an activity float and different crews' requirement as shown in figure 3.4 and 3.5 respectively.

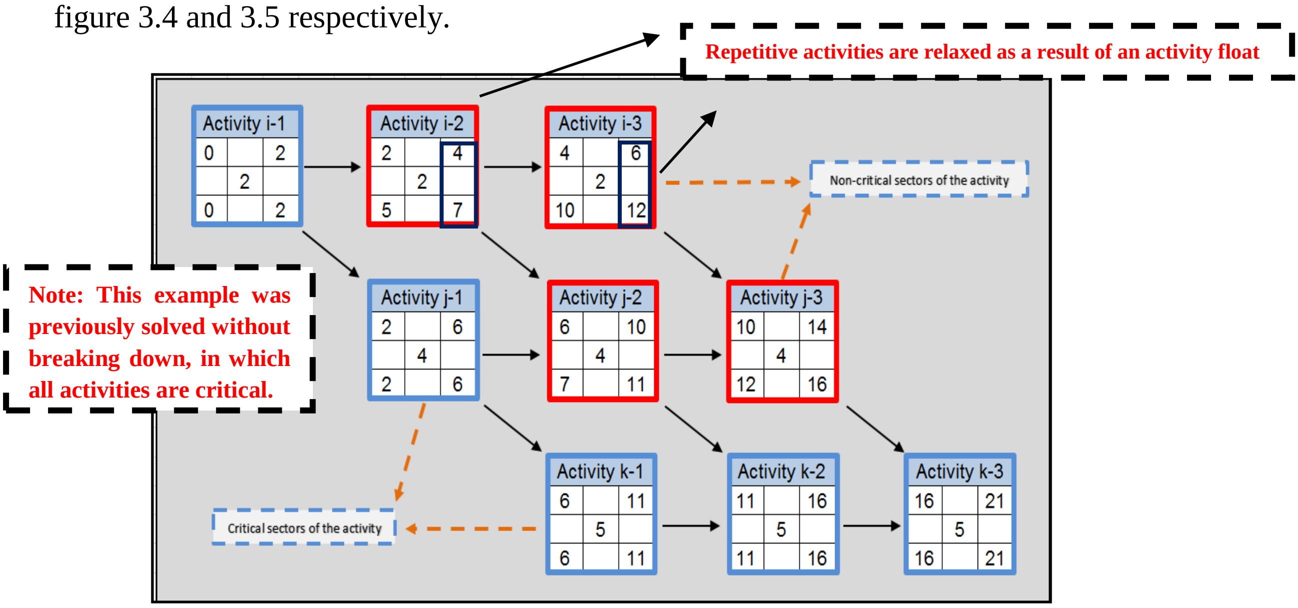


Figure 3.4: Methodology of Breaking-down activities

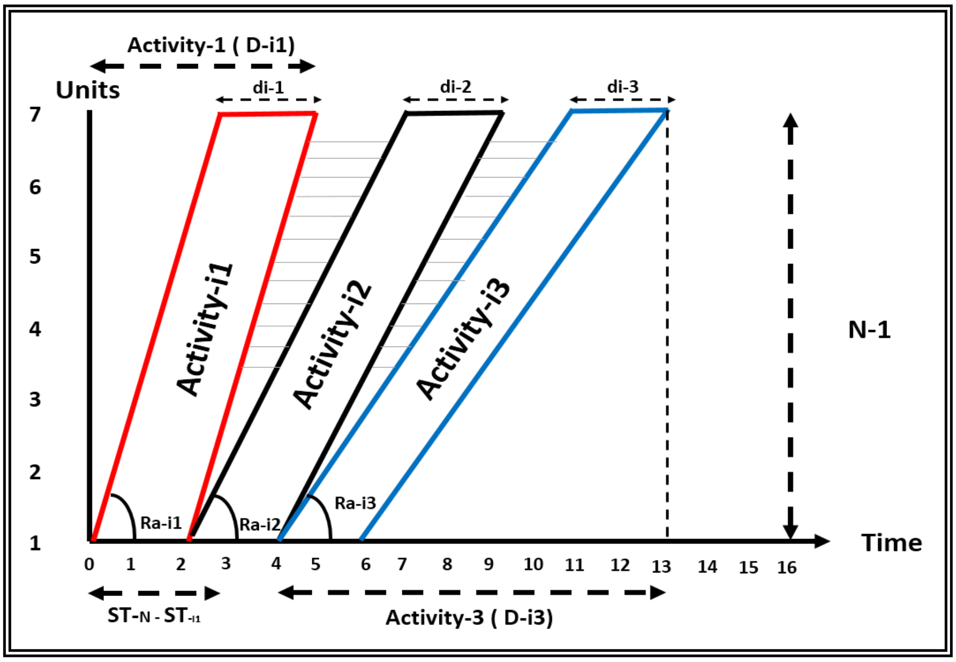


Figure 3.5: LOB representation for the simple example

3.4. A proposed algorithm (Model) for minimizing number of Crews utilized in LOB Scheduling Projects and allocating crews among different activities.

3.4.1. Introduction.

The allocation of resources to repetitive activities of a construction project is regarded as a difficult managerial issue, since inaccurate allocation of crews in LOB scheduling technique can result in extension of the project time and increase in the project overall cost. This proposed optimization model presents a platform to minimize the total resource usage of a project, while meeting the requirements for work continuity and the target deadline of each activity. Moreover, the proposed model have the capability of accurately identifying the critical path in LOB schedules.

3.4.2. Process outline of the proposed optimization Model.

The following sections will discuss the outlined procedures in detail covering required input data for model formulation and the nature of computations within them. First, an overview of the main attributes and parameters associated with the proposed model and their relevance will be fully presented. This will be followed by a detailed description of the sequential processes and steps needed to construct the model skeleton and realistically to generate the expected outputs. Finally, the output modules of the model will be displayed. MATLAB R2013a is used to run the proposed optimization model.

3.4.3. Main attributes and parameter associated with the proposed model

Table 3-1 shows the major attributes and parameters associated with proposed optimization model, in which the main objectives, variables and constraints accompanied with the proposed algorithm or model is illustrated in details.

Attribute	Description
Objective Functions	▪ Minimize the number of resource usage. ▪ The assignment of multi task skilled crews in LOB among different activities in different units. ▪ Accurately identifying the critical path in LOB schedules
Variables	▪ Number of crews. ▪ Crews' formulation. ▪ Circulation or routing of each Crew.
Constraints	▪ Start and finish date of each activity. ▪ Activity Production rate. ▪ Overall project completion date. ▪ Logic relationships among activities.

Figure 3.6 illustrates sequential processes and steps undertaken to construct the proposed algorithm or optimization model skeleton by which the data is utilized to generate the needed outcome module.

3.4.4. Description of Optimization Model Formulation

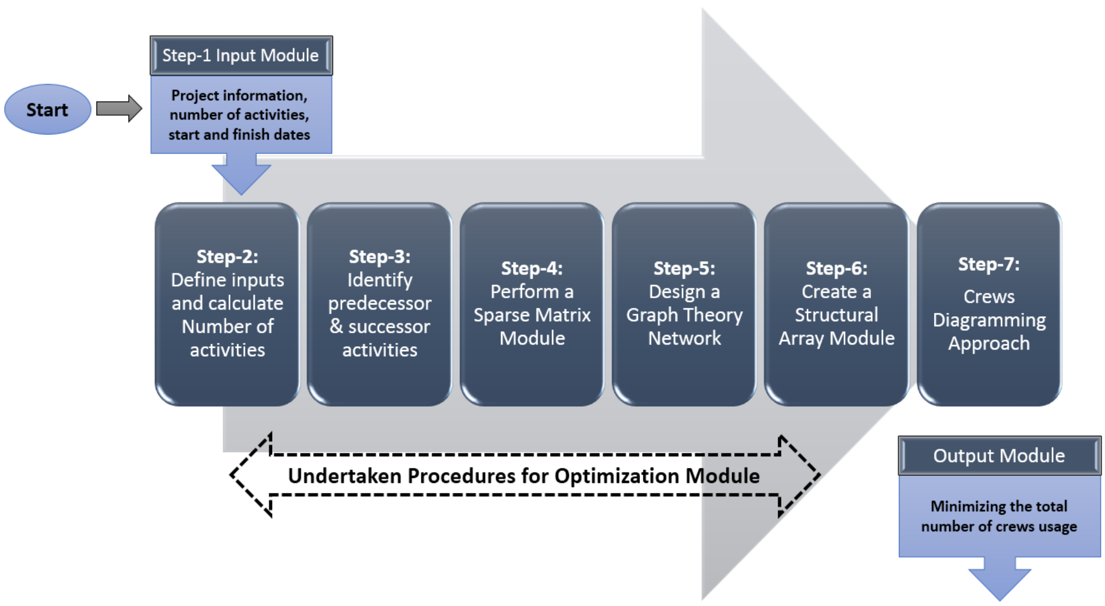


Figure 3.6: Optimization Model Flowchart.

3.4.4.1Proof of Concept

To demonstrate the ability of this model to provide better results and analysis than the traditional LOB, the following example is introduced throughout the model steps to ensure and test the capabilities of this optimization model. Figure 3.7 illustrates the simple example, which is composed of three repetitive activities with different production rate. The three activities i1, i2 and i3 require number of crews equal to 5, 3, 2 respectively to meet the desired completion date. The total crews' number using traditional LOB is ten, needed to complete the five units in the specified date.

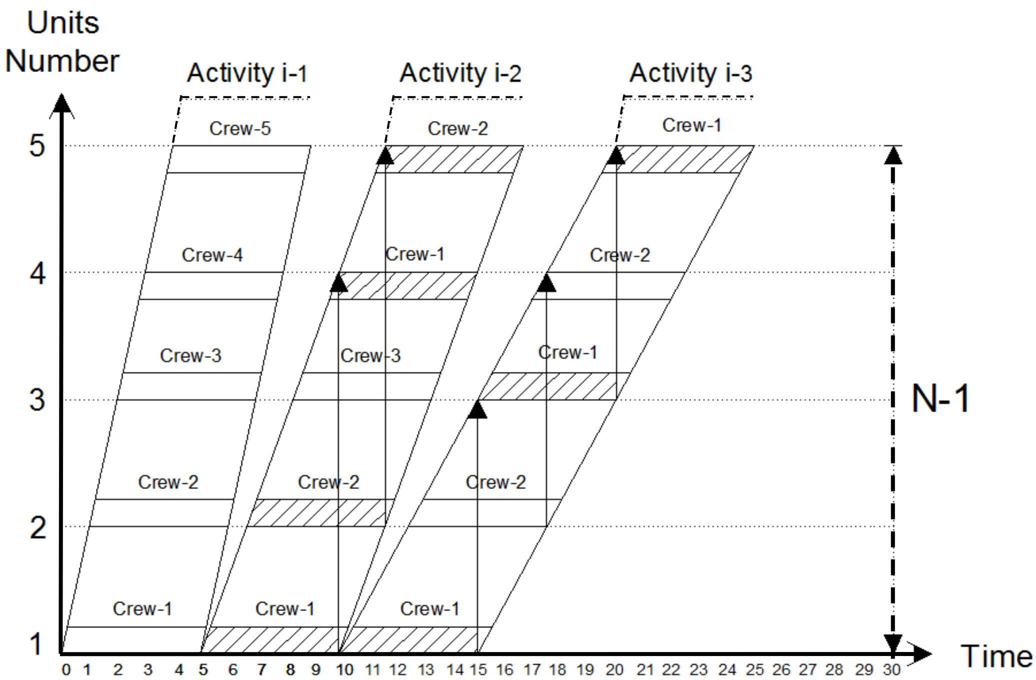


Figure 3.7: Case Study to show model efficiency

3.4.5. Optimization Model Framework

Step-1: Input module

This module is used by the scheduler for inputting data related to the project. Figure 3.8 shows the gathering data required for the input module

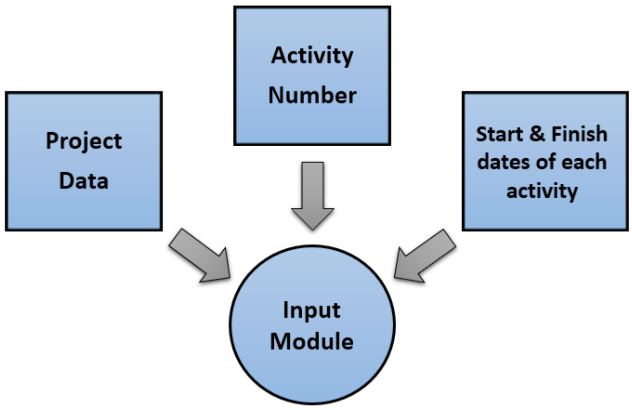


Figure 3.8: Data grouping for the input module

- **Project related information.** Information related to the project such as the project name, project code, number of repeated units, start and completion date of the project.
- **Activities.** Descriptions of activities and their codes.
- **Activity Start and finish dates.** The start and finish date of each activity should be specified to identify relationship between activities.

The first step in model formulation is calculating the total number of activities (N_T) of each repetitive activity, where (N_T) is equal to the number of repetitive sub-activities (Ns) multiplied by number of repetitive unit (N).

Step -2: The second step is defining the initial inputs of the model that are activities start date, finish date and activities numbers as shown in figure 3.9 , where the first activity (start node) is defined as X_1 followed by X_2, X_3, X_4…Till the final activity that is expressed as $X_{(NT-1)}$. Each activity is represented by two variables, variable one is the start point (event) and the second variable is the finish point.

Segment 1………………… X_1.

Segment 2………………… X_2.

Segment final……………....$X_{\text{-final}}$.

Application of step 1&2 on MATLAB.

1- The total number of activities = number of units (5) multiplied by number of sub-sub-activities per unit (3), which is equal to 15.

❖ Functions used in MATLAB to calculate number of activities.

Numactivity=A (size (A, 1), 3).

- Where A is the input values (start date, finish date and number of activities).
- 1 implies the start dates of activities
- 3 represents the number of activities

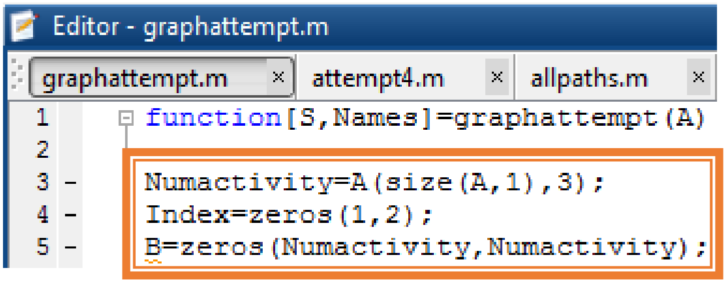
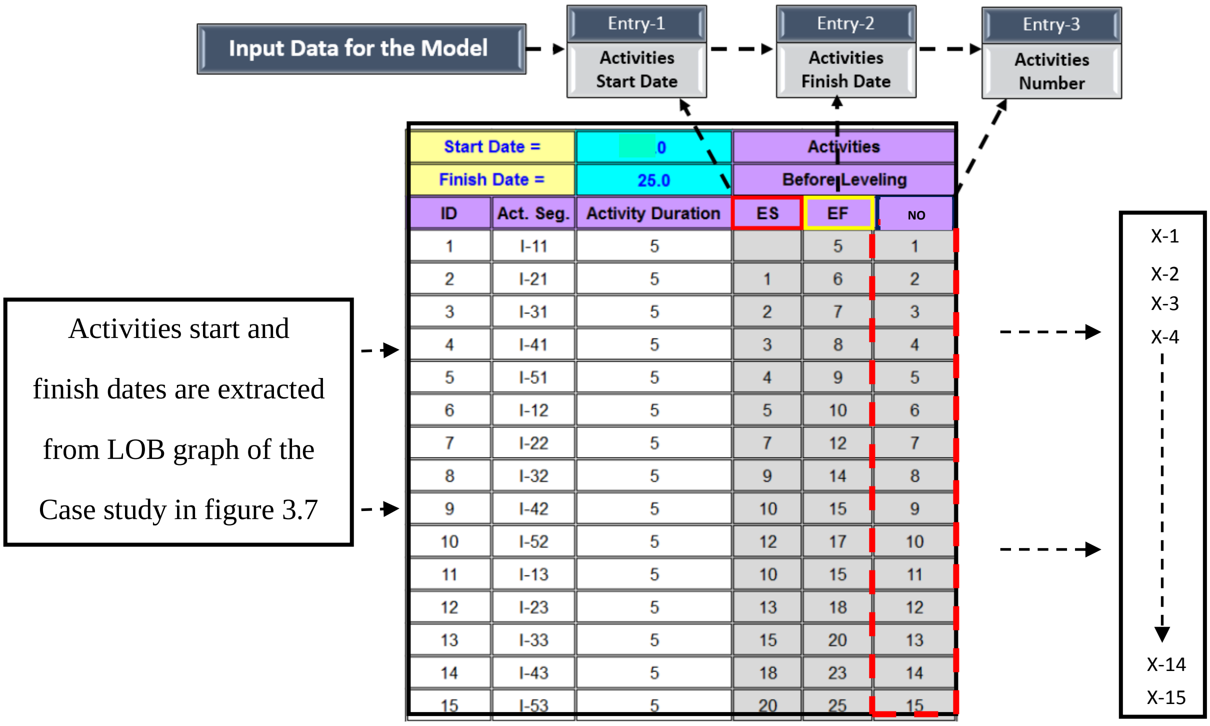


Figure 3.9: A Snap shot for the function used in MATLAB for step 1&2.

2- Defining the initial inputs.

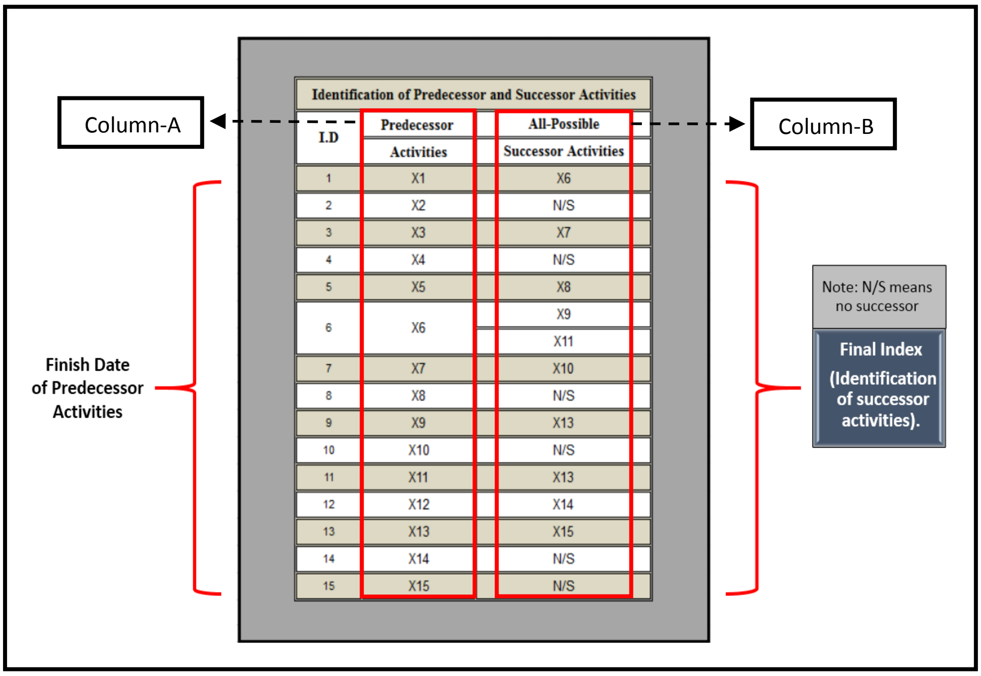


Start Date =		0	Activities		
Finish Date =		25.0	Before Leveling		
ID	Act. Seg.	Activity Duration	ES	EF	NO
1	I-11	5		5	1
2	I-21	5	1	6	2
3	I-31	5	2	7	3
4	I-41	5	3	8	4
5	I-51	5	4	9	5
6	I-12	5	5	10	6
7	I-22	5	7	12	7
8	I-32	5	9	14	8
9	I-42	5	10	15	9
10	I-52	5	12	17	10
11	I-13	5	10	15	11
12	I-23	5	13	18	12
13	I-33	5	15	20	13
14	I-43	5	18	23	14
15	I-53	5	20	25	15

Figure 3.10: Defining Input Data of the Model.

After inserting all of the abovementioned parameters shown in figure 3.10, these inputs are used in step 3 to determine predecessor and successor activities.

Step -3: The third step is identifying the successor and predecessor activities depending on the input variables. Moreover, a table is tabulated that include two columns, the left hand side column (A) that contain the initial segment (X_1), while on the right hand side column (B) the successor activities of the initial one is specified. The finish date of each activity of array A is compared for equality with the corresponding start date of activities of array B. If A and B are equal then activity in column B is successor to that on columns A, but if A and B are not equal then activity in column B is not successor to that in column A. Afterwards the previous steps are iterated until all successor activities are identified. Eventually, a final index will be displayed showing successor activities as show in figure 3.11.



I.D	Predecessor Activities	All-Possible Successor Activities
1	X1	X6
2	X2	N/S
3	X3	X7
4	X4	N/S
5	X5	X8
6	X6	X9
		X11
7	X7	X10
8	X8	N/S
9	X9	X13
10	X10	N/S
11	X11	X13
12	X12	X14
13	X13	X15
14	X14	N/S
15	X15	N/S

Figure 3.11: Identification of successor activities.

Application of step 3 on MATLAB.

❖ Functions used in MATLAB for the illustrative example are shown in Figure 3.12.

- i=1: size (A, 1)-1
- Indexr=find((A(:,1)==A(i,2))| A(:,1)==A(i,2));
- Index1 (:, 2) =A (Indexr,3);
- Index1 (:, 1)=A(i,3);
- Index= [Index; Index1];

- Where A is the input values (start date, finish date and number of activities).
- 1 implies the start dates of activities
- 2 represents finish dates
- 3 represents the number of activities

```
for i=1:size(A,1)-1
     Indexr=find((A(:,1)==A(i,2))| A(:,1)==A(i,2));
    Index1(:,2)=A(Indexr,3);
    Index1(:,1)=A(i,3);
    Index=[Index;Index1];
    clear Index1
end
```

Figure 3.12: A Snap shot for the function used in MATLAB for step 3.

Step 4-Perform Sparse Matrix Module:

This module is accountable for performing a (NT-by-NT) matrix composed of zero and one entries (number of columns = number of rows = number of activity segments), this module uses the data generated from previous step to perform the adjacent matrix. This matrix is achieved by observing the predecessor and successor activities presented in step three. If there is a relation between an activity and another one, then the intersected entry between the row and column will be 1 (non-zero entry). On the other hand, if there is no relation between an activity and another one, then the intersected entry will be zero (zero entry) as shown in figure 3.13.

$(X_1, X_4) \xrightarrow{\text{With a relationship}}$ A one entry will be acquired

$(X_2, X_3) \xrightarrow{\text{Without a relationship}}$ A zero entry will be acquired

Application of step 4 on MATLAB.

❖ Functions used in MATLAB for the illustrative example are shown in Figure 3.13.

The sparse matrix function is generated using MATLAB, in which S = sparse (A) converts a full matrix to sparse form by squeezing out any zero elements. A sparse matrix was created from a list of nonzero elements using the sparse function with five arguments.

S = sparse (i, j, s, m, n)………………………………… Input arguments.

- **i** the row indices of the nonzero elements;
- **j** the column indices of the nonzero elements;
- **s** the values of the nonzero elements;
- **m** the number of rows in the matrix;
- **n** the number of columns in the matrix;
- **nz_max** the maximum number of nonzero elements in the matrix;
- **nz_max** is omitted, in which case its value is taken from the length of **s**.

Sparse Matrix Functions in MATLAB

S=sparse(Index(:,1),Index(:,2),ones,Numactivity,Numactivity);

- Where Sparse: Create a sparse matrix or convert full matrix to sparse matrix.
- Index (:,1): The column that includes all number of activities.
- Index (:, 2): The column that includes predecessor and successor activities.
- Numactivity : Implies the total number of activities (NT)

To generate a Sparse Matrix, the following function is used

[S, Names]=graphattempt (A);

- Where S=sparse(Index(:,1),Index(:,2),ones,Numactivity,Numactivity);
- Names: Means the activities names (X1, X2, X3, X4,………..).
- Graph attempt: The Name of the file incorporating the code
- A is the initial inputs (start date, finish date and number of activities).

```
for ii=1:Numactivity
    %Names1=genvarname(num2str(A(ii,3)));
    Names1=genvarname(num2str(ii));
    Names=[Names;Names1];
end

Names(1,:)=[];
Names=cellstr(Names);

S=sparse(Index(:,1),Index(:,2),ones,Numactivity,Numactivity);
% for ii=1:max(Index(:,2))
%     Initial=find(Index(:,1)==ii);
%     for iii=1:Initial
%     end
%     Path(:,ii)=ii;
%     Path=[Path;Index(ii,2)];
% end
```

Figure 3.13: A Snap shot for the function used in MATLAB for step 4.

Figure 3.14 demonstrates the results of implementing the sparse matrix as a result of sets of data obtained in step three. This figure points out data extracted from Matlab, in which the sparse matrix is developed.

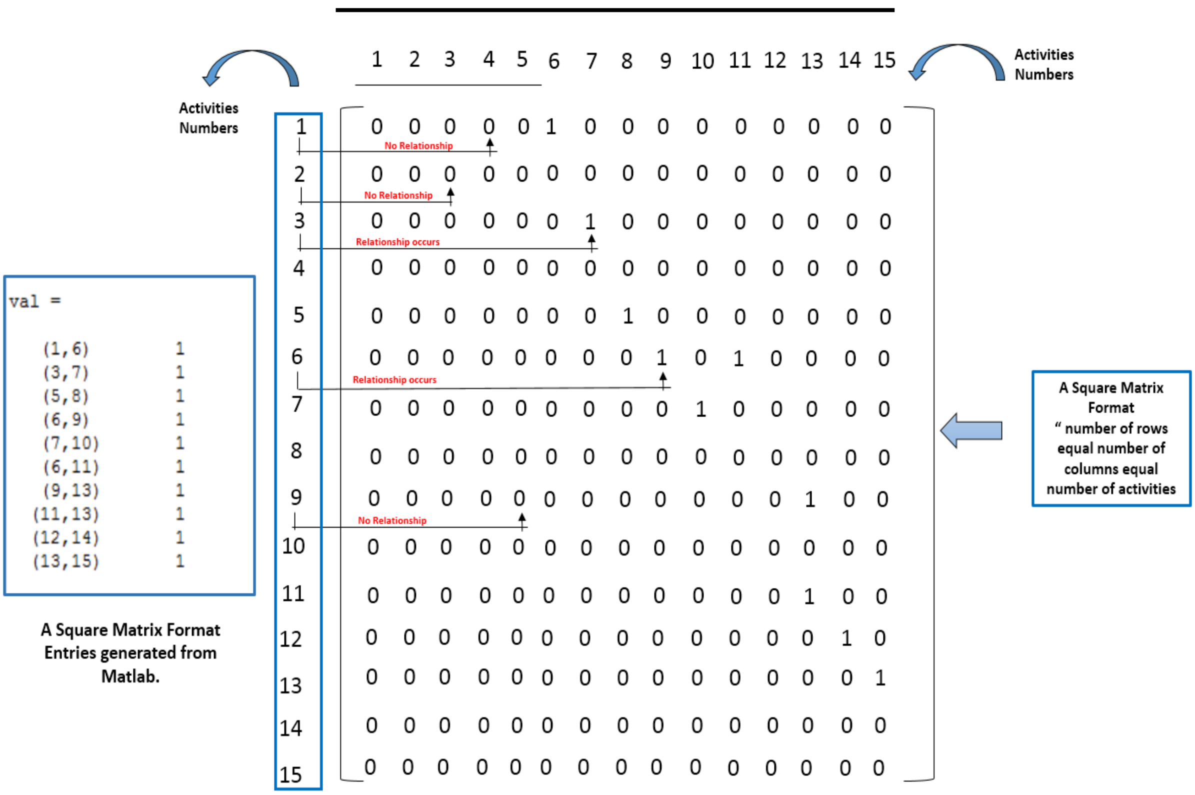


Figure 3.14: A Sparse Matrix Formulation Diagram.

Step 5-Graph Theory Module:

Graph theory is a mathematical way of representing connections or relationships between activities. Graph theory pairwise relations between objects using vertices and edges. The abovementioned sparse matrix is responsible for establishing a graph theory network (GTN) by identifying number of activities that are represented as nodes (vertices) and number of lines that are called edges, which connect the nodes according to assigned relationships between activities as mentioned earlier in step three and four. The main objective of the graph theory network is classifying and catering out the possible and total number of paths of each crew throughout the entire network. The arrangement and allocation of the nodes is defined according to the relationships among activities as shown in figure 3.16.

Application of step 5 on MATLAB.

❖ Functions used in MATLAB for the illustrative example are shown in Figure 3.15.

The graph theory functions work on sparse matrices. The only restriction is that the matrix should be square. In graph theory there are two variables: 1) S, a sparse matrix, and 2) Names, a list of the names of the nodes (activities) of the graph.

Visualizing the Graph

The first function used in visualizing the graph is the biograph object, which is a way of indicating the number of nodes and edges

1- gObj = biograph(S,Names)

- Where S is the Sparse Matrix
- Names: List of activities

The result generated from function 1 is Biograph object with 15 nodes and 10 edges (In which nodes are number of activities and edges are the number of arrows representing relationships between activities).

The second function is the view method, which lays outs the graph and displays it in a figure or network format.

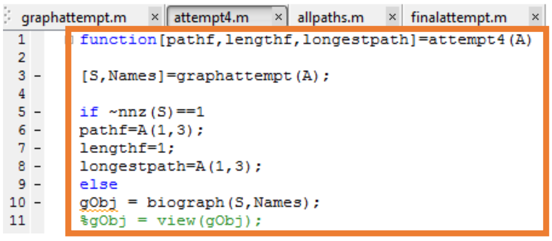


Figure 3.15: A Snap shot for the function used in MATLAB for step 5.

Figure 3.16 shows the graph theory network rendered from Matlab, which is generated by identifying number of Nodes (activities) and number of Arrows (relationship between activities).

2- gObj = view(gObj);

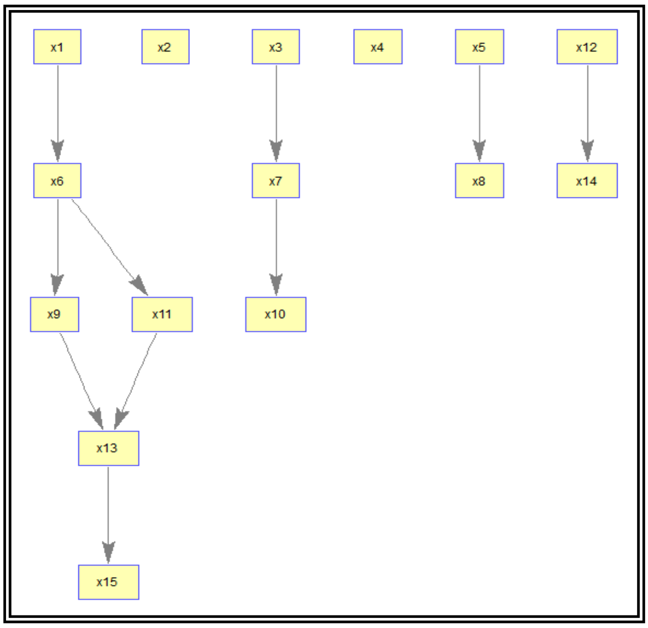


Figure 3.16: Graph Theory Network Diagram

Step 6- Structural Array Module:

This step is proceeded through an integration between the sparse matrix conducted from step four and the graph theory network genertaed from step five to develop a structure array module that include and list out all the possible paths for each crew routing. The procedures of this step is as follows:

Application of step 6 on MATLAB.

❖ Functions used in MATLAB for the illustrative example.

1) This step begins with the crew path containing just the start node (X_1).

MATLAB code for this step: lastpath = [startnode];

2) A matrix is created with a row for each possible path, in which each crew path is accompanied by a cost equal to the number of activities included in this path.

MATLAB code for this step: nextmove = wt (lastpath (:, i - 1), :) ~= 0;

3) The first crew is assigned to the path (crossed nodes) with the highest cost, which is the longest path in the graph theory network.

4) Zero out the crossed nodes already visited by the first crew from the list of paths.

MATLAB code for this step: d = diag(1:size (lastpath,1));

```
nrows = d * ones(size(lastpath));
inds = sub2ind(size (nextmove), reshape(nrows,[],1), reshape (lastpath,[],1));
nextmove(inds) = false;
```

5) The second crew cross out the nodes (activities) with the highest cost, the crossed node is eliminated from the list of available paths

MATLAB code for this step: nextmoverow = d * nextmove;

```
nextmovecol = nextmove * diag(1:N);
rowlist = reshape(nonzeros(nextmoverow),[],1);
collist = reshape(nonzeros(nextmovecol),[],1);
nextpath = [lastpath(rowlist,:), collist];
inds = sub2ind([N,N],nextpath(:, i-1),nextpath(:,i));
costs = costs(rowlist) + wt(inds);
reachedend = nextpath(:,i) == endnode;
paths = [paths; {nextpath(reachedend, :)},{costs(reachedend)}];
lastpath = nextpath(~reachedend, :);
costs = costs(~reachedend);
```

6) The previous step is iterated until there are no more available moves.

Figure 3.17 illustrates the steps undertaken to assign crews for the available activities and to minimize their usage by changing their routing while maintaining work continuity. This figure shows the procedures of structural array module achieved to reach the objective function of this model.

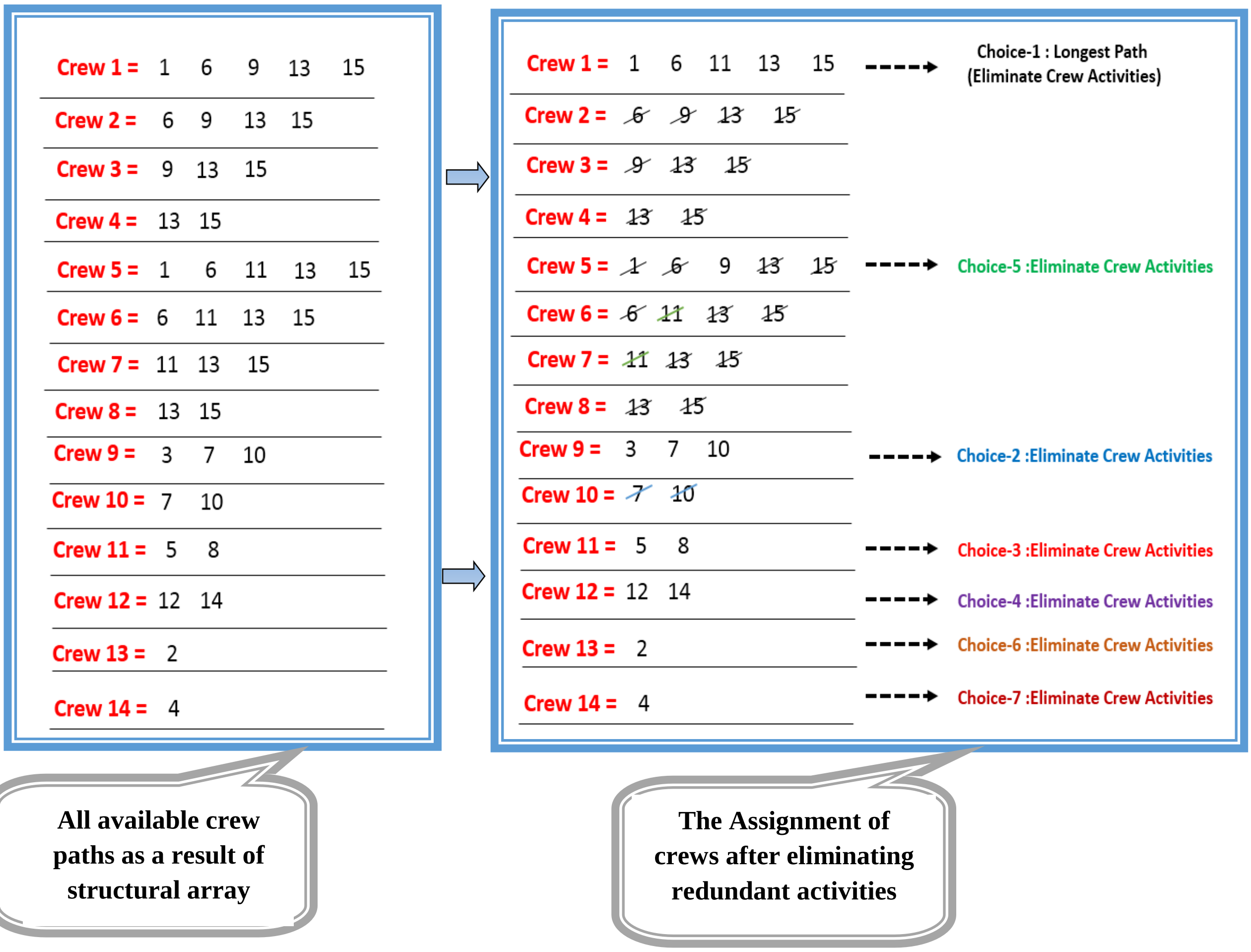


Figure 3.17: Structural Array Module

Step-7: Crew Diagramming Approach (CDA).

In case of multi repetitive construction projects more than one crew is used to execute the repetitive activities of a construction project. The above-mentioned proposed model assign crews to different activities, where these activities may exists in different units and in different sub activities. Hence, a new representational system for different crews circulation need to be performed that focuses on a good acknowledgment of the relationships between various activities in different unit that acquires the same crew while maintaining the crew work continuity. This system is called Crew Diagraming Approach (CDA), which enhance planning of crews' circulation and avoid the problems associated with the confusion that occurs due to increasing number of crew paths from one unit to others. Besides, it is considered a networking technique that offers the simplest possible scheme to enable the visual display of planning and circulation of different crew among different units. Moreover, this method allows project managers, superintendents, key subcontractors and other stakeholders to have a hands-on, planning tool that utilizes a variety of simple logic ties to convey crew circulation and relationships.

3.4.6. Description of Crew Diagramming Approach.

The crews diagram approach is composed of a time scale on the horizontal direction, and number of units required on the vertical direction. CDA denotes activities as a bar between two nodes, which are start and finish nodes, and these two nodes are connected to each other by a bar that resemble duration of the activity. The embedded nodes connect dependent activities and permits only finish to start relationship to ensure the maintaining of crew work continuity. This bar is highlighted by a segment code which includes the activity and unit number as shown in figure 3.18.

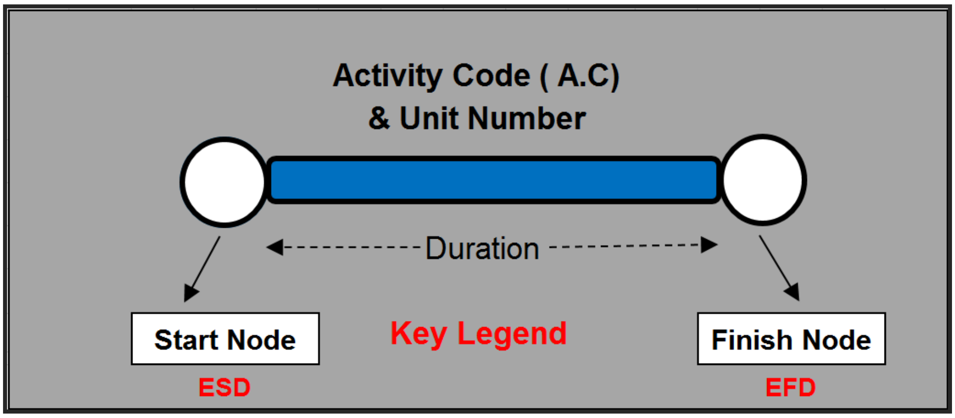


Figure 3.18: Simple representation of an activity in CDA

Figure 3.19 shows a series of arrows that are used to follow the passage of the crews from one unit to the other in an upward and downwards direction. Each crew is highlighted by a color to distinguish between crews and to assist on the mapping out crew's circulation from one unit to the other one. The CDA contain a legend with the different crew names and various crews' colors.

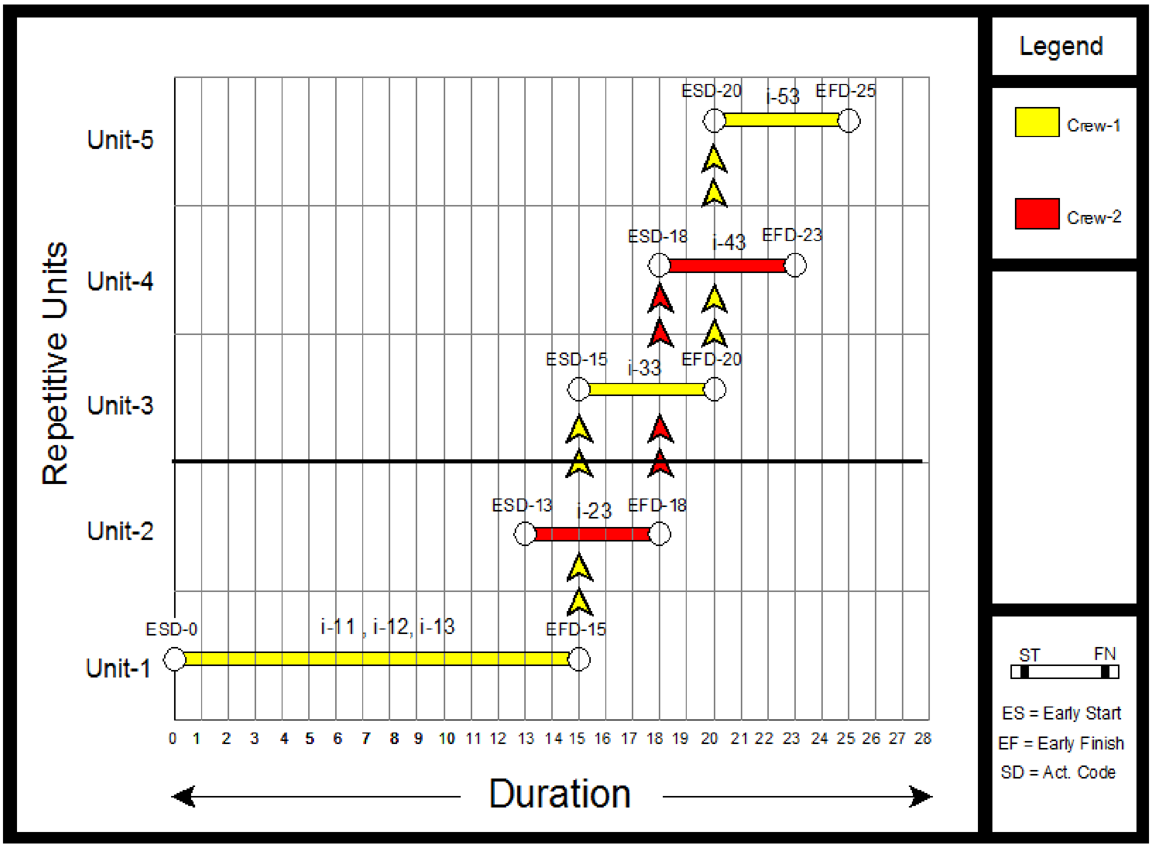


Figure 3.19: Crew Diagramming Approach

3.4.7.Optimization tool

MATLAB R2013a is the optimization tool used, which is considered a high-level language and interactive environment for numerical computation, visualization, and optimization. In MATLAB, the user can analyze data, develop algorithms, and create models and applications. In this model, codes and mathematical function for optimization were built-in to enable exploring multiple approaches and reaching a solution faster and more precise than that generated using spreadsheets or traditional programming languages. Functions used in MATLAB are written as follows:

Function [B] = C (A), where C is the name of the function that accepts inputs A and returns outputs B. This declaration statement must be the first executable line of the function.

3.4.8.Model Development

The model is composed of four different files, each is accountable for performing a mathematical function, in which the function's output is utilized by the successor file. Each function code is saved in a text file with a .m extension. The name of the file should match the name of the first function in the file. Valid function names begins with an alphabetic character. The model files is as follows:

1- **Graph attempt.m (Figure 3.20):** Responsible for pinpointing number of activities, predecessor and successor of each activity to execute the sparse matrix.

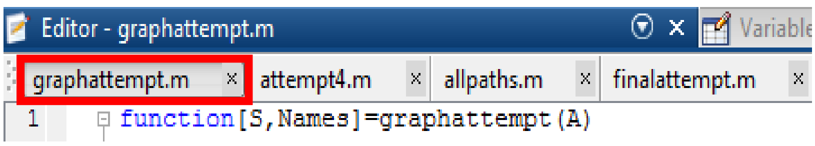


Figure 3.20: A Snap shot for the function used in MATLAB to figure out number of activities.

- ❖ **Function used:** function[S, Names] =graphattempt (A).
    - Where S refers to the sparse matrix.
    - Name refers to the activities names (X1, X2, X3,………).
    - A represents the input data (start date, finish date and activity number).

2- **Attempt 4.m (Figure 3.21):** Accountable for plotting the graph theory network based on data picked out from the previous file (sparse matrix). Besides in this file a structural array is performed relying on the extracted information from the graph theory network, in which all possible crews paths and longest crew path are identified.

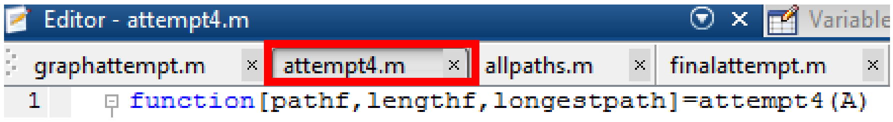


Figure 3.21: A Snap shot for the function used in MATLAB to plot the graph theory.

❖ **Function used:** function [pathf, lengthf,longestpath]=attempt4(A)

- Where path f stands for all possible paths for crews.
- Length f refers to length of each path to determine the longest crew path.
- Longest path is the longest crew path as a result of structural array
- A represents the input data (start date, finish date and activity number).

3- All paths.m (Figure 3.22): Responsible for generating a decision making criteria for assigning the crews for different paths by computing cost of each path and zero out the redundant activities in each crew path.

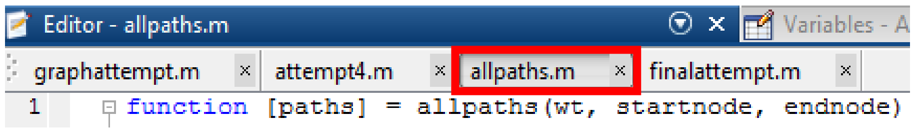


Figure 3.22: A Snap shot for the function used in MATLAB to formulate a decision making criteria.

❖ **Function used:** function [paths] = allpaths (wt, startnode, endnode).

- Where all path stands for all possible paths for crews.
- Wt refers to weight or cost of the path.
- Start node represents is first activity in each path
- End node represents is final activity in each path.

4- Final attempt.m (Figure 3.23): Accountable for generating the output by assigning crews and determining the routing of each crew.

❖ **Function used:** function [crew] = Final attempt4(A)

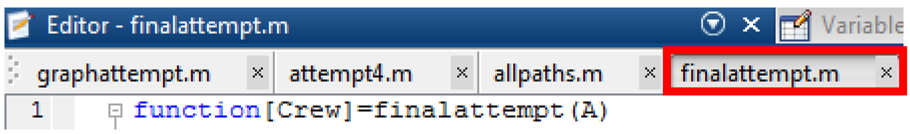


Figure 3.23: A Snap shot for the function used in MATLAB to Conduct Output data.

3.5 The proposed Simulation Model for resource leveling using Entropy Maximization.

3.5.1. Introduction.

To meet the physical limitation of construction resources, to avoid day-to-day fluctuation in resource demands, and to maintain the flow of implementation for construction resources, resource leveling is needed in the construction industry. This section deliberates the employment of different strategies for resource allocation and assignment per activity per period through simulation to single out an optimum solution for resource constraint problems. Moreover, this method guarantees the satisfaction in respecting the logic relationships, resource continuity and resource availability

3.5.2. Overview of the Simulation Model.

Simulation modeling using entropy maximization for leveling linear repetitive construction projects has not been applied either in LOB scheduling or any other linear scheduling technique. As discussed previously, there are two main properties of entropy that are associated with subadditivity and maximality. Subadditivity concept is a property which means that the function's value for the sum of two elements is less than or equal to the sum of the function's values for each element. On the other hand, the concept of maximality implies that the entropy function takes the greatest value when all results have equal probabilities. With respect to the concept of entropy, a higher percentage of a resource-based entropy optimization should achieve a well-executed project in term of resource utilization. The dilemma of resource leveling in LOB technique can be translated to an entropy maximization problem, where the number of resource needed by an activity per period should be diverted to increase its entropy while taking into account the total resource availability of an activity. This section tackles employing a simulation model templates using entropy maximization to level linear construction projects in compliance with discrete-event simulation. To level linear repetitive projects successfully using entropy maximization through simulation modeling, the following parameters must be employed when establishing the simulation model.

3.5.3. Main attributes and parameter associated with the proposed model

Table 3-2: Major attributes of the Simulation model.

Attribute	Description
Objective Function	▪ Minimizing the daily resource usage ▪ Smoothing the fluctuation in resource utilization profile
Variables	▪ Start and Finish dates of activities. ▪ Activities duration. ▪ Daily resource assignment. ▪ Resource usage per period. ▪ Value of daily resource entropy.
Constraints	▪ Resource continuity constraints. ▪ Resource availability constraints. ▪ Total available number of resource per each activity. ▪ Overall project completion date. ▪ Total float of each activity.

In accordance with the abovementioned attributes of the simulation model, three templates are used. 1) Activity and resource flow template, 2) Bar chart template and 3) Maximum entropy analogy template are designed to systematically level resource in LOB scheduling technique. Activity and resource flow template is designed for modeling crew's different paths, variability in activity durations, early start, early finish and total float of each activity, resource availability constraints, total available number of resources per each activity, and total project duration constraint.

Additionally, the bar chart template is used for modeling different scenarios for the number of resources used per activity per period, while taking into account the total number of resources per activity, which consequently reflects on the total number of resources per day and on the resource profile. On other hand, maximum entropy analogy template is for showing the best scenarios accompanied with the maximum entropy and the allocation of resources per period for each activity.

To demonstrate the implementation of abovementioned three templates used in the simulation model, an extensive detailed description is introduced showing the usability, flexibility, and extensibility of the three templates as shown in figure 3.24.

3.5.4 Description of Simulation Model formulation

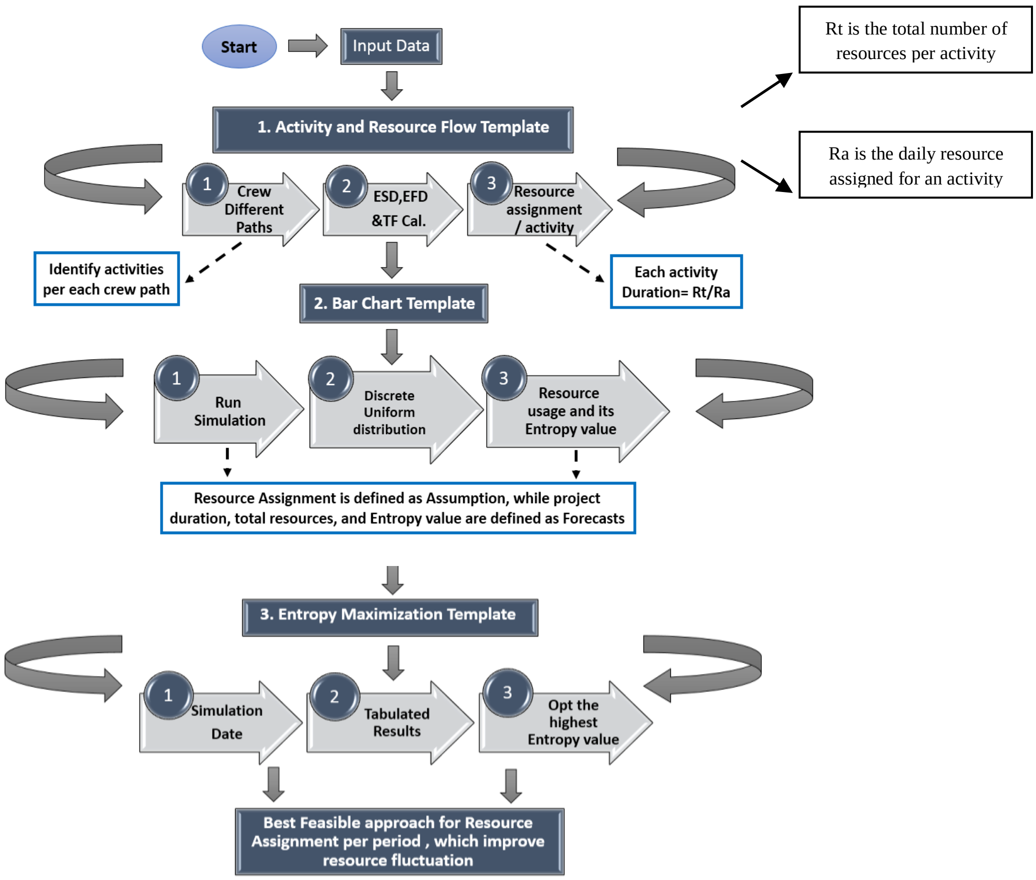


Figure 3.24: A Flowchart for Simulation using Entropy Maximization.

3.5.5. An overview of the proposed simulation Model.

1- Activity and Resource Flow Template

Main functionalities of the activity and resource flow template are shown in figure 3.25.

- Maintaining crew's different paths.
- Identifying early start, early finish and total float of each activity.
- Pinpointing the available number of resources per period for each activity.
- Figuring out the total sum of number of resources per each activity.

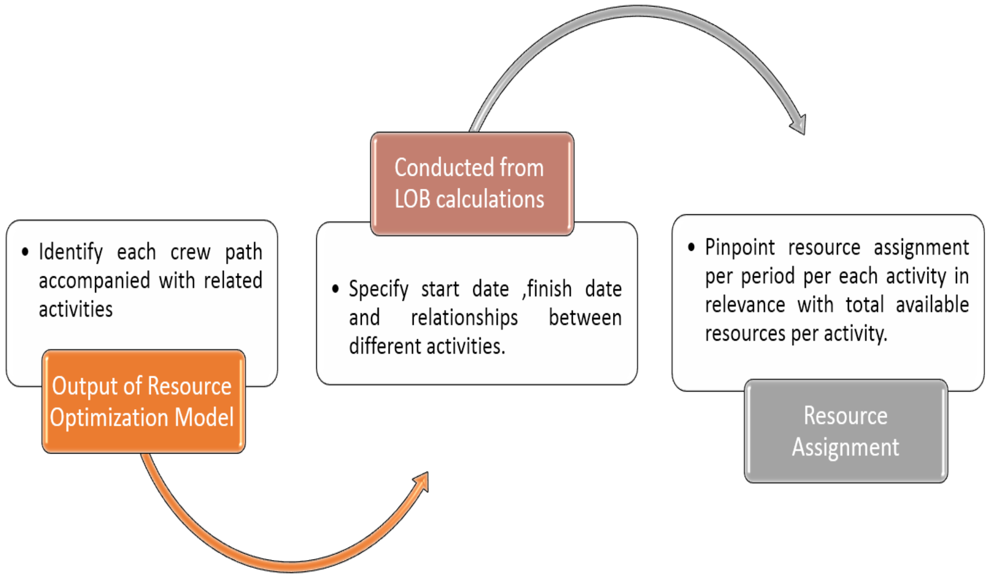


Figure 3.25 the main functionalities of the activity and resource flow template.

Following are the steps to be followed for implementing this template.

1) The first step in implementing the activity and resource template is listing out the different crews or resources paths obtained from LOB, and determining the number of activity per each path.

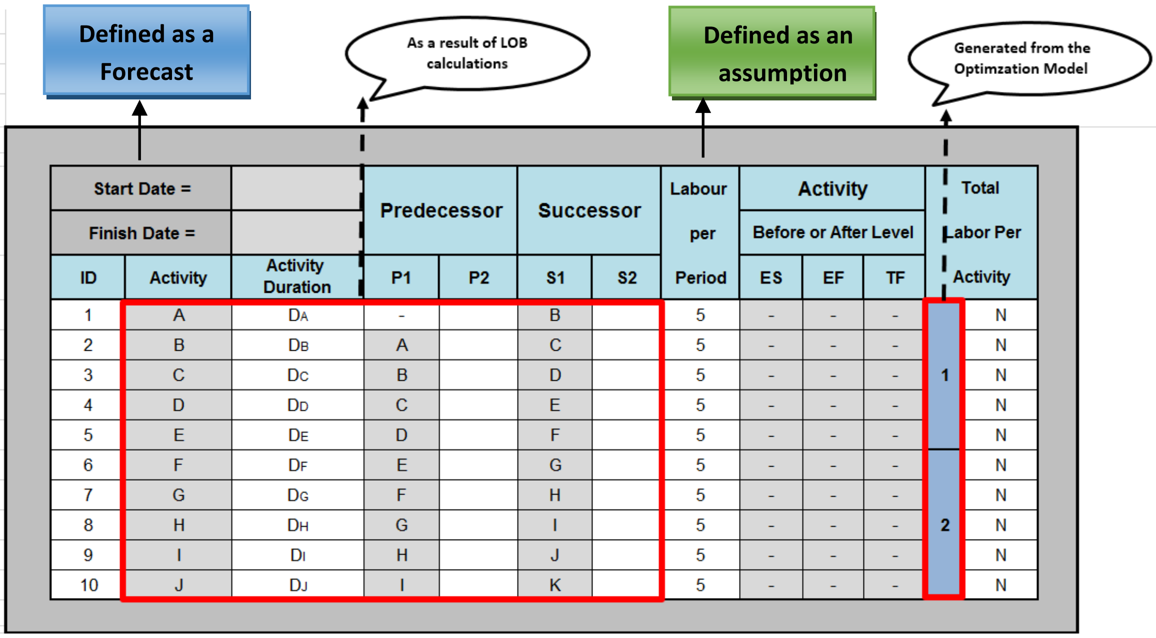
2) The second step is specifying the predecessor and successor of each activity with respecting each crew circulation in order to calculate ES, EF &TFof each activity.

3) The third step is representing the available number of resource per each activity per period (the number which will be adjusted to reach the most appropriate allocation to minimize resource fluctuation). Furthermore, resource assignment

per period is an input variable defined as an assumption using a discrete uniform distribution probability.

4) The final step is calculating the total available number of resource per each activity by multiplying the activity duration by the available number of resources per period for each activity.

Figure 3.26 shows the spreadsheet activity and resource flow template that is composed of six main columns which are activity duration, predecessor, and successor, Resource assignment per period, activities calculations and total resource per activity. This template includes start and finish date of the project.



Start Date =			Predecessor		Successor		Labour per Period	Activity				Total Labor Per Activity
Finish Date =								Before or After Level				
ID	Activity	Activity Duration	P1	P2	S1	S2		ES	EF	TF		
1	A	D_A	-		B		5	-	-	-		N
2	B	D_B	A		C		5	-	-	-		N
3	C	D_C	B		D		5	-	-	-	1	N
4	D	D_D	C		E		5	-	-	-		N
5	E	D_E	D		F		5	-	-	-		N
6	F	D_F	E		G		5	-	-	-		N
7	G	D_G	F		H		5	-	-	-		N
8	H	D_H	G		I		5	-	-	-	2	N
9	I	D_I	H		J		5	-	-	-		N
10	J	D_J	I		K		5	-	-	-		N

Figure 3.26: Activity and Resource Flow Excel Template

2- Bar Chart Template.

Based on the abovementioned data extracted from activity and resource flow template, a total of 500,000 simulation cycles are run on Crystal Ball Ribbon Simulation Software. Resource assignments for each activity per period are defined as an assumption that are randomly selected from discrete uniform distributions, with a minimum and a maximum values to generate resource assignment combinations by means of simulations, subject to a limited resource availability based on activity type that was obtained from expertise and keep records of worker hours, crew sizes, and daily working hours in previously completed projects Several assumption should be taken into consideration to be well performed like:

1) All assigned resource units have the same productivity rate.
2) The total project duration is a constraint
3) There is no restriction in extending the activity duration.
4) The resource assignment per period is an integer value not a fractional one.

The total entropy of the system, the total resources of the activity and project duration are defined as forecasts. The outputs are classified into two parts, which are variable output and constant output. The variable output is the total entropy of the system, while the constant output is the total resources of the activity and the project duration (driven from possible resource assignments combination). Moreover, the resulted simulation is filtered for values with a summation equal to the total number of available resource for the all activities. Besides, the entropy of each resource usage per period is computed to come up with the total project entropy. The resource usage per period entropy can be calculated as follows: H_{Ru} = Ru ln (Ru/Rt), where H_{Ru} is the daily resource entropy, Ru is the resource usage per period, and Rt is the total number of resources.

Whereas the total project entropy can be calculated as follows:

$$H_T = \sum_{i=1}^{n_t}\left[\frac{r_i}{r_T}\ln\left(\frac{1}{r_i/r_T}\right)\right] = -\sum_{i=1}^{n_t}\left[\frac{r_i}{r_T}\ln\left(\frac{r_i}{r_T}\right)\right]$$

In which, *ri*=number of resources assigned to the project on period *i*; *nt*=number of total time-units in the project, and *rT*=total number of resource required to complete the project. The aforementioned entropy framework aims to maximize the project's total entropy, with respect to resource constraints.

Figure 3.27 shows the bar chart template designed for the simulation model. This template uses the data generated from the previous template, in which each activity include number of cells where the resource assignment is diverted and extended or shrunken among all activities. The stretching of activities is constrained with the premise of increasing or decreasing resource assignment (constrained by a limited value based on activity type) per period till the maximum entropy is reached.

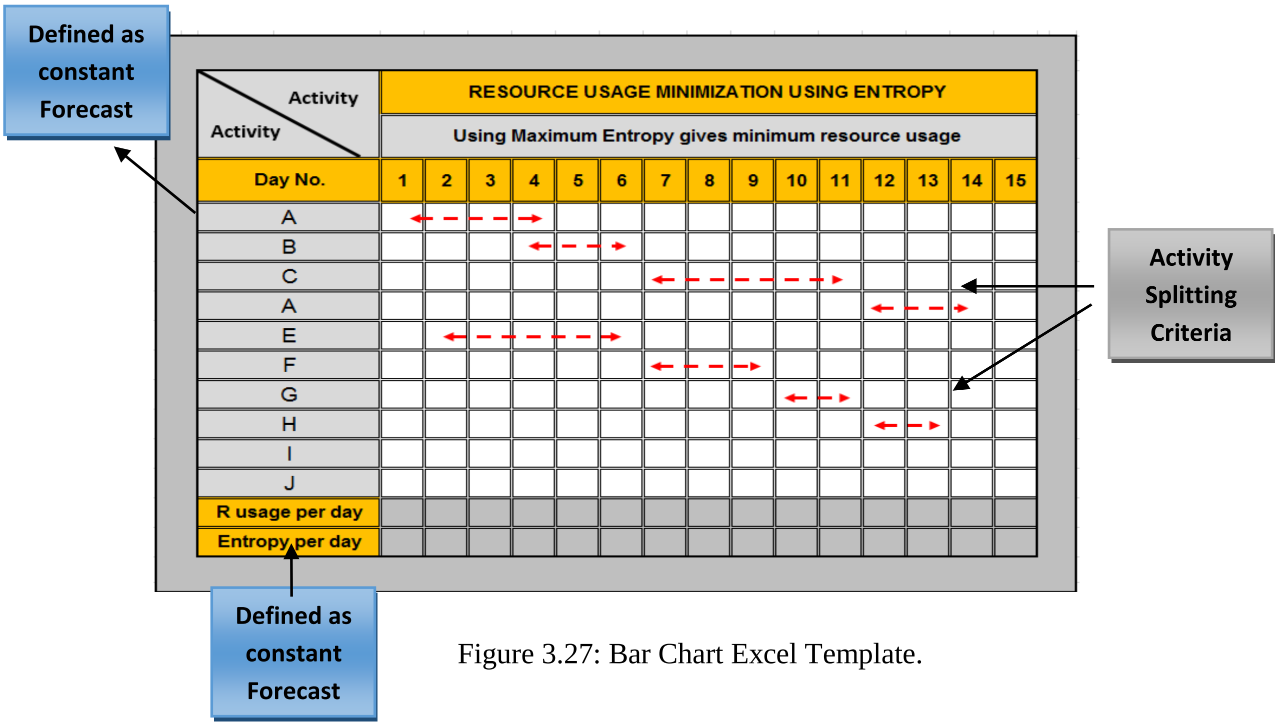


Figure 3.27: Bar Chart Excel Template.

3- Maximum Entropy analogy.

In this step, a template is tabulated that includes all activities, and the best scenarios having the highest entropy value, using simulation the best feasible entropy-based and resource-leveled cane be achieved. Figure 3.28 shows different scenarios and their associated total entropy, project duration and maximum resource assignment. Consequently, the scenario attaining the maximal entropy value and maintaining the total project duration with the least resource usage is opted.

ID	Act. Seg.	Scenario-1	Scenario-2	Scenario-3	Scenario-4	Scenario-5
1	A	3	3	4	3	5
2	B	8	5	7	5	3
3	C	3	5	3	5	3
4	D	4	7	7	5	7
5	E	4	7	3	7	7
6	F	7	5	5	3	7
7	G	10	4	5	7	7
8	H	10	7	10	7	7
9	I	10	7	10	10	7
10	J	10	7	7	7	`10
11	K	4	5	3	3	3
12	L	4	4	5	5	3
13	M	4	4	5	7	7
14	N	4	5	7	3	7
15	O	7	7	7	5	10
Total Entropy		-	-	-	-	-
Duration		-	-	-	-	-
Max Res / Day		-	-	-	-	-

Figure 3.28: Maximum Entropy analogy Template.

3.5.6. Optimization tool

Once having variables, constraints and the objective function ready, the simulation tool is used. There are several simulation applications available, one of these is Crystal Ball ribbon. Crystal Ball ribbon is a program created by oracle and run on several versions of Microsoft excel. Crystal Ball ribbon is a graphical, analytical oriented forecasting and risk analysis program that takes the uncertainty out of decision-making. Crystal ball represents the relationships between input and output variables using functions, formulas, and data, in which it closely matches the behavior of a real project circumstances. Crystal Ball ribbon uses Monte Carlo simulation to overcome limitations encountered with traditional spreadsheet analysis, where the user can describe a range of possible values with Monte Carlo simulation. Moreover, Crystal Ball displays results in a forecast chart that shows the entire range of possible outcomes and the likelihood of achieving each one. In addition, Crystal Ball keeps track of the results of each scenario for the user.

3.5.7. Output module

To substantiate the feasibility of the proposed model, its outputs are represented graphically using LOB graph. This LOB graph is drawn using the data generated from the simulation model (start date, finish date and production rate of each activity). The LOB has an X-axis representing the unit numbers and a Y-axis representing the duration. Due to the applicability of this model, LOB is drawn with different production rates for each activity per each unit (stretching and extending of the repetitive activities along the units' number).

3.5.8. Model Development

A computerized model was implemented using the abovementioned framework of the proposed model, in which a spreadsheet modeling tool (Microsoft Excel) is utilized. The process of the proposed model is composed of three main stages, which are overviewed as follows:

1) Establishing a spreadsheet model that describes an uncertain variables of the daily assignment of resource usage, which is defined as an assumption with a probability distribution (uniform discrete distribution). The simulation process calculates numerous scenarios of the model by repeatedly picking values from the probability distribution for the uncertain variables (resource assignment).

2) Running a simulation based on the input values entered and stored in the assumption cell.

3) Analyzing the results through keep tracking the forecasts of each assumption. For each forecast, crystal ball represents the cell value for all the trials, and after hundreds or thousands of trials, the user can view sets of values, the statistics of

the results (Output values for daily resource assignment), and certainty of each value.

3.6. Summary and Closure of the Chapter.

This chapter has overviewed areas of required improvements in LOB scheduling tool which are: (1) providing a schedule approach for scheduling repetitive projects in case of time and resources; (2) Clearly identifying critical and non-critical activities; (3) Minimizing the number of crews usage to perform a repetitive activity by altering the crews routing and applying multi-task skilled crews; (4) Enhancing the visualization of crews' movement and circulation between repetitive activities, and; (5) Improving the resource leveling in the LOB scheduling technique.

First and foremost, this chapter highlighted the research framework in depth, where it presented the optimization model for minimizing number of crews utilized by changing the criteria of their routings. A small case study has been presented throughout the model in order to demonstrate the feasible approach that can reduce the number of crews assigned without influencing the activity or total project duration.

Moreover, this chapter introduced the methodology of the proposed simulation model and its procedures for resource leveling with activity stretching or crunching using entropy maximization theory, in which all the templates designed to run the model are extensively discussed in details to obtain a near optimum integration of the variable leading to the reliable outputs. In order to show the doable implementation of the proposed models and validate its ability to generate near optimum results, the following chapter shows the model validation by applying a real case study of a pipeline installation project from the literature review.

CHAPTER 4 - VERIFICATION AND VALIDATION

4.1. Introduction

In this chapter, validation and practical implementation of the proposed methodology for scheduling multi repetitive projects in Chapter 3 – Research Framework and methodology is explained. In order to ensure that the proposed models for the new approach is capable of successfully improving the resource constraint problems associated with linear projects, a case study is conducted that demonstrates the effectiveness of proposed models for meeting constraints and for enhancing the efficiency of resource usage. Nevertheless, this chapter represents the model verification process in details and the computational methods which is applied on a real case study obtained from the literature.

4.2. The Developed Strategy for the Proposed Approach.

This chapter shows the implementation of the tremendous efforts done to improve the scheduling of linear projects through LOB; accordingly, the first section in this chapter deals with the assumption that production rates of repetitive activities are linear and constant which is erroneous and unrealistic due to the stochastic nature of construction processes. The second section tackles applying the developed decision support tool (algorithm) that aims for minimizing the number of crews employed to attain a repetitive activity by altering the crews' itinerary. This model applies the usage of multi-task skilled crews to execute a repetitive construction project, and accurately identify the critical path in LOB. Eventually, the final section addresses improving the resource leveling in LOB scheduling technique via a simulation spreadsheet model based on entropy maximization metric, in which parameters of the simulation model (i.e. assumptions, decisions and forecasts) are presented as they are defined within the spreadsheet model. Figure 4.1 shows the flowchart diagram attained to validate the proposed approaches by measuring their feasible application on a real case study from the literature.

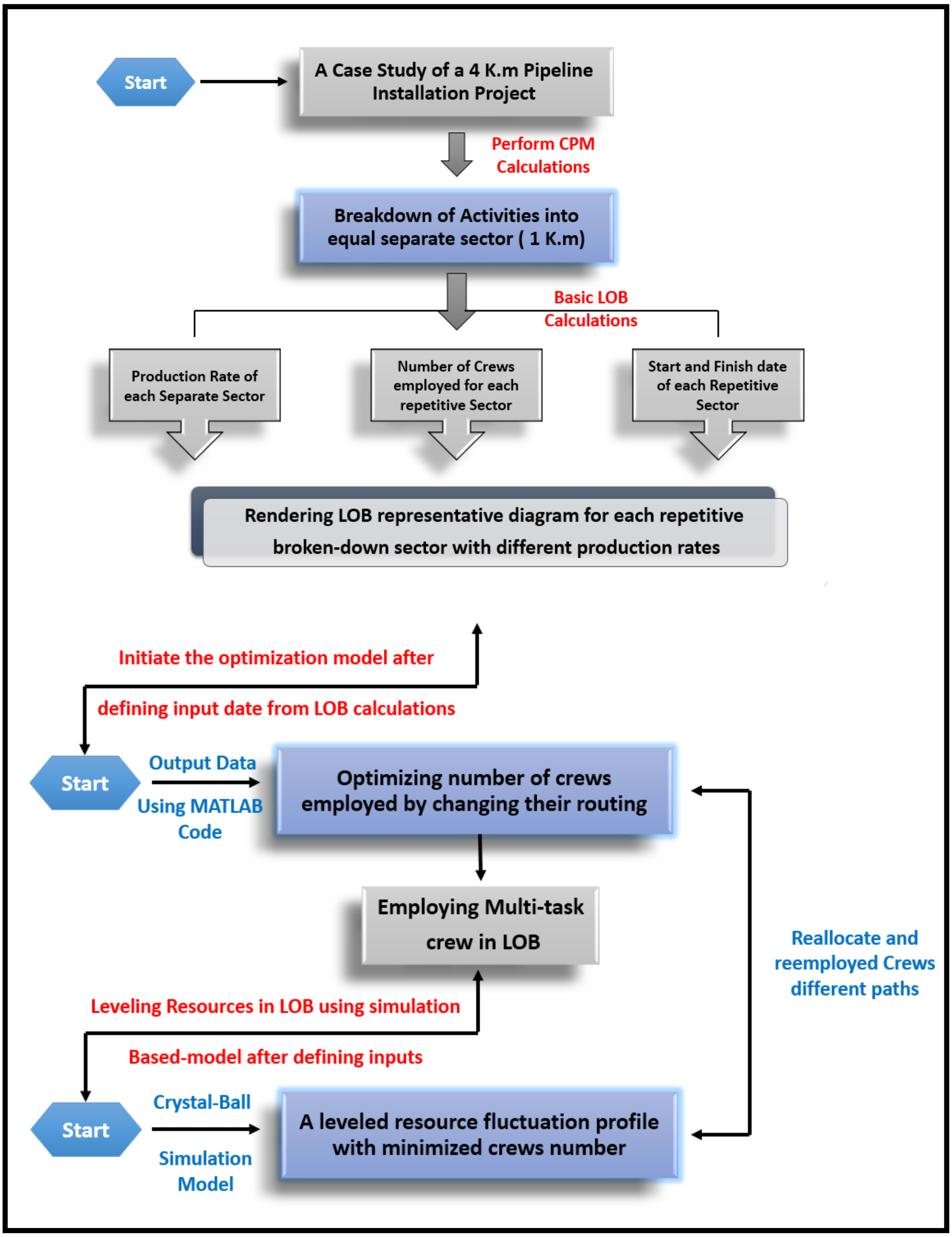


Figure 4.1: Implementation of Proposed Approach based on the case study.

4.3. Description of the Case Study.

In order to demonstrate and to evaluate the feasibility of the proposed framework models, a real case study is undertaken to validate and to test the developed framework. Since the approach developed works best at horizontal infrastructure projects, a 4-Km pipeline installation and control room project is the repetitive case study that consists of 5 repetitive activities. These activities, in their order of precedence are identified, and all precedence relations are finish to start, with no lag time as summarized in table 4-1.The project is divided into 10 parallel relocated repetitive pipelines of equal lengths, each is 4 km length.

Table 4.1- Summary for the activities code, name, description, duration and precedence relations of a single 4-K.m pipeline installation project.

Activity Code	Activity Name	Duration	Predecessor
A	Move in	2	---
B	Survey & Layout	1	A
C	Locate & Clear (4km)	16	B
D	Excavate (4Km)	20	C
E	Prepare Pipes (4 KM)	16	C
F	Lay Pipes (4 KM)	36	E , D
G	Local Test for (4 KM)	4	F
H	Foundation for Control Room	8	B
I	Finishing Control Room	17	H
J	Installing Control Equipment	5	I
K	Testing Control with Pipe Line	4	G , J
L	Clean up	2	K

4.4. Traditional Manner for solving the Case Study.

4.4.1. CPM calculations for a single unit.

A time analysis (CPM) is performed, in which forward pass calculations are conducted to determine early timings of activities, whereas late timings of activities are proceeded in the backward pass calculations. The forward and backward pass calculations result in having critical and non-critical activities. Critical activities are A, B, C, D, F, G, K, and L respectively, while non-critical activities are E, H, I, J respectively. Work breakdown of activities and estimated total project duration of a single 4-Km pipeline are calculated as 86 days according to CPM calculations as shown in figure 4.2. The desired contract date to complete installing 10 identical pipeline is 95 days.

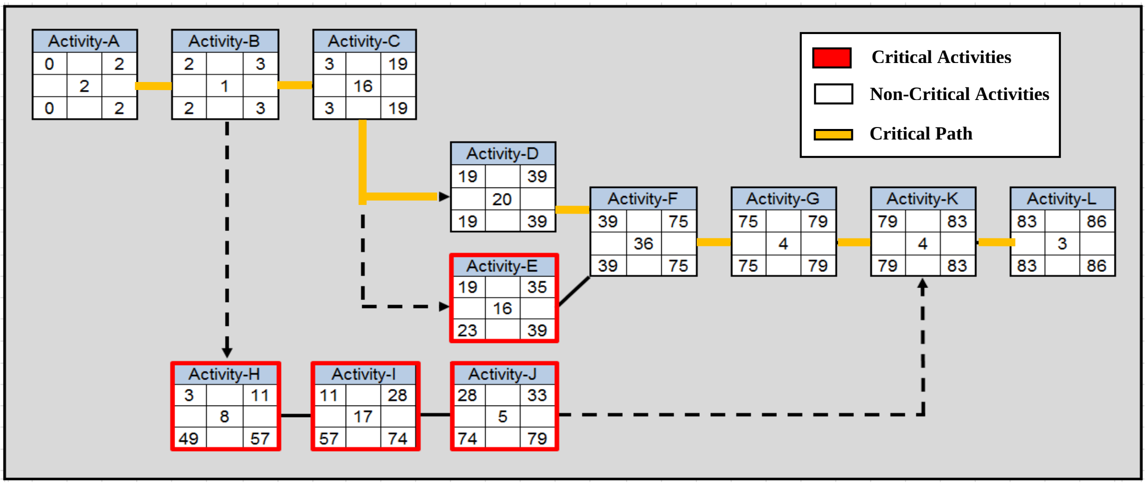


Figure 4.2: Traditional CPM calculations for a single 4-Km Pipeline installation.

4.4.2. Basic LOB Representation using Integrated CPM-LOB Model.

The main objective of LOB formulation is to attain a resource-balanced schedule by identifying the number of crews to be employed in each repetitive activity. The integrated CPM and LOB model developed by Ammar (2012) is utilized to schedule repetitive projects in an easy manner, in which logic dependency and resource continuity constraints are taken into account. Furthermore, overlapping activities of a single typical unit is used to figure out duration and logical dependency relationships among different activities that can be specified according to the selected rate of progress of each activity. To specify such relationships, the actual progress rate of each activity is compared with that of its successors, in which overlapping repetitive activities with start to start relationship is specified when the rate of predecessor activity is faster than that of the successor one. On the other hand, finish to finish relationship is specified when the rate of predecessor activity is slower than that of the successor one. The calculation steps and procedures (LOB calculations, calculating activity duration along all repetitive units, specifying logical relationships using overlapping activities, and CPM time analysis) undertaken to schedule the case study are discussed in details in Appendix-A. Figure 4.3 represents the CPM time analysis achieved as a result of applying the CPM-LOB integrated model.

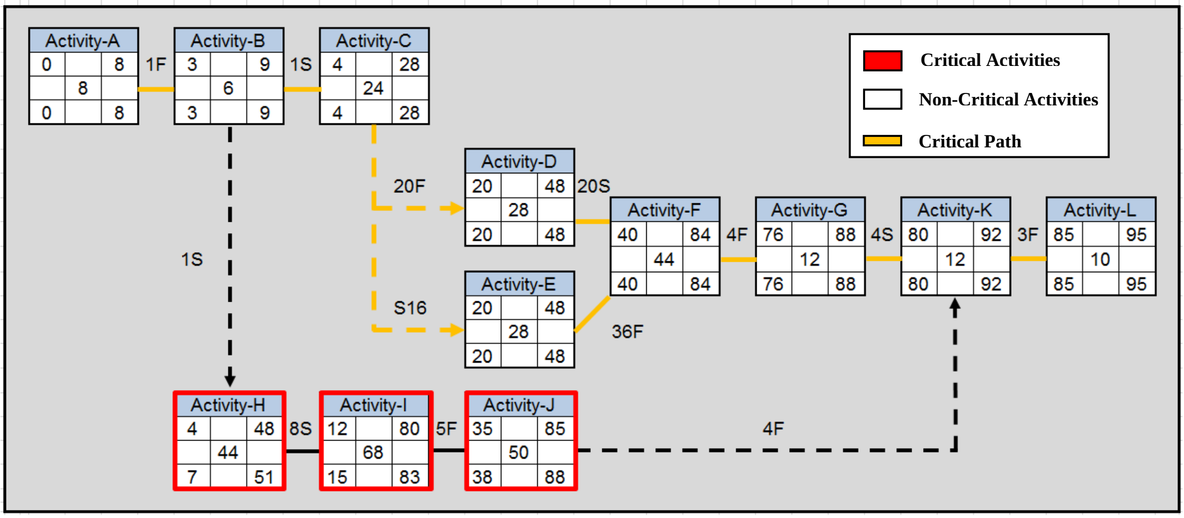


Figure 4.3: Traditional CPM time analysis of the case study.

4.5. The Proposed Approach for Scheduling Repetitive Construction Projects

To better represent practical instances in actual construction projects, the abovementioned activities are being split into equal separate sector (sub -activities), in which each broken-down activity is considered a separate flexible activity with a 1-Km length and a duration equals total activity duration divided by 4. This approach intents the creation of inner relationship between detached activities that produce more practical and realistic schedules.

Figure 4.4 shows the implemented case study after splitting each activity into equal separate sub-activities, where activity "C,D,E & F" is broken-down into four equal separate 1-Km distance (for instance, activity C is sub-divided into C1, C2, C3, & C4). In contemplating the abovementioned network with the one conducted in figure 4.2, it is clearly noticeable the reduction in single unit duration by 30 days. Not only the optimization in duration is the only benefit, but also the activity C, D and G that were regarded as critical activities using traditional method in figure 4.2, includes partly non-critical activities as in figure 4.4. For instance in activity C, C1 is critical activity while C2, C3 and C4 are non-critical activities. Another benefit outcomes from splitting activities is the precise detection of the critical path.

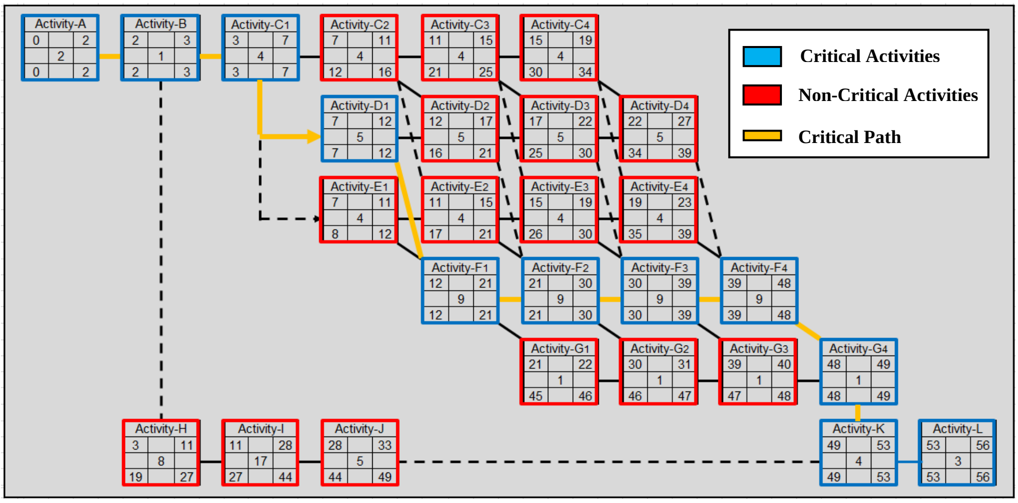


Figure 4.4: CPM network for a single unit after splitting activities

4.5.1 Basic LOB Representation using Integrated CPM-LOB Model.

Appendix-A shows calculation steps and procedures (LOB calculations, calculating activity duration along all repetitive units, specifying logical relationships using overlapping activities, and CPM time analysis) undertaken to schedule the presented case study and to generate CPM time analysis as shown in figure 4.5. Figure 4.5 shows the early and late time after accounting for logical dependency relationships among different activities that are specified according to the rate of progress of each activity. Activities C1, C2, C3 & C4 have different durations because the total float of noncritical activities (C2, C3 & C4) is utilized to reduce the number of crews employed and to relax activity production rate. For instance, C1, C2, C3& C4 originally requires 5 crews, which is reduced into 4, 3 & 2 crews for activities C2, C3 & C4 respectively as summarized in LOB calculation procedures in Appendix-A and shown in figure 4.6. The resulting project duration is 71 days, in which the timing of activities determined in figure 4.5 is graphically plotted on a LOB format with the number of crews required as shown in figure 4.7, 4.8, 4.9, 4.10 and 4.11

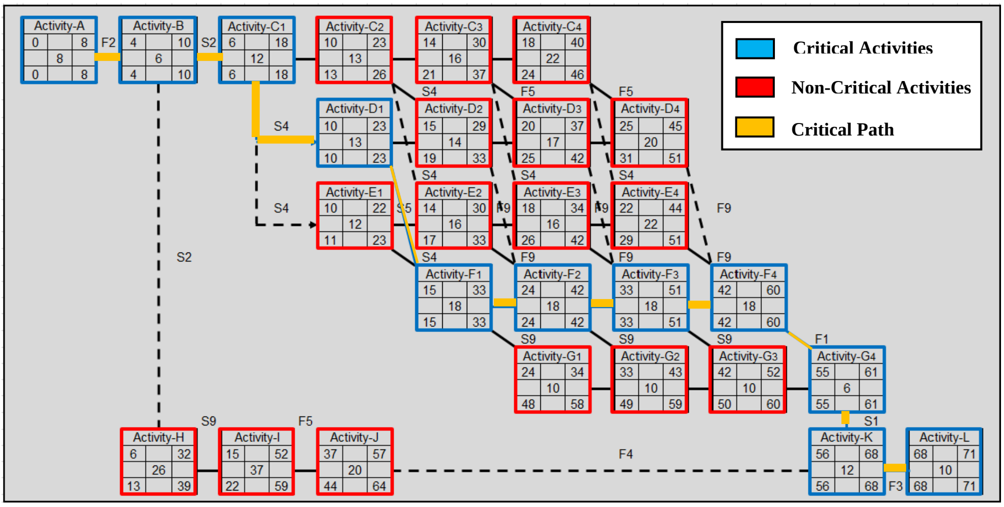


Figure 4.5: CPM time analysis of the hypothetical proposed case study after splitting activities.

Figure 4.6 shows LOB graph of activities C1, C2, C3 and C4 with constant production rates before using total float to relax activity production rate and to reduce crews employed, in which each activity employs 5 crews to be achieved. The crew is assumed to work in a single activity not multiple (linear sequential route).

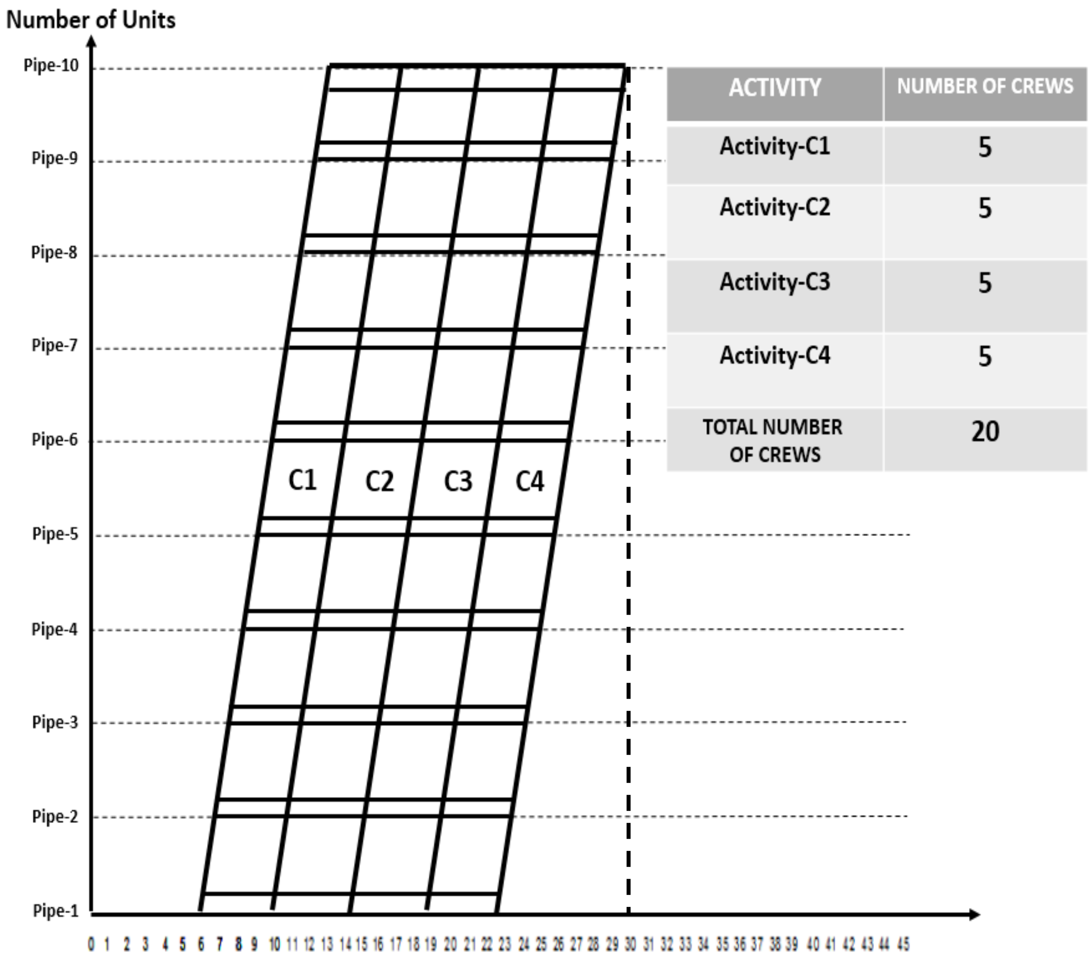
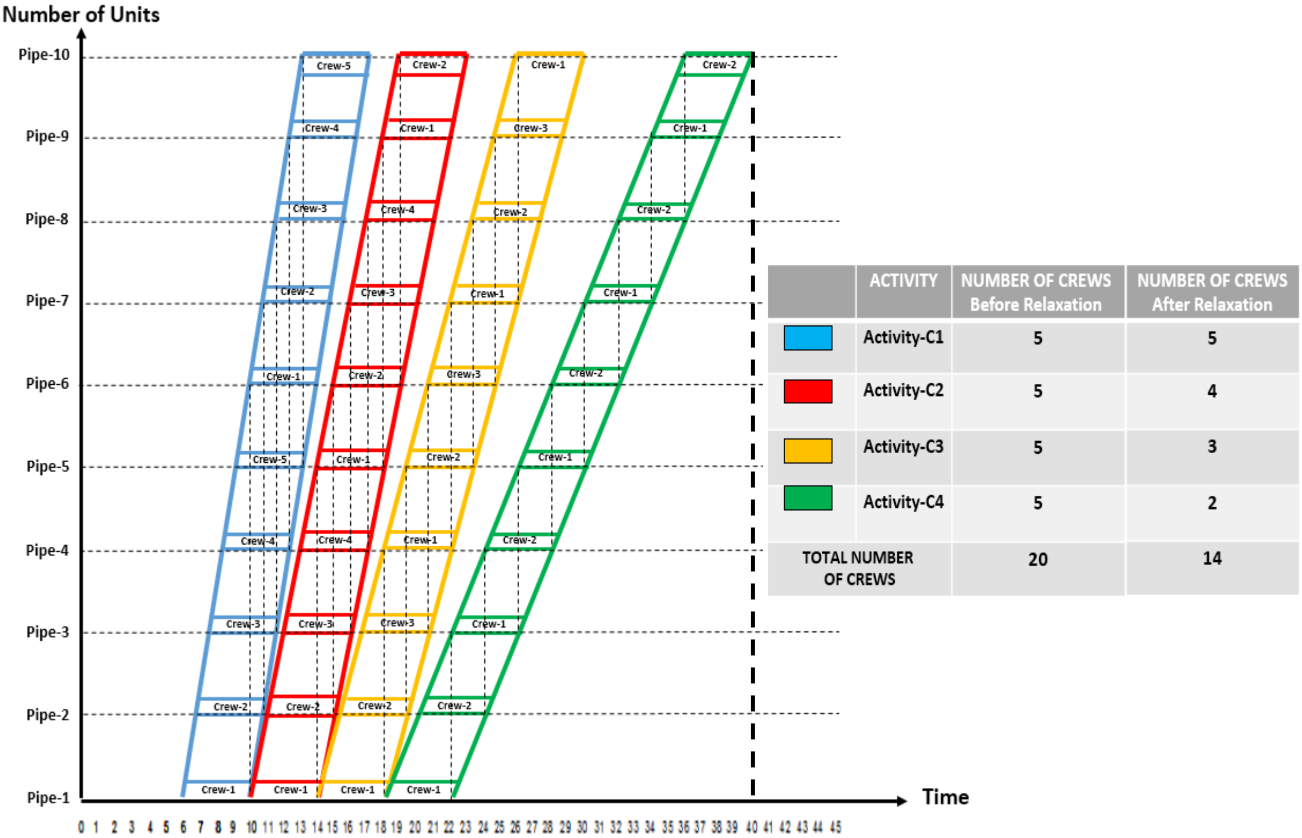
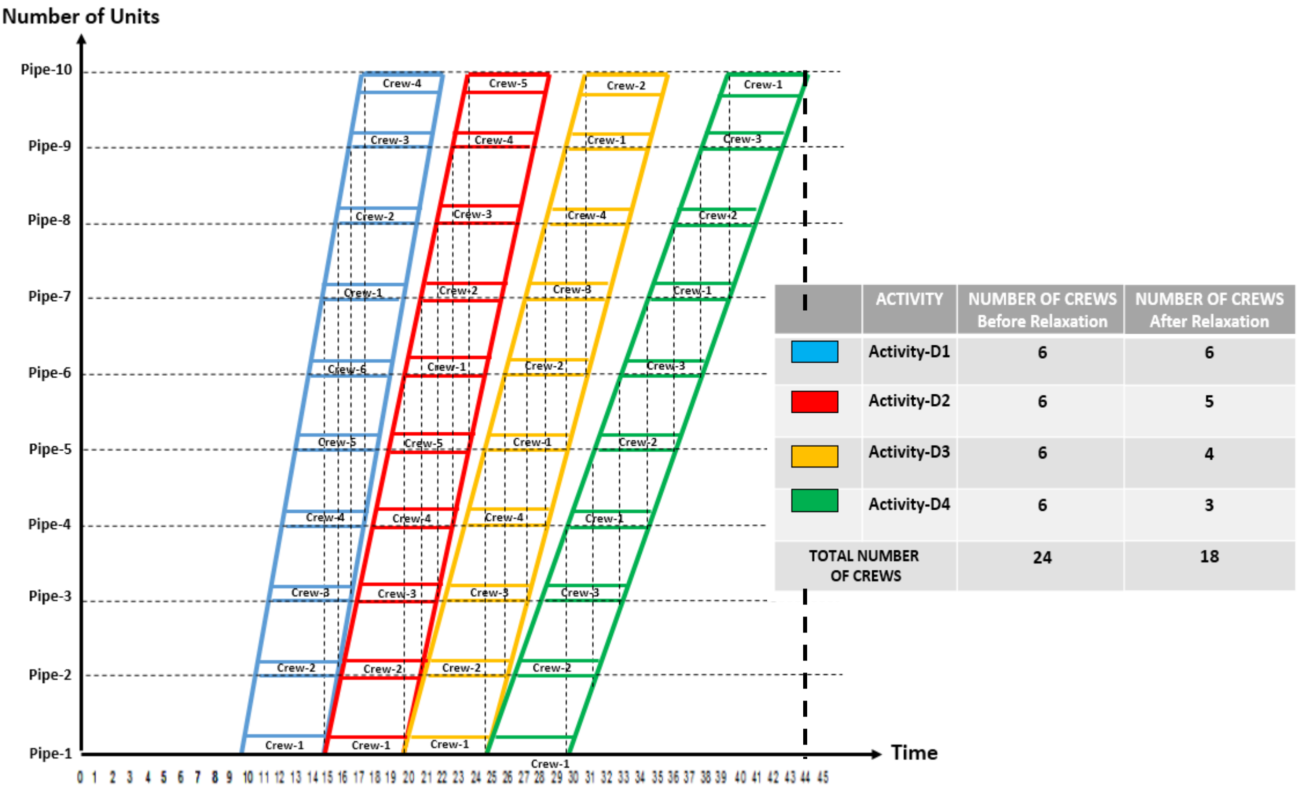


Figure 4.6: LOB of activities C1, C2, C3 & C4 before relaxing production rates



	ACTIVITY	NUMBER OF CREWS Before Relaxation	NUMBER OF CREWS After Relaxation
	Activity-C1	5	5
	Activity-C2	5	4
	Activity-C3	5	3
	Activity-C4	5	2
TOTAL NUMBER OF CREWS		20	14

Figure 4.7: LOB schedule for activities C1-C2-C3-C4.



	ACTIVITY	NUMBER OF CREWS Before Relaxation	NUMBER OF CREWS After Relaxation
	Activity-D1	6	6
	Activity-D2	6	5
	Activity-D3	6	4
	Activity-D4	6	3
TOTAL NUMBER OF CREWS		24	18

Figure 4.8: LOB schedule for activities D1-D2-D3-D4.

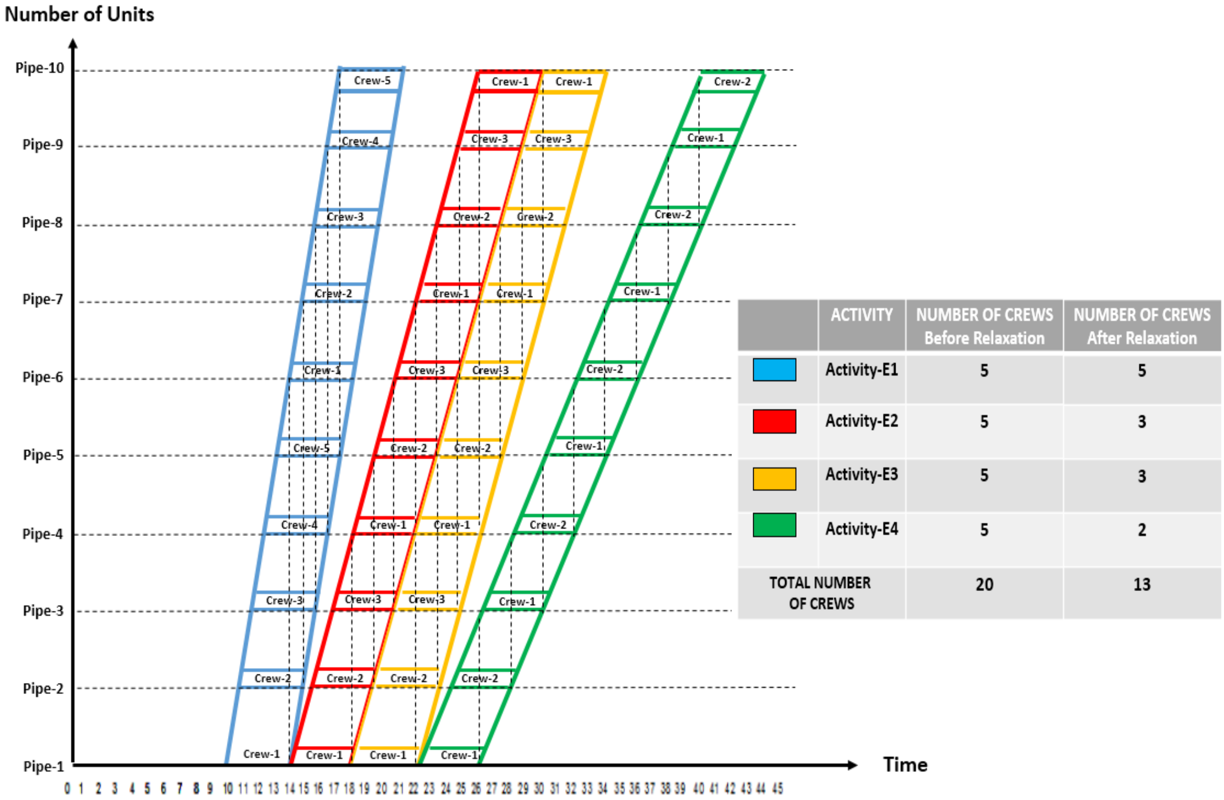


Figure 4.9: LOB schedule for activities E1-E2-E3-E4.

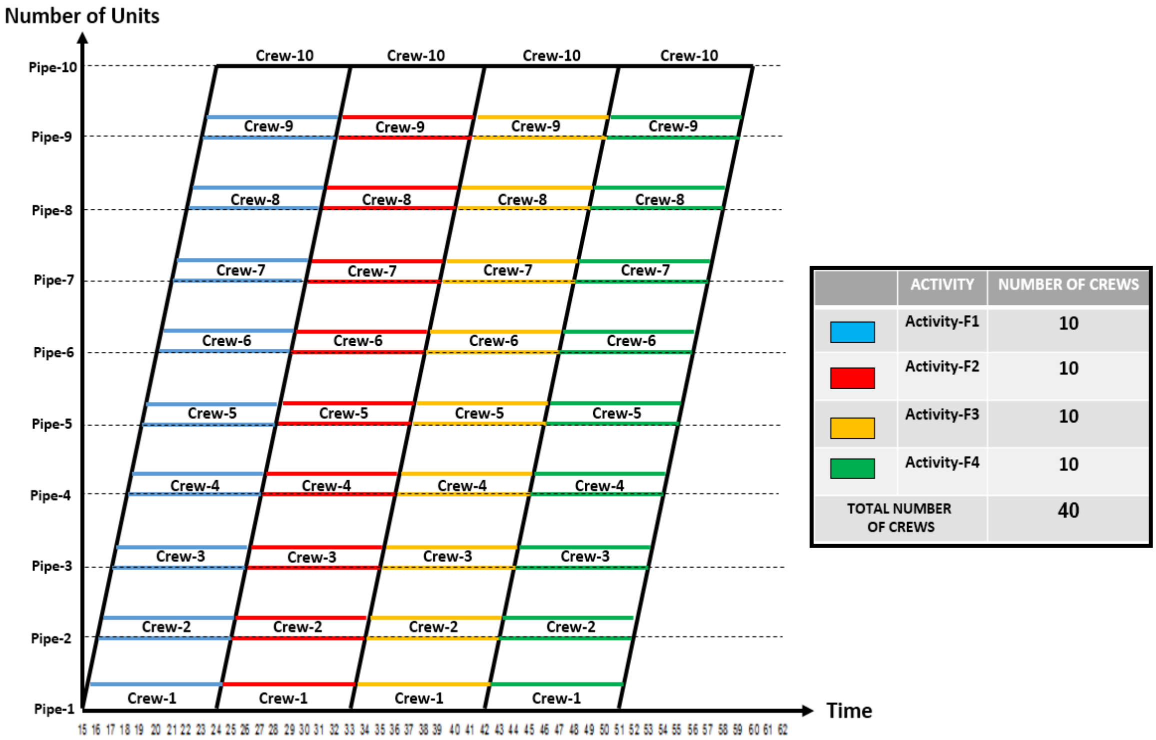


Figure 4.10: LOB schedule for activities F1-F2-F3-F4.

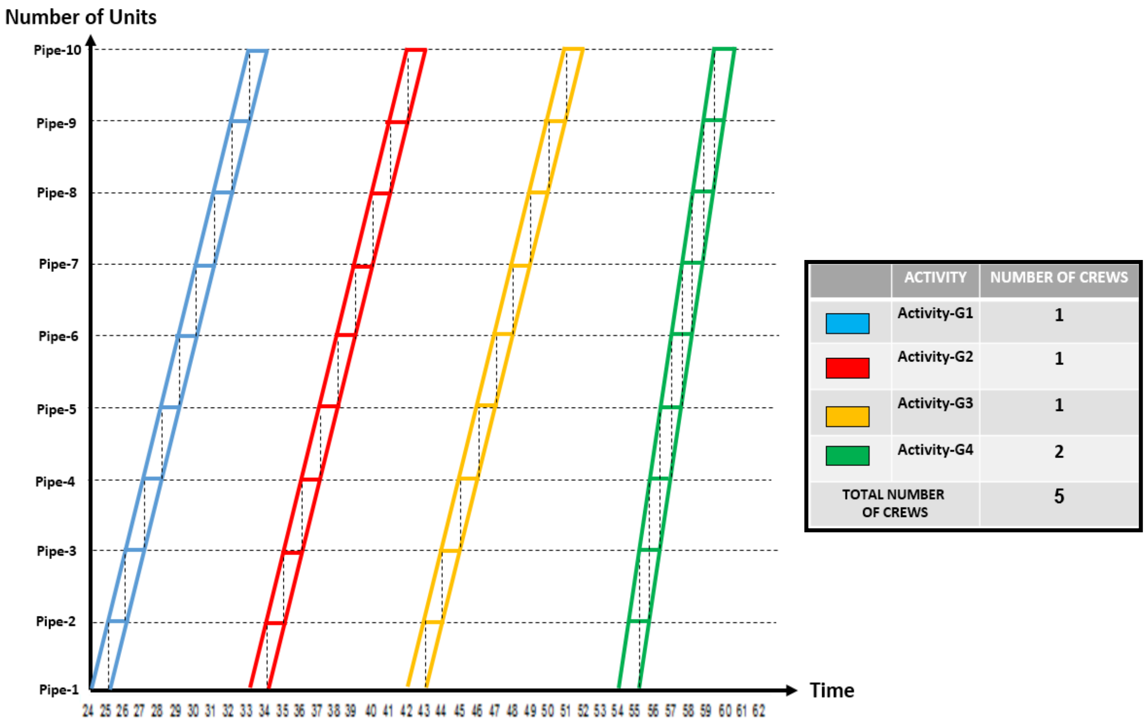


Figure 4.11: LOB schedule for activities G1-G2-G3-G4.

4.6. The implementation of the developed framework of the Optimization model using MATLAB on the case study.

4.6.1. Step-1: Input module.

Table 4.2. Project related information

Project Name	Pipeline Installation Project
Project Code	
Number of repeated units	Ten Repetitive Pipeline Installation
Project start date	0
Completion date of the project.	71

- Total number of activities (N_T) of each repetitive activity, where (N_T) is equal to the number of repetitive sub-activities (Ns) multiplied by number of repetitive unit (N) = 4 (Number of sub-activities) * 10 (Repetitive Pipelines) = 40 activity.

4.6.2. Step-2: Defining Initial Inputs.

This step deals with identifying the initial inputs of the model by tabulating the start date, finish date and activities numbers of repetitive activities as showing in Appendix-B.

4.6.2.1. Application on MATLAB.

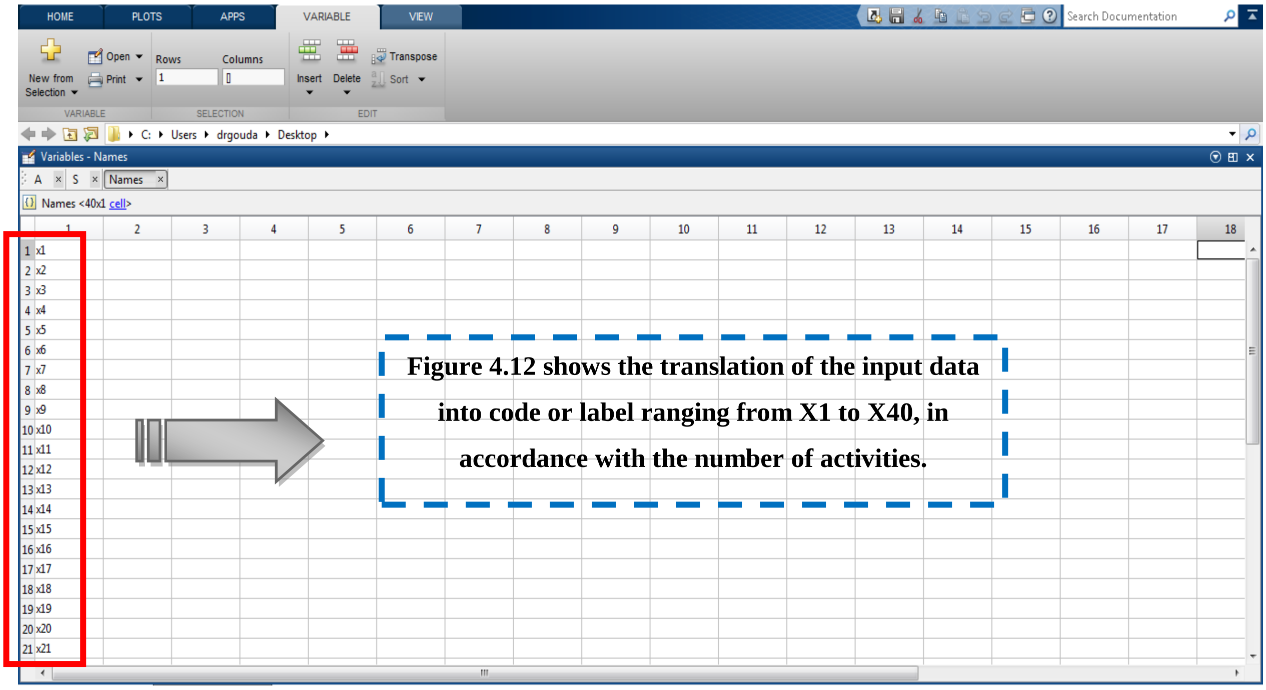


Figure 4.12: A screen shot for input variable data on MATLAB.

4.6.3. Step-3: Forecasting the successor and predecessor activities depending on the input variables.

The start and finish date of each activity are arrayed and compared for equality with the entire available corresponding activities. A final index is conduced and displayed by applying this step on MATLAB.

4.6.4. Step-4: Sparse Matrix Module

Using the abovementioned function for this module discussed on Chapter-3 Research Methodology, sparse matrix for each activity is tackled as shown in figure 4.13, 4.14, and 4.15 respectively.

4.6.4.1. Application on MATLAB

1- Activity-C

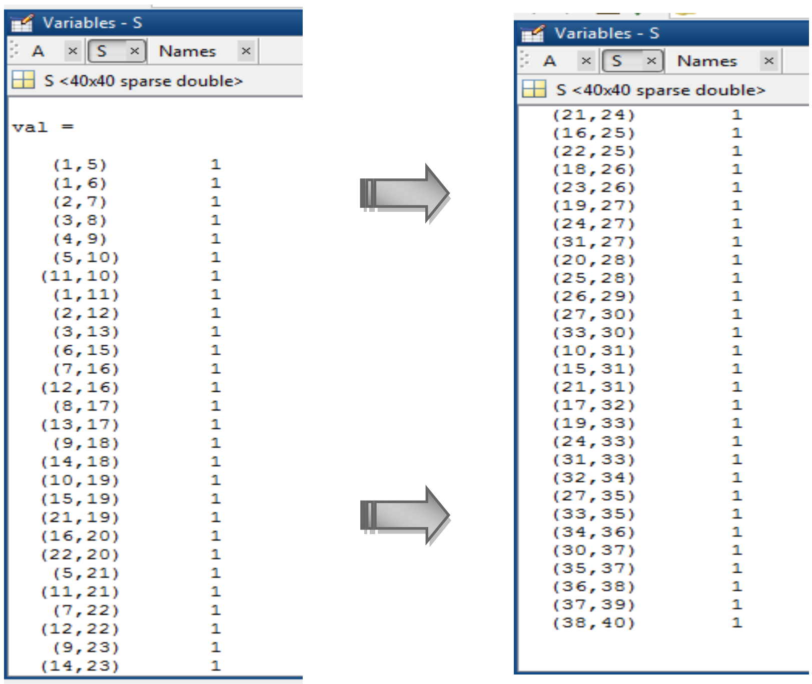


Figure 4.13: A screen shot for sparse matrix application on MATLAB for activity-C1, C2, C3, C4.

2- Activity-D

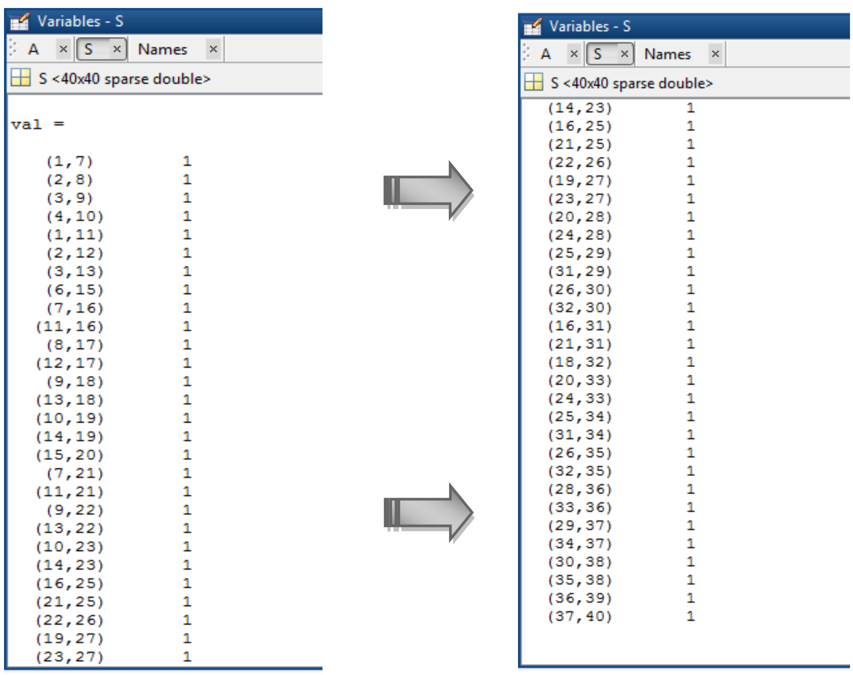


Figure 4.14: A screen shot for sparse matrix application on MATLAB for activity-D1,D2, D3, D4.

2- Activity-E

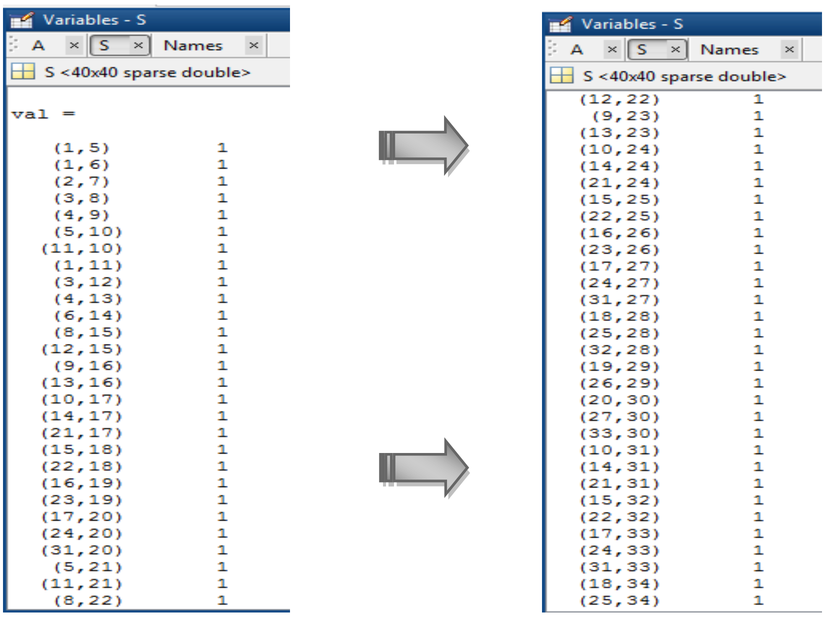


Figure 4.15: A screen shot for sparse matrix application on MATLAB for activity-E1, E2, E3, E4.

4.6.5. Step 5-Graph Theory Module:

The graph theory functions work on sparse matrices generated from step-4, in which a graph theory network is rendered and displayed using MATLAB function by identifying number of activities that are represented as nodes (vertices) and number of lines that are called edges, which connect the nodes according to assigned relationships between activities. The outcome shows catering out the possible and total number of paths of each crew throughout the entire network.

4.6.5.1. Application on MATLAB

1- Activity-C1, C2, C3, C4

Figure 4.16 shows conducted graph theory functions for activity C1,C2, C3, C4 based on the abovementioned data required, where number of nodes is 40, whereas number of vertices is 56.

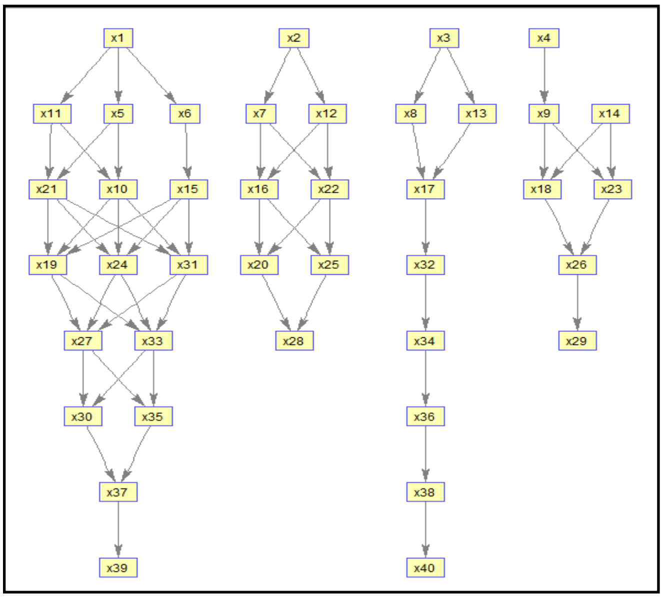


Figure 4.16: A screen shot for graph theory network application on MATLAB for activity-C1,C2,C3,C4.

2- Activity-D1, D2, D3, D4

Figure 4.17 shows conducted graph theory functions for activity D1, D2, D3, D4 based on the abovementioned data required, where number of nodes is 40, whereas number of vertices is 51.

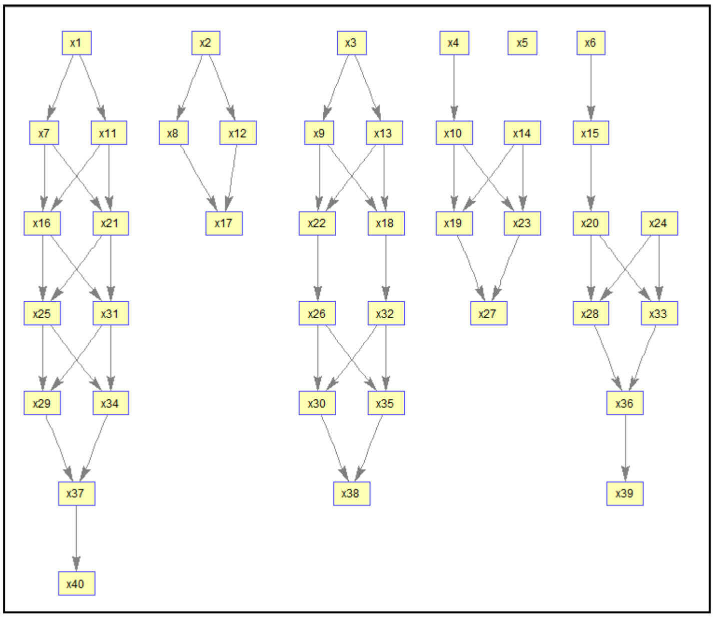


Figure 4.17: A screen shot for graph theory network application on MATLAB for activity-D1,D2,D3,D4.

3- Activity-E1, E2, E3, E4

Figure 4.18 shows conducted graph theory functions for activity E1, E2, E3, E4 based on the abovementioned data required, where number of nodes is 40, whereas number of vertices is 69.

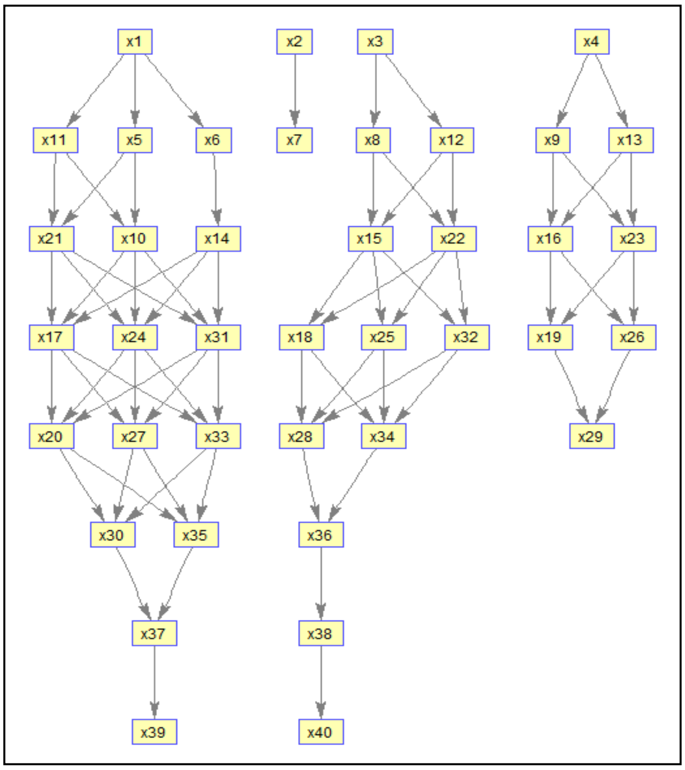


Figure 4.18: A screen shot for graph theory network application on MATLAB for activity-E1,E2,E3,E4.

4.6.6. Step 6- Structural Array Module:

As mentioned previously, this step is accountable for proceeding an integration between the sparse matrix conducted from step four and the graph theory network genertaed from step five to develop a structure array module that includes and lists out all the possible paths for each crew routing.

4.6.6.1. Application on MATLAB.

The procedures undertaken for implementing a structural array module to attain the objective function of this model is illustrated in chapter-3 Research Methodology. The optimization model features a MATLAB code as a solution algorithm with an objective of forecasting an optimum number of crews and allocation required to maintain the crews work continuity without impacting total project duration. Hence, this model targets minimizing the resource usage employed to attain activities.

1- Activity-C (Crew assignment and routing based on the proposed model)

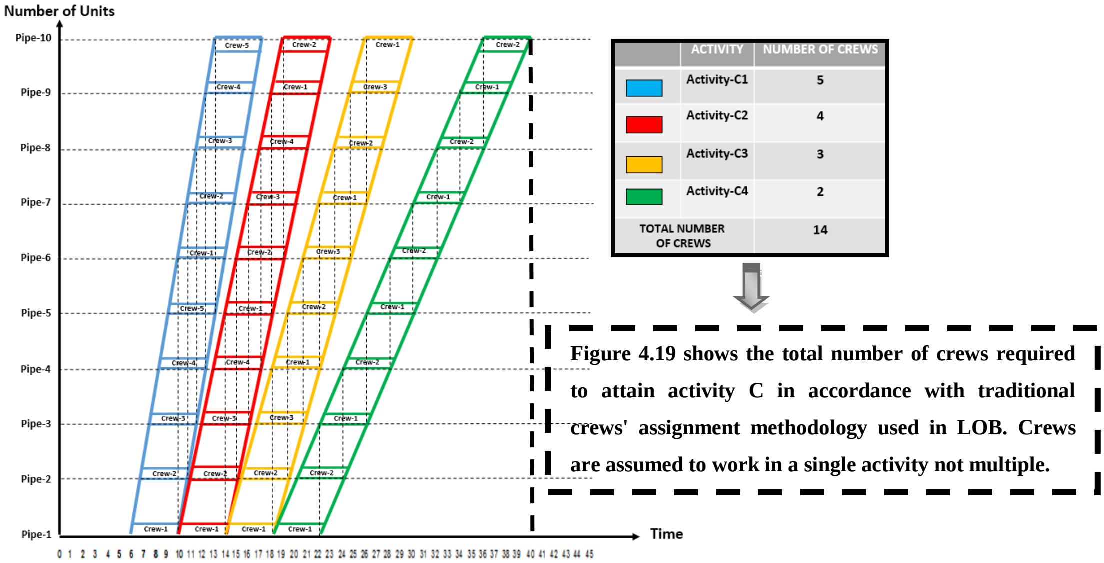


Figure 4.19: Number of crew for activity-C after implementing the optimization model.

4.6.6.2. Output Crews routing after implementing the optimization model.

After running the optimization engine, the model resulted in a near optimum crews' number with each crew path relying on the production rate of each activity generated from LOB calculations. The crews number usage is minimized into 9 crews' instead of 14 crews by applying crews to work in multiple activities while maintaining crew work continuity to meet the desired project completion date. The path of each crew can be visualized in table 4.3. Furthermore, figure 4.20 demonstrates the codes imbedded for each activity to indicate different crew's paths and to outcome all crews routing rendered on LOB format based on the output generated from MATLAB.

Table-4.3 Activities enrolled under each crew based on the model output "C".

Figure 4.21 includes two diagrams, the left hand side one includes the number of crews employed after performing the optimization model, and number of activities enrolled under each crew. While the right hand side one includes the number of crews assigned before and after relaxing production rate, and number of crews employed after applying the optimization model.

COLOR CODE	ACTIVITY C (ACTIVITIES CODE)	CREW NUMBER
	(1- 11- 21- 31- 33- 35- 37- 39)	1
	(3 -13 -17 -32 -34 -36 -38 -40)	2
	(2 -12 -22 -25 -28)	3
	(4 -9 -23 -26 -29)	4
	(5 -10 -24 -27 -30)	5
	(6 -15 -19)	6
	(7 -16 -20)	7
	(14-18)	8
	8	9
TOTAL CREWS NUMBER		9

Longest Crew Path

Total number of crews assigned is 9 crews

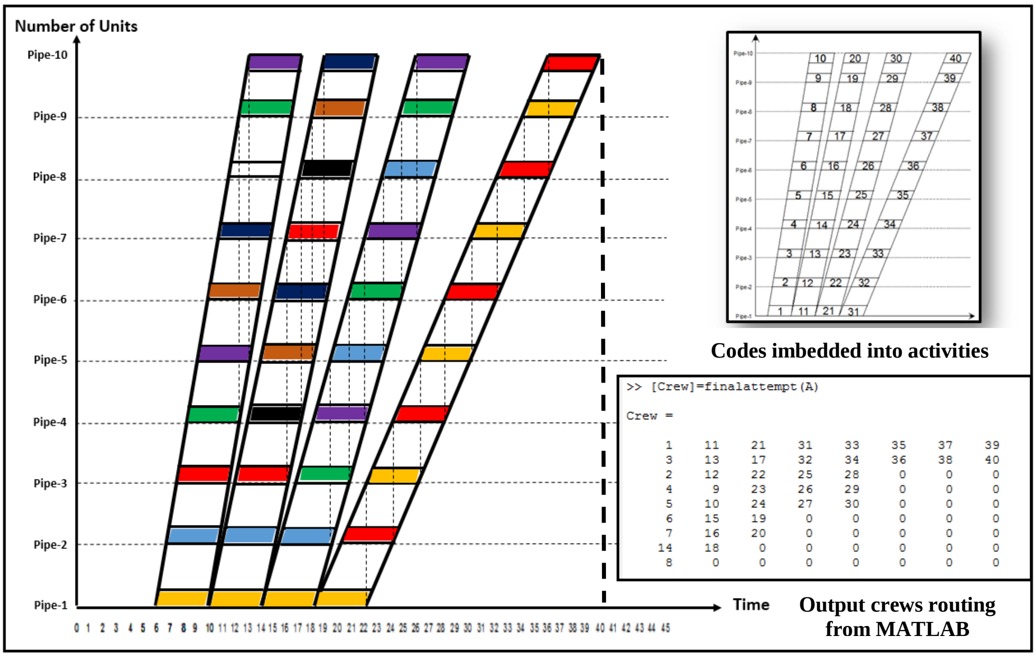


Figure 4.20: LOB graph after implementation new crews routing using proposed model outputs

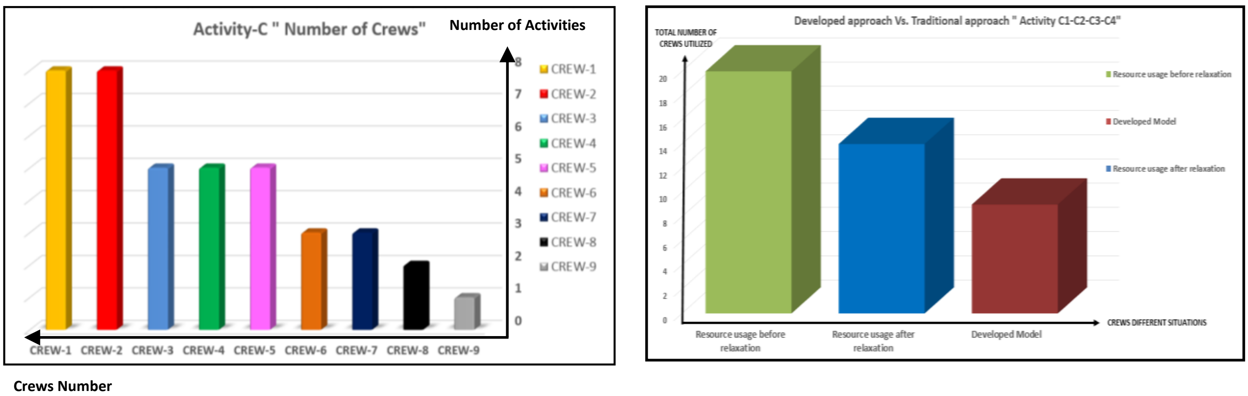


Figure 4.21: Developed Approach Vs. Traditional Approach for Activity C1-C2-C-C4

2- Activity-D (Crew assignment and routing based on the proposed model)

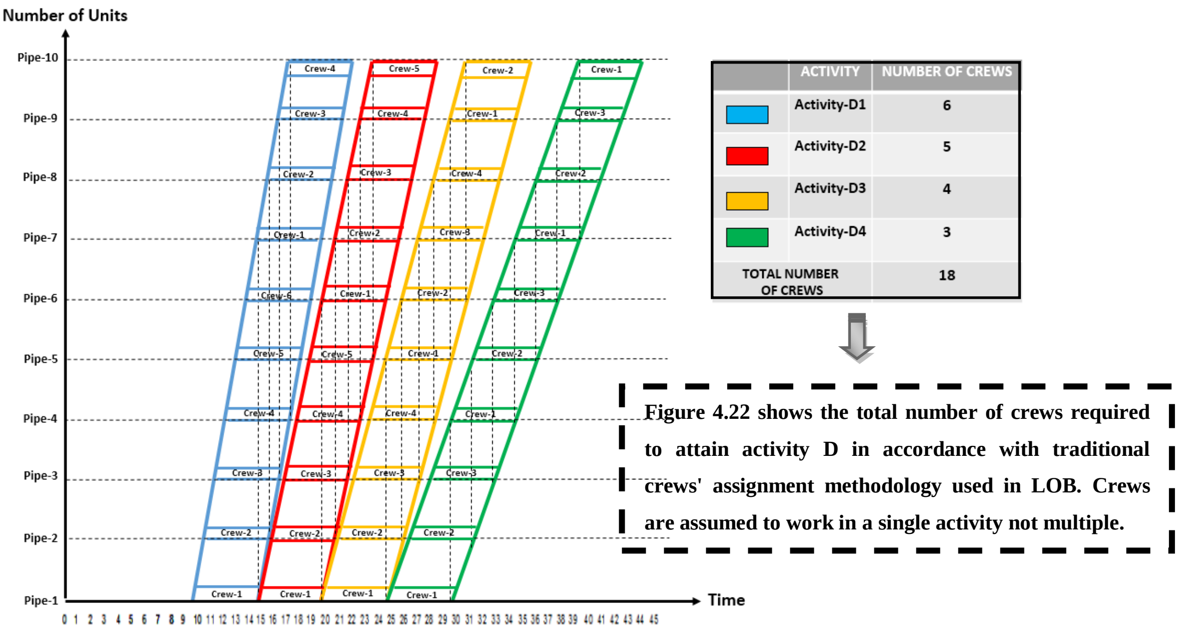


Figure 4.22: Number of crew for activity-D after implementing the optimization model.

4.6.6.3. Output Crews routing after implementing the proposed optimization model.

After running the optimization engine, the model resulted in a near optimum crews' number with each crew path relying on the production rate of each activity generated from LOB calculations. The crews number is minimized into 11 crews' instead of 18 crews by applying crews to work in multiple activities while maintaining crew work continuity to meet the desired project completion date. The path of each crew can be visualized in table 4.4. Furthermore, figure 4.23 demonstrates the codes imbedded for each activity to indicate different crew's paths and to outcome all crews routing rendered on LOB format based on the output generated from MATLAB.

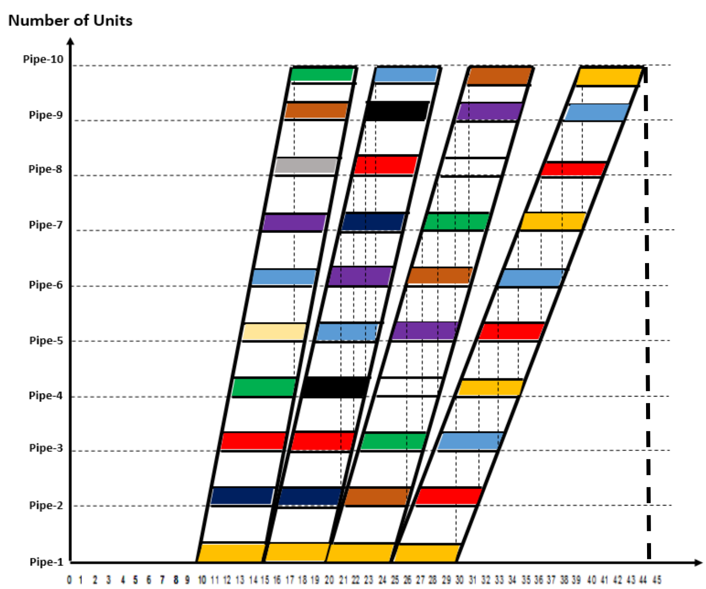
Table-4.4 Activities enrolled under each crew based on the model output "D"

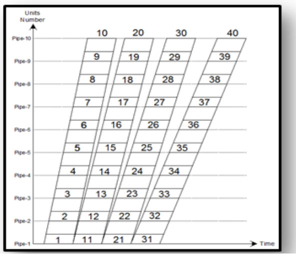
Figure 4.24 includes two diagrams, the left hand side one includes the number of crews employed after performing the optimization model, and number of activities enrolled under each crew. While the right hand side one includes the number of crews assigned before and after relaxing production rate, and number of crews employed after applying the optimization model.

COLOR CODE	ACTIVITY D (ACTIVITIES CODE)	CREW NUMBER
yellow	(1- 11- 21- 31- 34- 37- 40)	1
red	(3 -13 -18 -32 -35 -38)	2
light blue	(6 -15 -20 -33 -36-39)	3
green	(4 -10 -23 -27)	4
purple	(7 -16 -25 -29)	5
orange	(9-22 -26 -30)	6
dark blue	(2 -12 -17)	7
black	(14-19)	8
white	(24-28)	9
light yellow	5	10
grey	8	11
TOTAL CREWS NUMBER		11

Longest Crew Path

Total number of crews assigned is 11 crews





Codes imbedded into activities

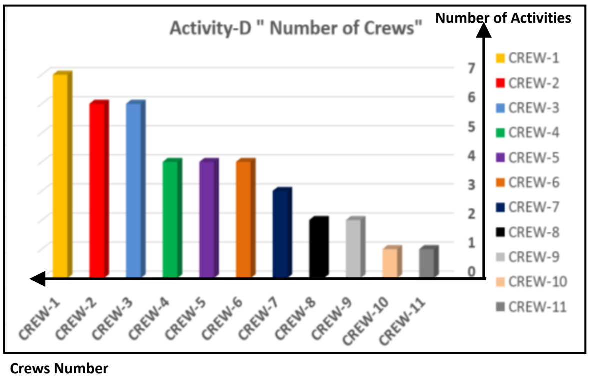
```
>> [Crew]=finalattempt(A)

Crew =

     1    11    21    31    34    37    40
     3    13    18    32    35    38     0
     6    15    20    33    36    39     0
     4    10    23    27     0     0     0
     7    16    25    29     0     0     0
     9    22    26    30     0     0     0
     2    12    17     0     0     0     0
    14    19     0     0     0     0     0
    24    28     0     0     0     0     0
     5     0     0     0     0     0     0
     8     0     0     0     0     0     0
```

Output crews routing From MATLAB

Figure 4.23: LOB graph after implementation new crews routing using proposed model output "D"



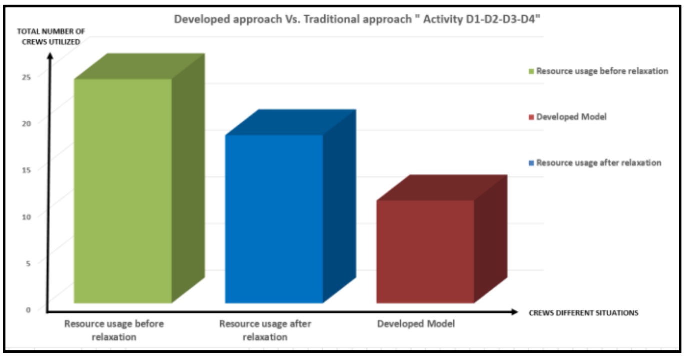


Figure 4.24: Developed Approach Vs. Traditional Approach for Activity "D"

3- Activity-E (Crew assignment and routing based on the proposed model)

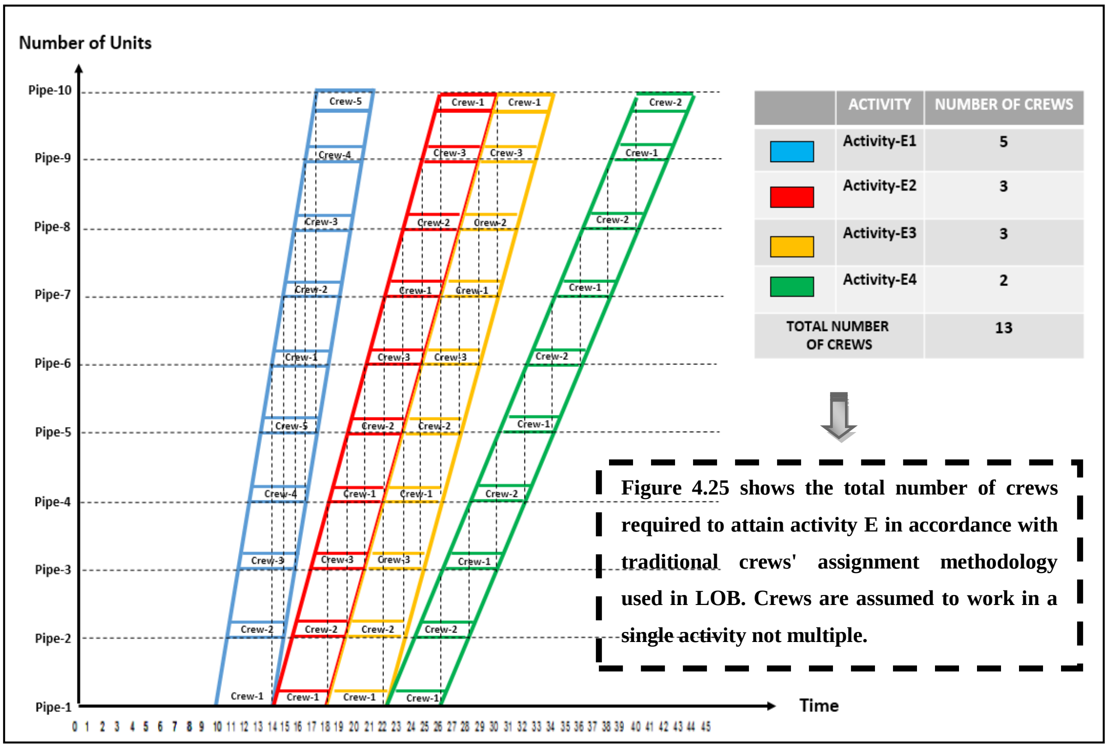


Figure 4.25: Number of crew for activity-E after implementing the optimization model.

4.6.6.4. Output Crews routing after implementing the proposed optimization model.

After running the optimization engine, the model resulted in a near optimum crews' number with each crew path relying on the production rate of each activity generated from LOB calculations. The crews number is minimized into 9 crews' instead of 13 crews by applying crews to work in multiple activities while maintaining crew work continuity to meet the desired project completion date. The path of each crew can be visualized in table 4.5. Furthermore, figure 4.26 demonstrates the codes imbedded for each activity to indicate different crew's paths and to outcome all crews routing rendered on LOB format based on the output generated from MATLAB.

Table-4.5 Activities enrolled under each crew based on the model output "E"

Figure 4.27 includes two diagrams, the left hand side one includes the number of crews employed after performing the optimization model, and number of activities enrolled under each crew. While the right hand side one includes the number of crews assigned before and after relaxing production rate, and number of crews employed after applying the optimization model.

COLOR CODE	ACTIVITY E (ACTIVITIES CODE)	CREW NUMBER
	(1- 11- 21- 31- 33- 35- 37- 39)	1
	(3 -12 -22 -32 -34 -36 -38 -40)	2
	(4 -13 -23 -26 -29)	3
	(5 -10 -24 -27 -30)	4
	(6 -14 -17 -20)	5
	(8 -15 -25- 28)	6
	(9 -16 -19)	7
	(2-7)	8
	8	9
TOTAL CREWS NUMBER		9

Longest Crew Path

Total number of crews assigned is 9 crews

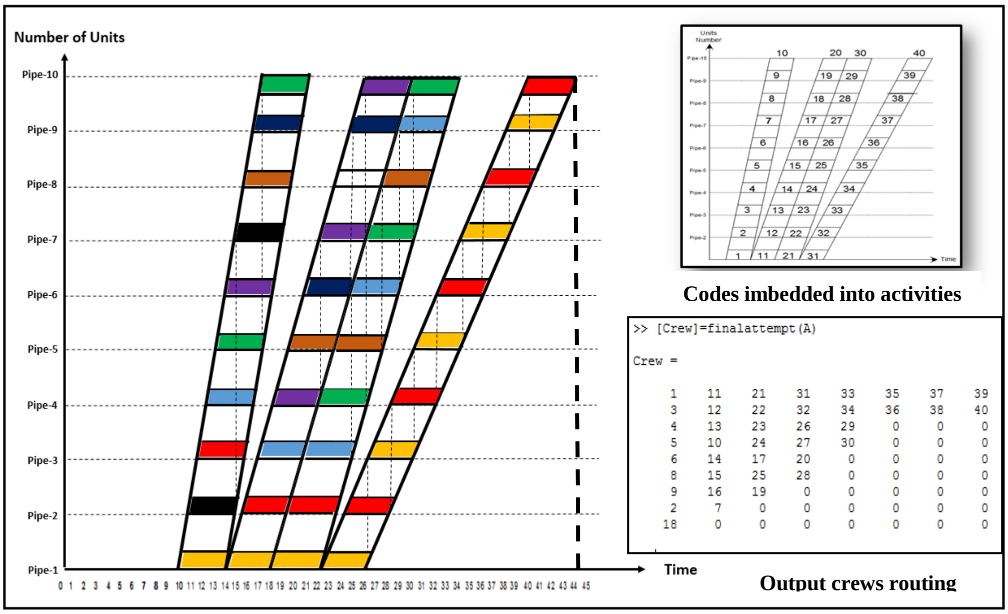


Figure 4.26: LOB graph after implementation new crews routing using proposed model output "E"

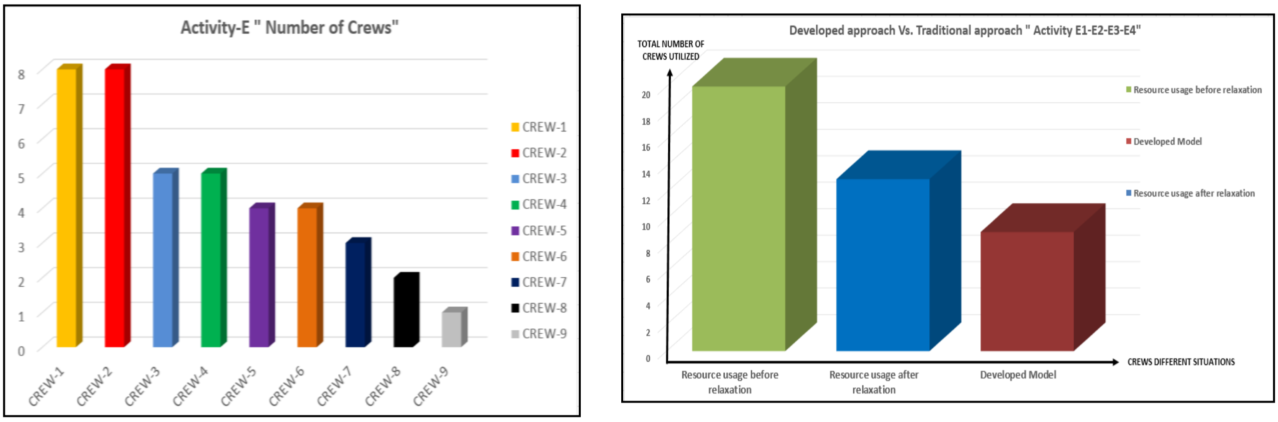


Figure 4.27: Developed Approach vs. Traditional Approach for Activity "E"

4.6.7. Step-7: Crew Diagramming Approach (CDA).

The above-mentioned proposed model assigns crews to different activities in different units. Hence, a new representational method called Crew Diagraming Approach (CDA) is developed to realistically enhance planning of crews' circulation and to overcome the dilemmas accompanied with the confusion due to different crew's passing through activities in different units. CDA consistently displays an interactive graph for each crew evolvement and route through different units highlighted by a color to differentiate between crews and to facilitate the mapping out of each crew passage.

4.6.7.1 Application of Crew Diagramming Approach on activity C.

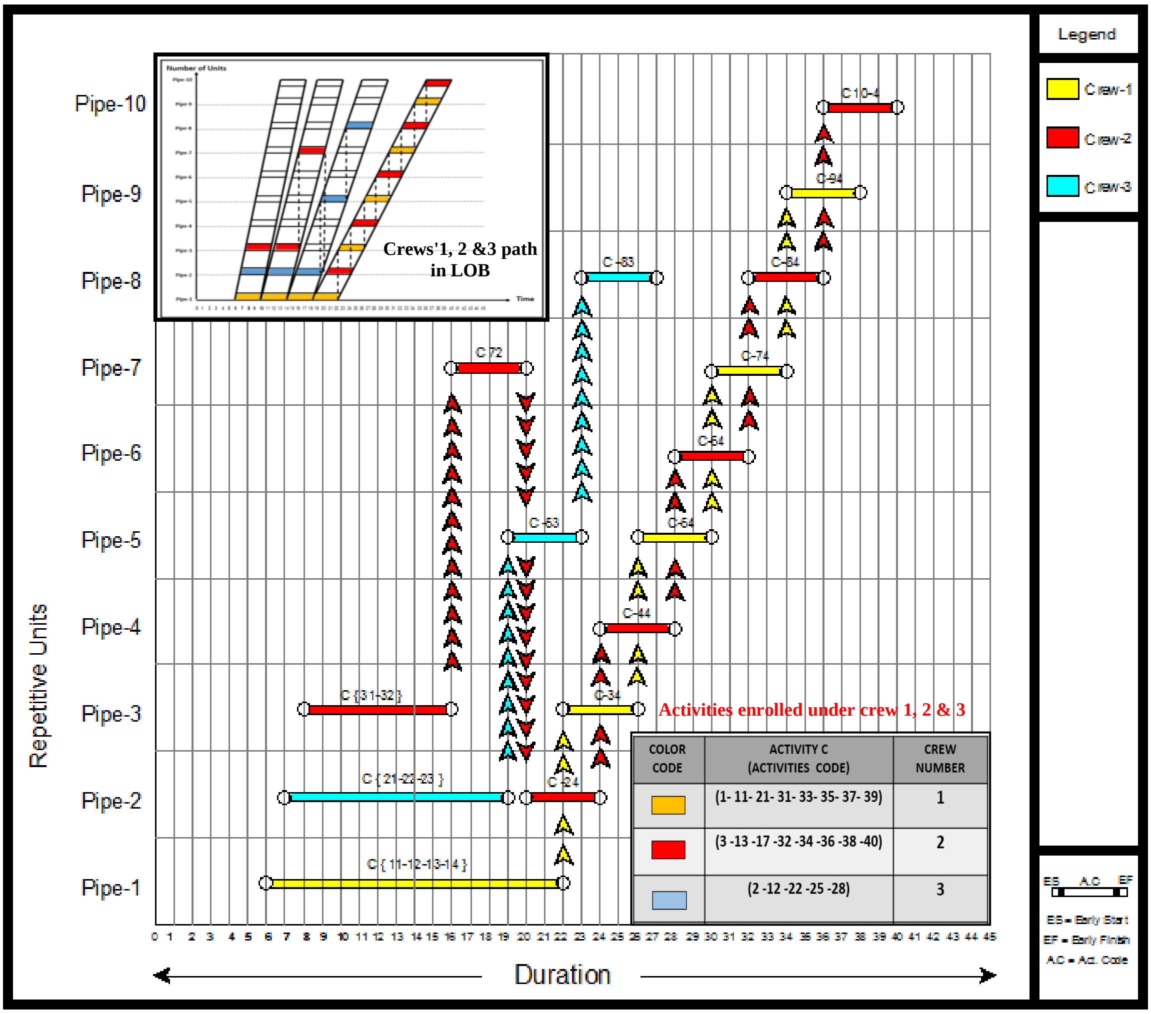


Figure 4.28: Developed CDA for first three crews in activity "C"

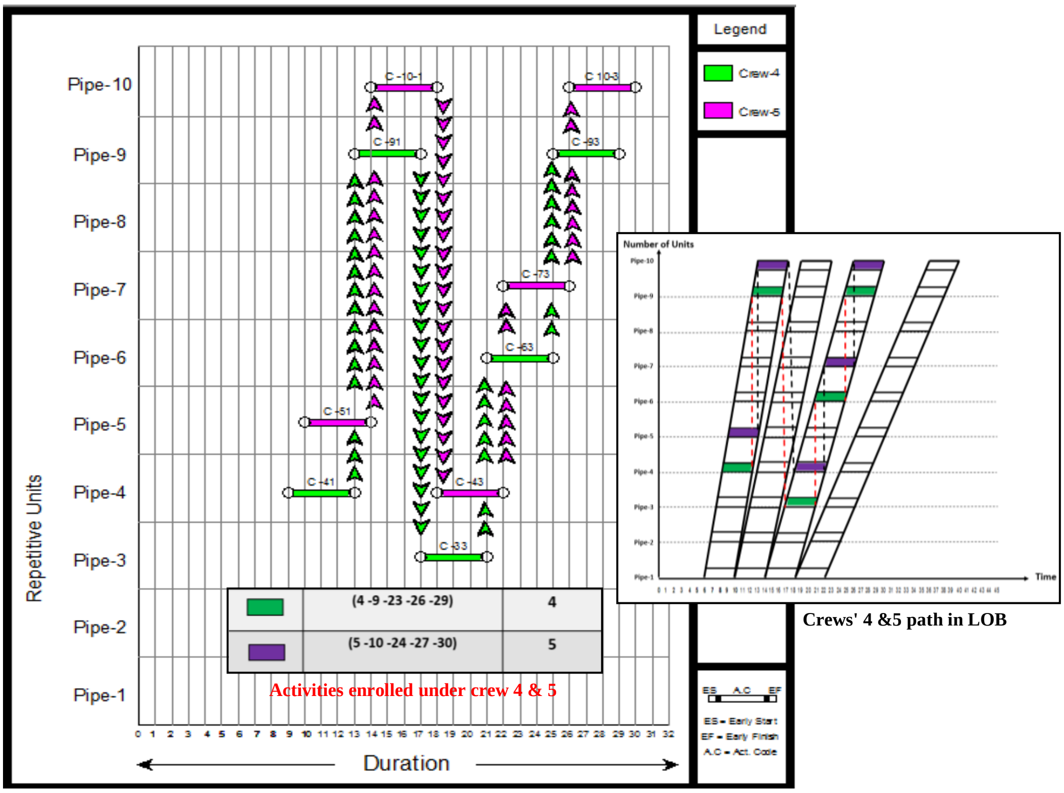


Figure 4.29: Developed CDA for crew 4 & 5 in activity "C"

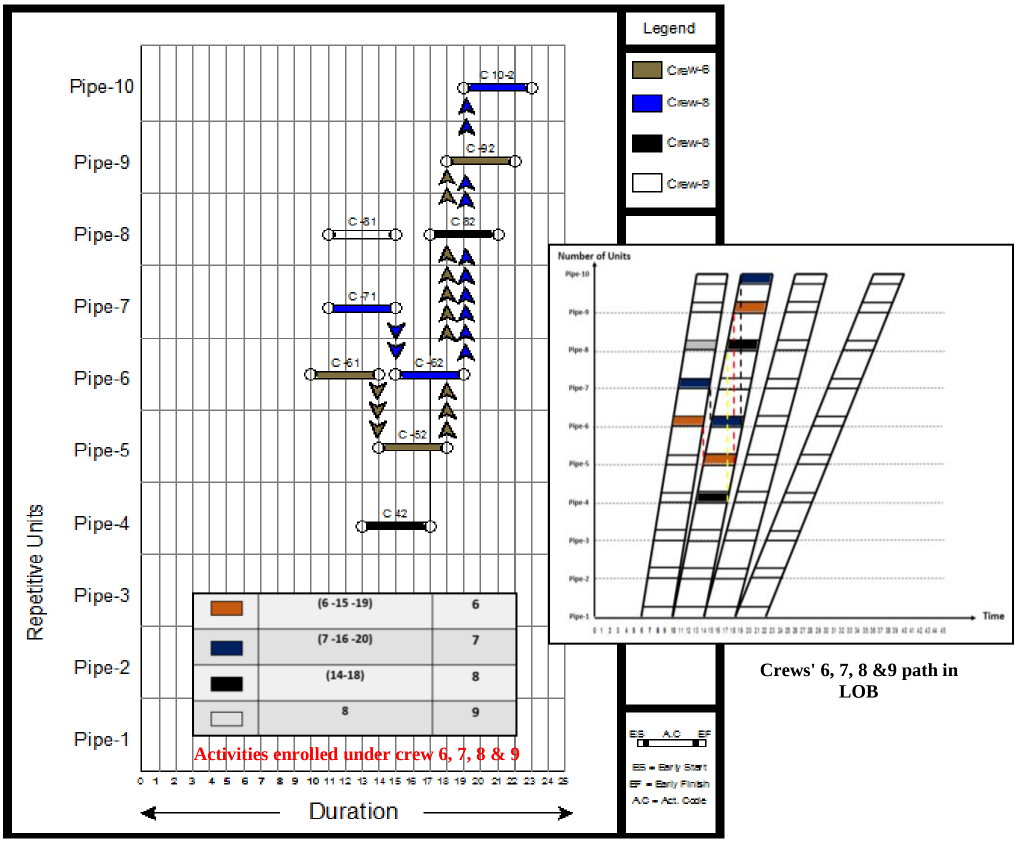


Figure 4.30: Developed CDA for crew 6, 7, 8 & 9 in activity "C"

Figure 4.28, 4.29 and 4.30 shows the interactive graph of CDA for activity "C", in which each of the nine crews of activity "C" is continuously displayed that enables the visualization of each crew profile as an intrinsic part of planning. Far too often, CDA breakthrough provides a renewed opportunity for visualizing each crew passage as a time-scaled calendar that allows each crew to move spontaneously rather than sequentially. Furthermore, each figure includes the activities enrolled under each crew path and the spontaneous circulation of each crew displayed on a LOB format.

4.6.8. The assignment of multi-task skilled workforce in LOB.

Another main objective of the developed optimization model using MATLAB is introducing the capability to assign crews in a more flexible and efficient manner. This strategy aims to optimize the total number of crews used on the project by increasing their employment duration on the project life. Moreover, this strategy has been shown to improve productivity by the participation and allocation of a crew in more than one activity in different units. These objectives reflect the challenges of planning and scheduling in the field, and achieving those results benefit to both the workers and the project. The capabilities of the proposed model to assign multi-task skilling crew on LOB was feasibly implemented on activity C and D. Figure 4.31 demonstrates the graph theory network applied on two different activities (C & D), where a multi task skilled crews are assigned to achieve those two different activities. Figure 4.32 shows the rendering of the generated paths or routes of each multi-task skilled crew as mentioned on table 4.6, which consequently results in implementing 20 multi skilled crew to attain activity C and D in accordance with their completion dates.

Table-4.6 Activities enrolled under each multi-skilled crew for activity C & D

COLOR CODE	Activity C&D	CREW NUMBER
	(1 11 21 31 33 35 37 76 79)	1
	(2 12 22 25 28 66 38 40 80)	2
	(3 13 17 32 34 36 75 78)	3
	(4 9 23 26 29 73 39)	4
	(5 10 24 27 30 74 77)	5
	(6 15 54 63 67)	6
	(7 16 55 64 68)	7
	(41 51 61 65 69)	8
	(8 52 57)	9
	(14 53 58)	10
	(44 50 59)	11

COLOR CODE	Activity C&D	CREW NUMBER
	(43 49 62)	12
	(47 56 71)	13
	(45 20)	14
	(42 48)	15
	(18)	16
	(19)	17
	(46)	18
	(60)	19
	(70)	20
TOTAL CREWS NUMBER		20

Total number of multi-task crews assigned is 20

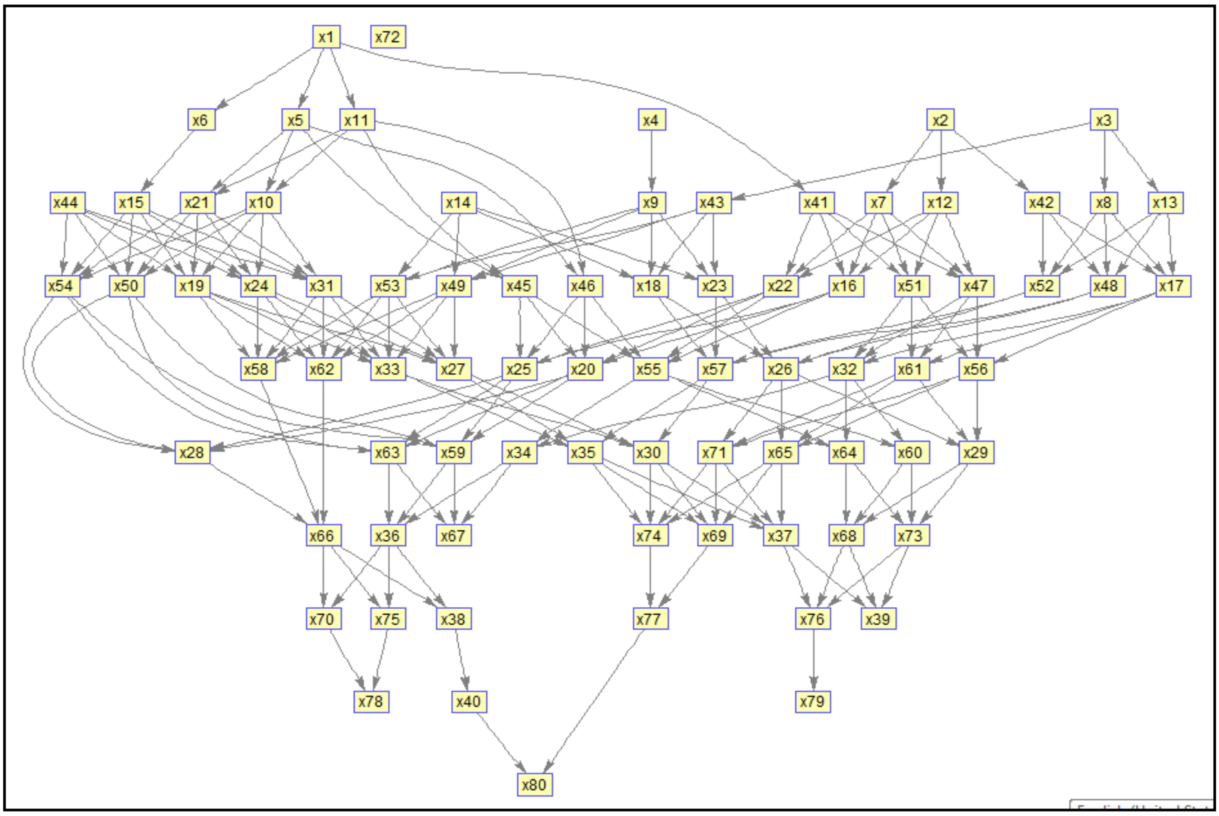
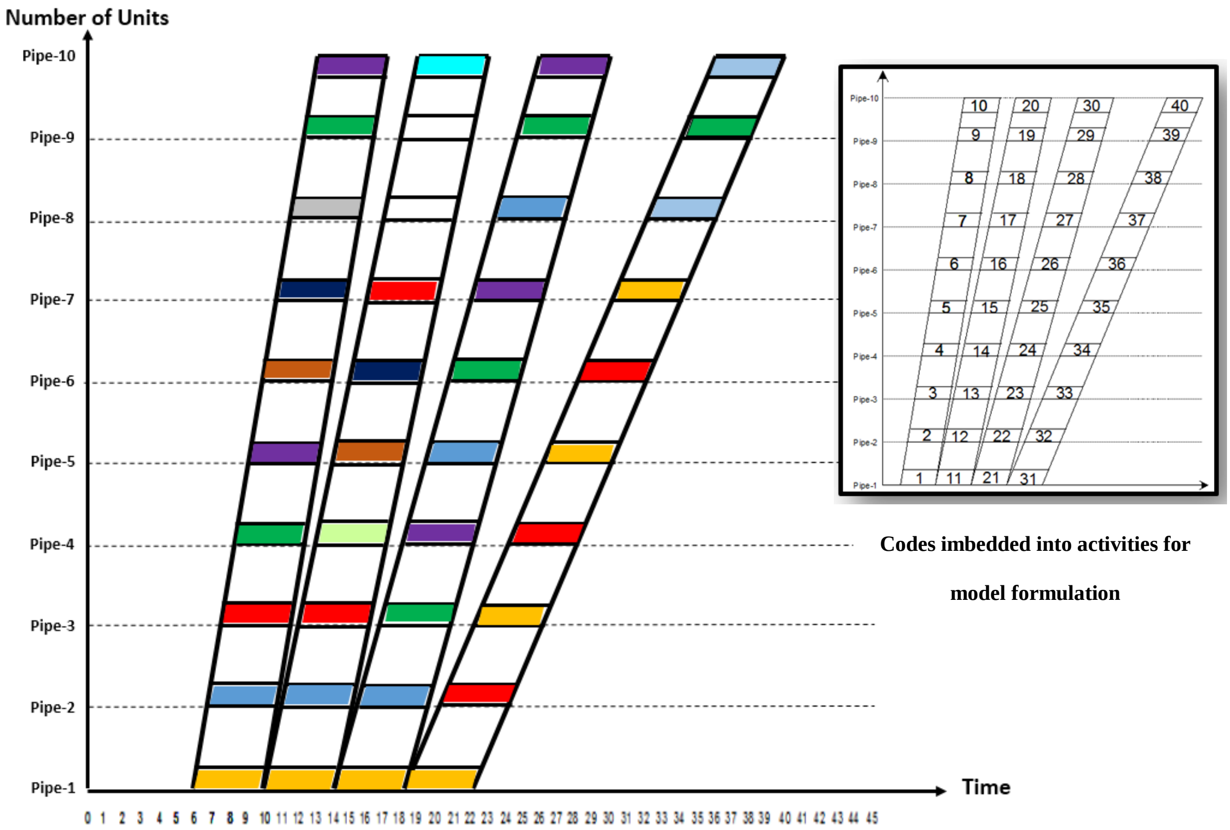


Figure 4.31: A screen shot for graph theory network application on MATLAB for activity C & D.

Repetitive Activity "C"



Repetitive Activity "D"

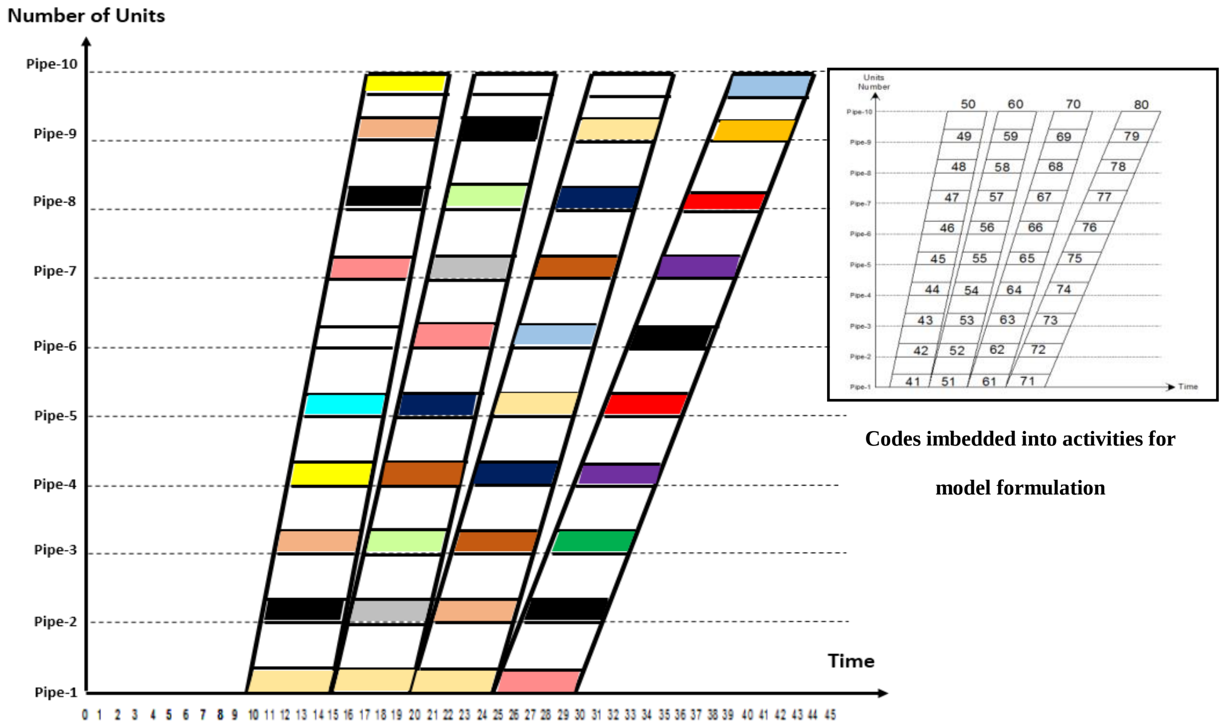


Figure 4.32: LOB graph after implementation multi-skilled crews using proposed model output C&D

4.7. Clearly Identifying Critical Path in LOB schedules

An additional objective of the developed optimization engine and algorithm using MATLAB is precisely forecasting the critical path in LOB schedules compared to conventional LOB due more accurate calculations. This algorithm can identify any partly critical activity by figuring out the all possible longest paths in the entire project (different critical paths in the project). This step is attained by inserting the input values, which are start dates, finish dates and number of all critical activities as shown in Appendix- D "The optimization model using MATLAB algorithm". The capabilities of the proposed algorithm was implemented using the hypothetical case study, in which critical activities are A,B, C1, D1, F1, F2, F3,F4, G4, K and L as shown in figure 4.33.

```
longestpath =

  Columns 1 through 15

     1     4    11    13    15    22    27    37    46    56    66    76    83    85    93

  Columns 16 through 18

   102   106   110
```

Figure 4.33: Longest path (critical path of the case study) pinpointed using the developed algorithm

Figure 4.34 shows the graph theory network for the critical activities rendered using the proposed algorithm that displays all possible critical paths in the project and identifies clearly each critical activity where all possible critical paths move through. Moreover, figure 4.35 shows one of the critical paths applied in LOB graph of the proposed case study.

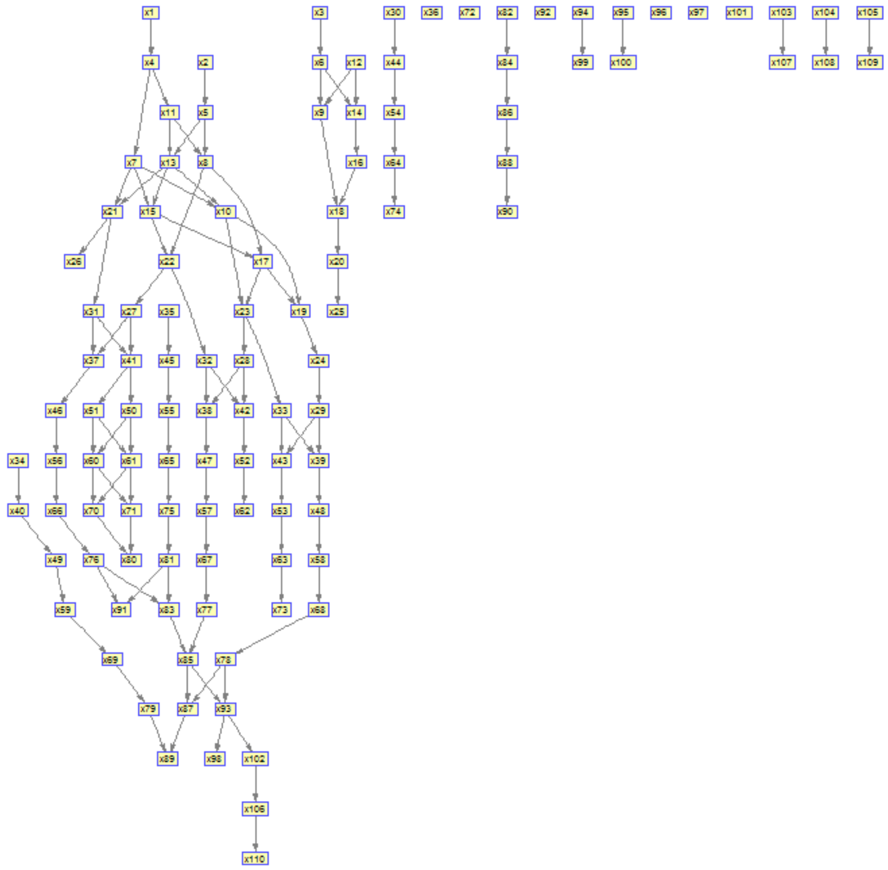


Figure 4.34: Graph theory network for all possible critical paths in the project

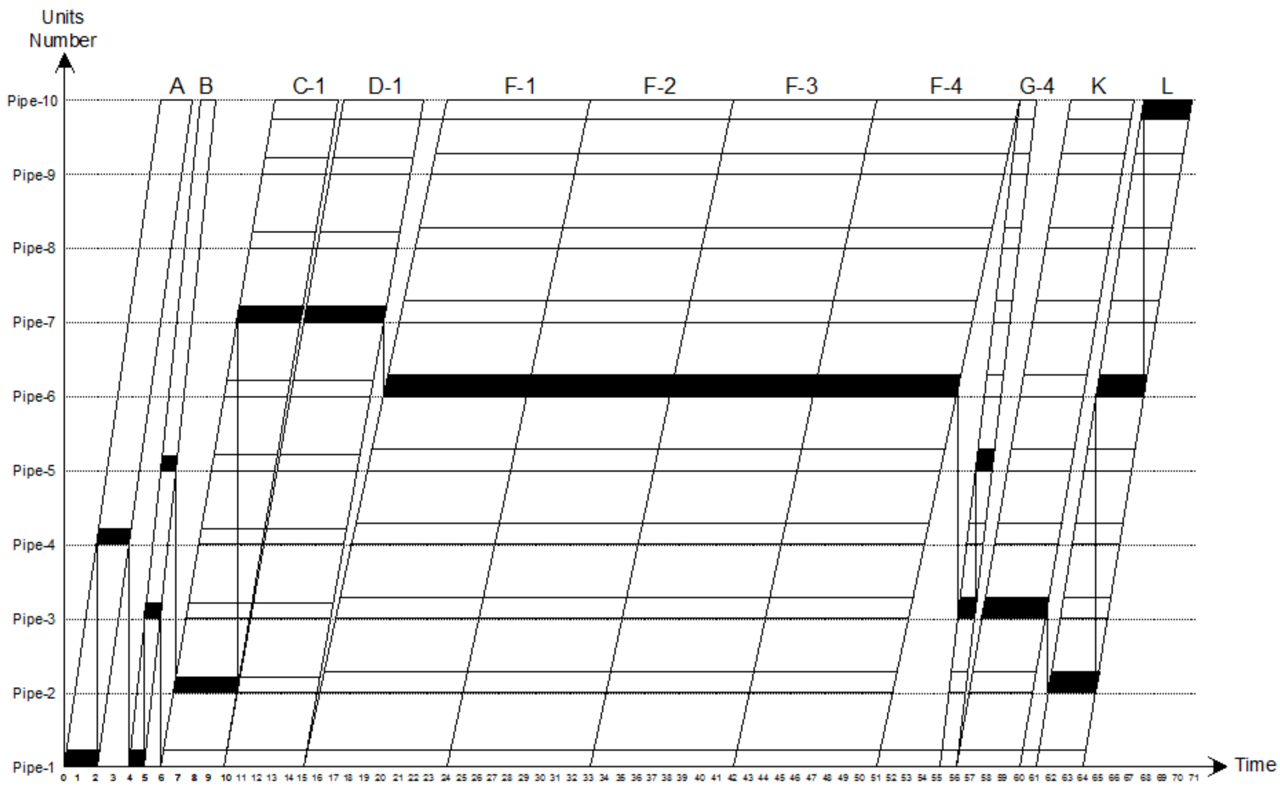


Figure 4.35: One of the critical paths presented in LOB format

4.8. Summary and Conclusions of this section

This section shows a new approach for scheduling repetitive projects is proposed, in which each repetitive activity is being simulated as separate activities with equal distances and durations. A case study of a repetitive pipeline installation project from the literature is used to reveal the ability of this approach to offer a detailed schedule, to generate a precise critical path, and to optimize time needed to schedule pipeline installation by allowing the presentation of the intent relationship between split activities

Furthermore, an proposed optimization model was introduced through promoting an algorithm or code on MATLAB to search for the feasible crews routing and to produce optimal crew formulation by permitting the accessibility of crews moving in a spontaneous direction not only a linear one. A case study was presented in order to demonstrate the ability of this model to achieve a better allocation of crews and minimizing the number of crews utilized to schedule activities in repetitive linear projects

4.9. The proposed Simulation Model for resource leveling in LOB using Entropy Maximization metric with stretching or crunching activity duration.

This part deals with the developed simulation model for leveling resource using entropy maximization theory with permitting extension of activities duration and allowing for different production rates per each activity. As previously mentioned, this simulation model is composed of three spreadsheet templates. 1) Activity and resource flow template, 2) Bar chart template and 3) Maximum entropy analogy template that are designed to systematically level resource in LOB scheduling technique. Activity and resource flow template is designed for modeling crew's different paths, variability in activity durations, early start, early finish and total float of each activity, resource availability constraints, total available number of resources per each activity, and total project duration constraint.

The implementation of the proposed simulation model is feasibility addressed on the repetitive activity C on the previous hypothetical case study used above-mentioned. Figure 4.36 shows the further procedures undertaken before applying the developed model to verify the workability and applicability of this engine.

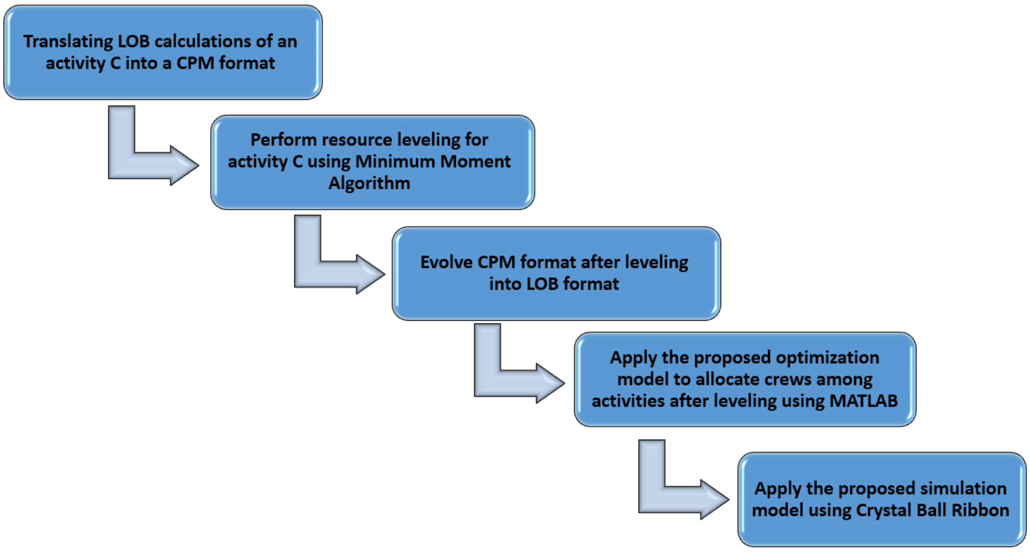


Figure 4.36: Sequential procedures performed to test the doable of the proposed model

Figure 4.37 demonstrates the rendering of LOB graph for activity "C", LOB calculations are transformed into a CPM format where each activity has its start and completion date to perform resource leveling. Each activity is represented by a code indicated as follows: For instance activity C 41, in which C is the activity name, 4 is the unit number and 1 defines the 1st kilometer. The starting date of each activity is conducted by dividing the activity duration with the number of crews needed for performing the repetitive activity obtained from LOB calculation as summarized in Appendix-C "Resource Leveling using Minimum Moment Algorithm".

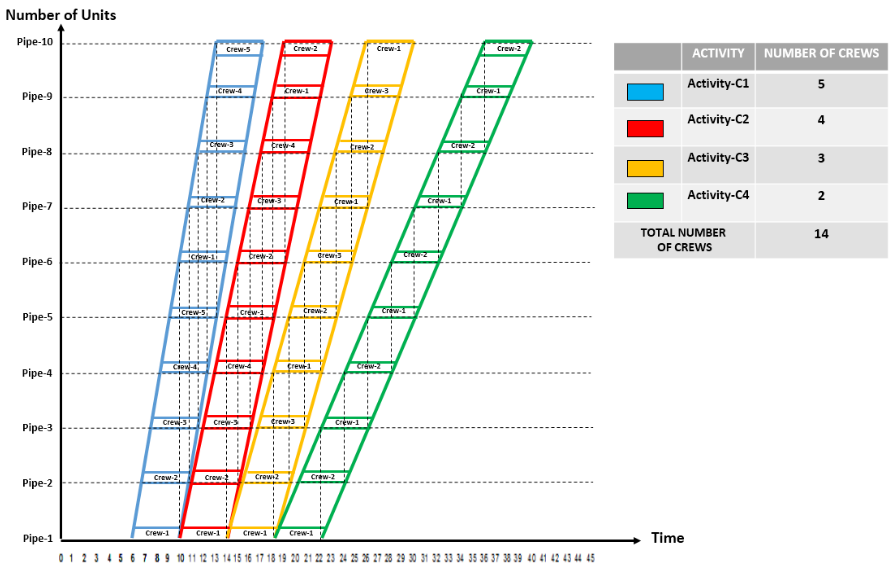


Figure 4.37: LOB diagram for activity C before leveling the resources

4.9.1. Resource Leveling using Minimum Moment Algorithm.

This method assumes that the moment of the daily resource usage about the horizontal axis of a resource histogram is a good measure of the resource utilization and that an optimal resource allocation exists when the total moment is at a minimum. The total resource moment Mx is calculated by summing up the individual resource moments about the time axis (Harris, 1978).

$$M_x = \sum_{i=1}^{n_t} [0.5 r_i^2]$$

This method targets the reduction of the daily fluctuations in resource demand by shifting non critical activities with their float. The overall project duration is definitely defined as a constraint. The minimum moment method relies on the following assumptions:

- The activities are time-continuous and, thus, once started they cannot be interrupted;
- The resource assignments for each activity are assumed constant.
- The duration of each activity remains as originally planned;
- The logic relationship between activities and overall project duration is fixed

A resource improvement factor is computed for all activities and the activity producing the largest positive improvement factor is shifted, this process is iterated. The improvement factor is given by

$$F_{J,S} = R\left(\sum_{i=1}^{m} x_i - \sum_{i=1}^{m} w_i - mR\right)$$

Where m=minimum between the time-units by which an activity is to be shifted and the activity duration; R=resource rate; x=sum of daily resources to which m daily resource units R are to be deducted; and w=sum of daily resources to which m daily resource units R are to be added.

4.9.1.1. Application of Resource Leveling using Minimum Moment Algorithm on Repetitive Activity "C".

As mentioned earlier LOB graph of repetitive activity C is translated into a CPM format to level activities using above mentioned procedures of the minimum moment algorithm. The procedures for implementing minimum moment algorithm on activity C can be overviewed in Appendix-C "Resource Leveling using Minimum Moment Algorithm". Figure 4.38 shows the enhancement in the resource usage profile compared to that before performing leveling using minimum moment algorithm.

Furthermore, the number of crews demanded to attain repetitive activity C is reduced from 14 to 12 crews by assuming that crews work in a single activity not multiple one in LOB as displayed in figure 4.39.

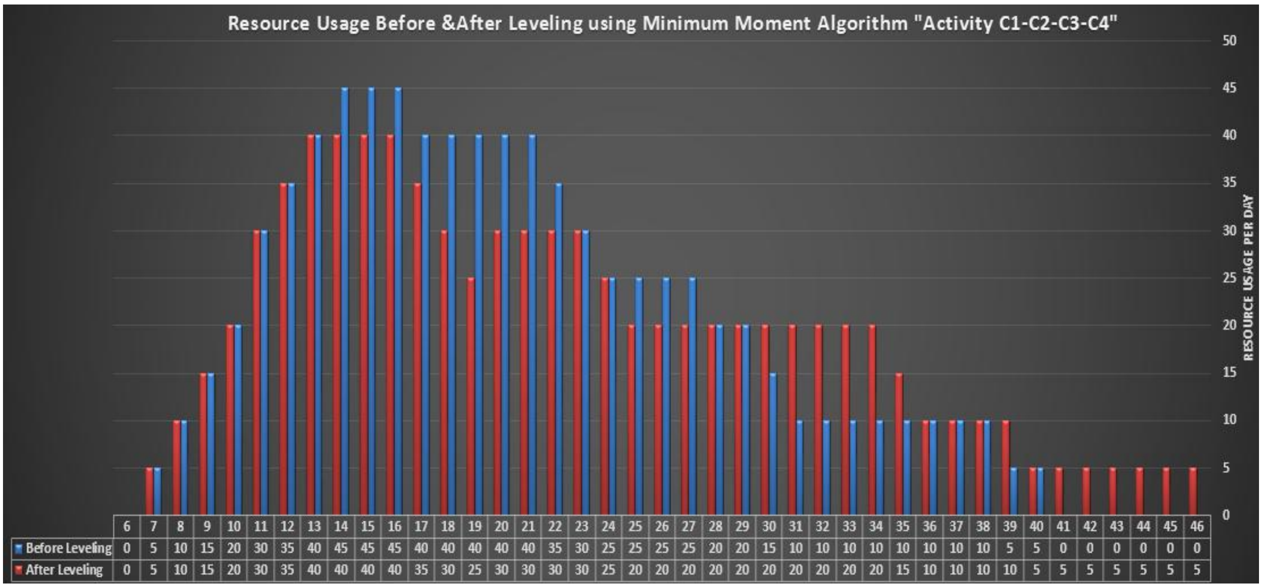


Figure 4.38: Resource leveling histogram after utilizing minimum moment algorithm on activity C

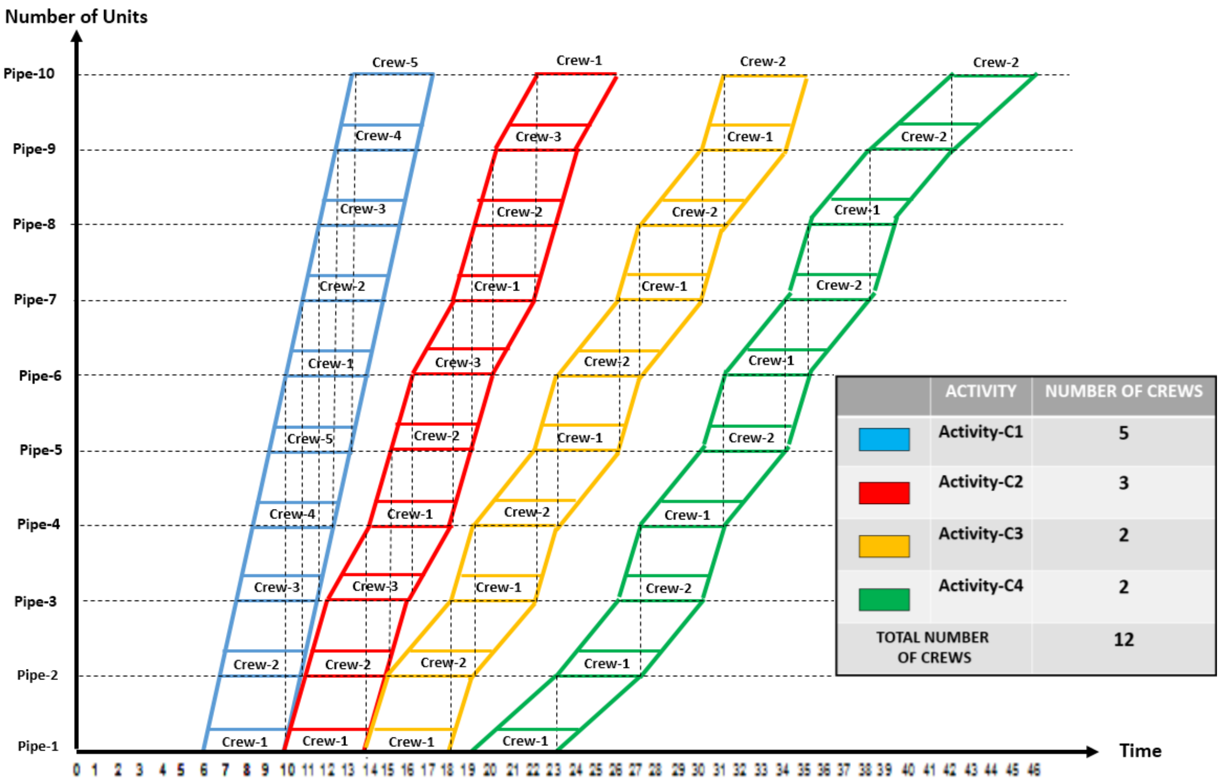


Figure 4.39: LOB representation of Activity "C" after leveling using minimum moment algorithm

4.9.1.2. Application of proposed optimization model on activity "C" after leveling with minimum moment algorithm.

Figure 4.40 shows graph theory network obtained after implementing the optimization engine using MATLAB. Graph theory network presents all possible paths of crews, which consequently results in generating and allocation each crew route as previewed in figure 4.41.

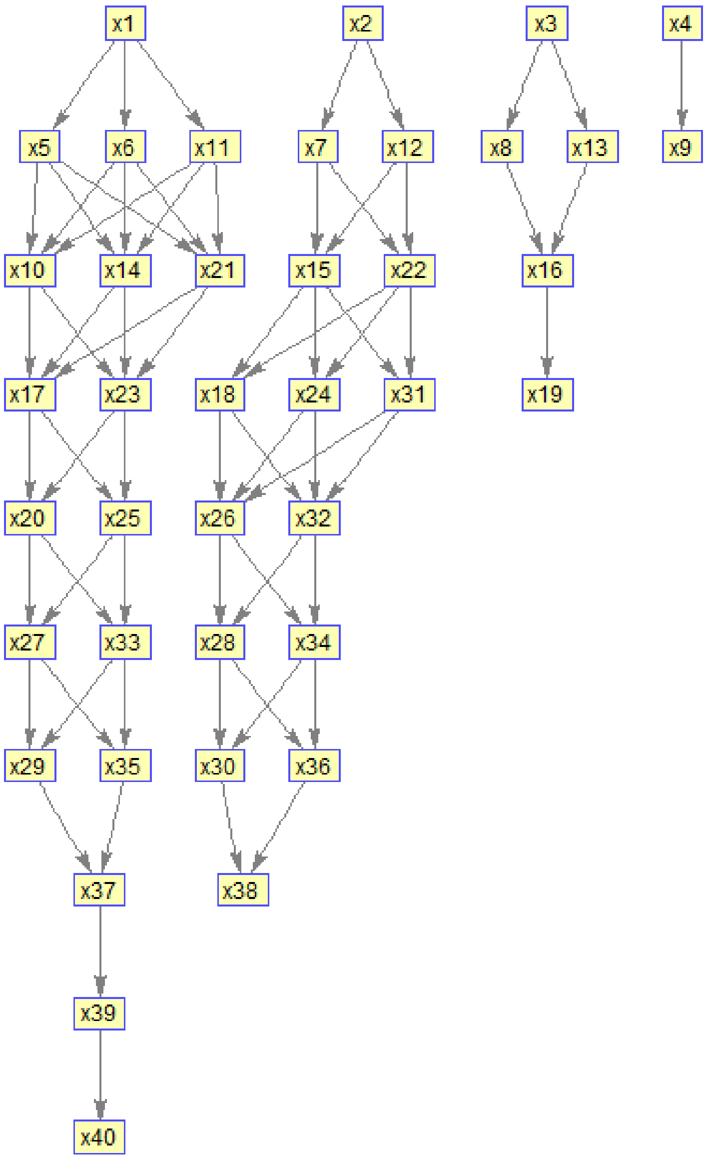


Figure 4.40: Graph theory network of Activity "C" after leveling using the optimization model

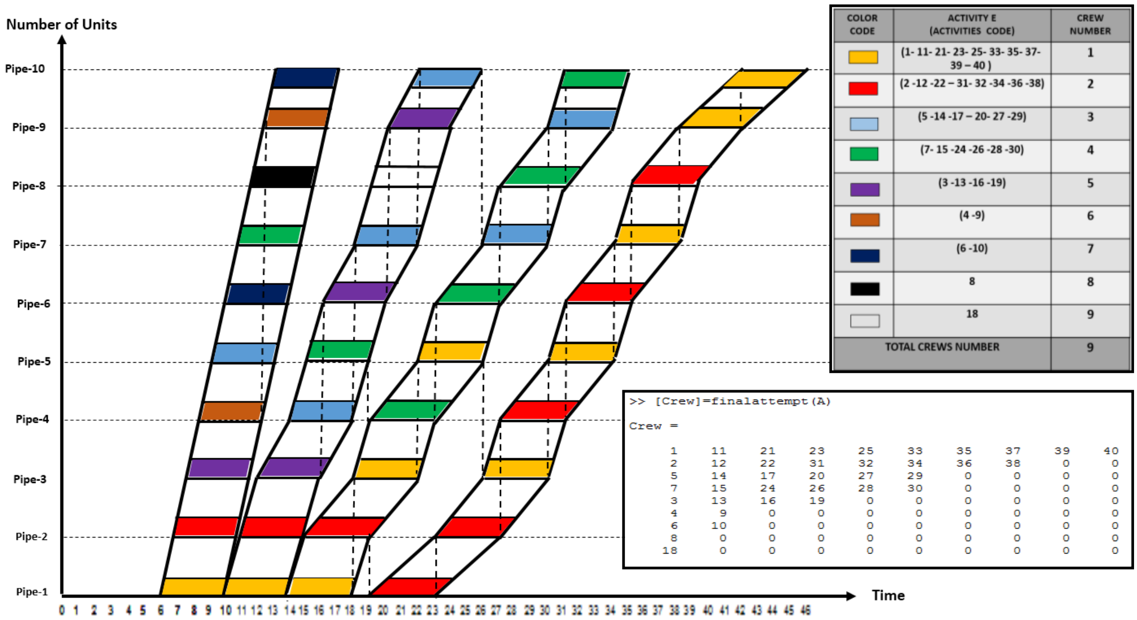


Fig. 4.41. LOB graph for activity C after implementation new crews routing using optimization model

4.9.2. Implementation of proposed simulation model for leveling resources using entropy maximization on activity "C".

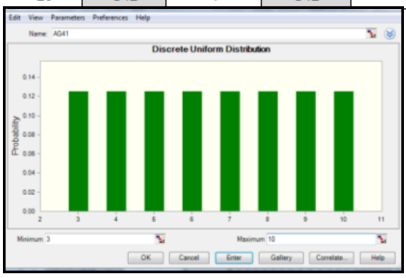
1- Activity and resource flow template

In this template, the following inputs are to be provided to the model.

- Different crews routing and activities enrolled in each crew as shown in figure 4.42.
- Early start, early finish of each activity as pointed out from LOB graph as shown in figure 4.42.
- Available number of resources per period for each activity, which is 5 resources per day as shown in resources column in figure 4.42.
- The total sum of number of resources per each activity, which is 20 resource per each activity (daily resource multiplied by activity duration).
- Indicating the total float for each activity to define the permeable stretching and splitting duration per each activity.

Figure 4.42 illustrates the activity and resource flow template used in the simulation process. The discrete uniform distribution of each activity with their parameters is explained deeply in Appendix-D.

Start Date =		6.0	Predecessor		Successor		Resource	Activities After Level			Total Resource		Allowable
Finish Date =		46.0											
ID	Activity	Activity Duration	P1	P2	S1	S2		ES	EF	TF			Finish Date
1	C11	4			C12		5	6	10		1	20	10
2	C12	4	C12		C13		5	10	14	3		20	17
3	C13	4	C13		C33		5	14	18	7		20	25
4	C33	4	C33		C53		5	18	22	6		20	28
5	C53	4	C53		C34		5	22	26	4		20	30
6	C34	4	C34		C54		5	26	30	2		20	32
7	C54	4	C54		C74		5	30	34	2		20	36
8	C74	4	C74		C94		5	34	38	2		20	40
9	C94	4	C94		C10-4		5	38	42	2		20	44
10	C10-4	4	C10-4		C21		5	42	46			20	46
11	C21	4	C21		C22		5	7	11		2	20	11
12	C22	4	C22		C23		5	11	15	3		20	18
13	C23	4	C23		C14		5	15	19	7		20	26
14	C14	4	C14		C24		5	19	23	5		20	28
15	C24	4	C24		C44		5	23	27	3		20	30
16	C44	4	C44		C64		5	27	31	3		20	34
17	C64	4	C64		C84		5	31	35	3		20	38
18	C84	4	C84		C51		5	35	39	3		20	42
19	C51	4	C51		C42		5	10	14			20	14
20	C42	4	C42		C72		5	14	18	2		20	20
					C10-2		5	18	22	1		20	23



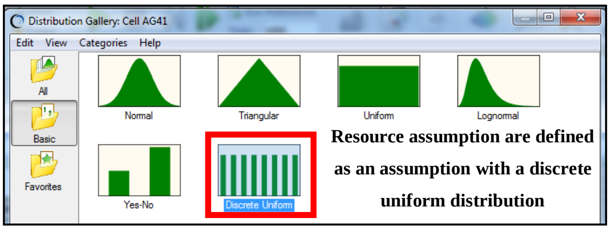


Fig. 4.42. A screen shot for the activity and resource flow template of activity "C"

2- Bar chart template

Figure 4.43 shows the bar chart template representing the stretching or crunching of each activity duration according to the assumed resource assignment that are randomly selected from discrete uniform distributions with a minimum and maximum value in accordance resource type and based on experience. Nevertheless, in this template, daily resource usage is displayed accompanied with its entropy, which is calculated as follows:

- Entropy of daily resource usage = $R_d * Ln (R_d / R_T)$
- Total Entropy of an activity = Summation of total activities entropy * $(-1/ R_T)$

Where R_d is the daily resource usage; R_T is the total number of resource of an activity. The total project duration, total activity entropy and total number of resource of an activity are defined as a forecast probability, this is extensively illustrated in Appendix-D. A total of 500,000 simulation cycles are run on Crystal Ball Ribbon Simulation Software.

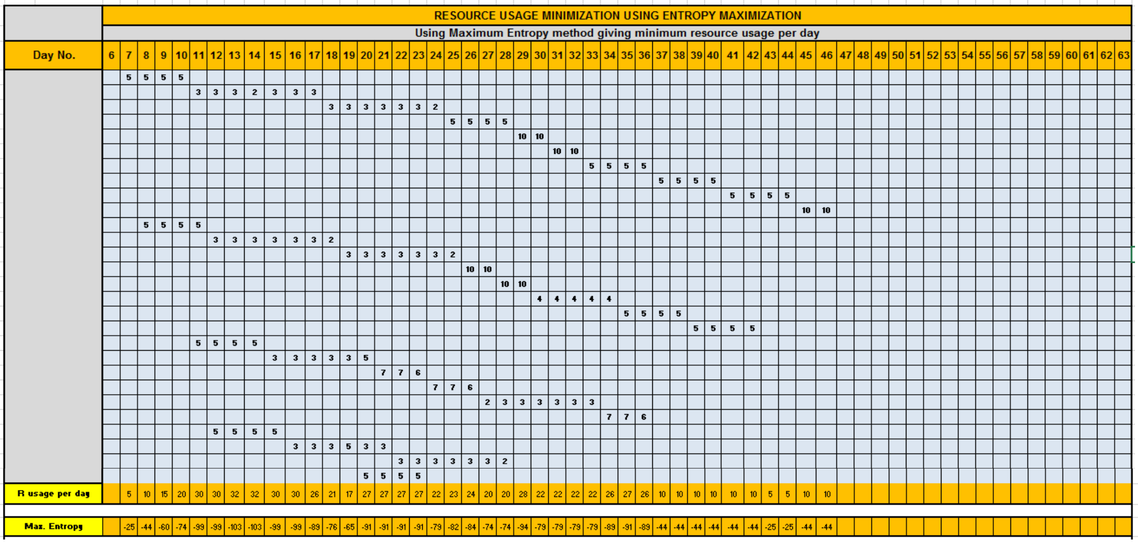
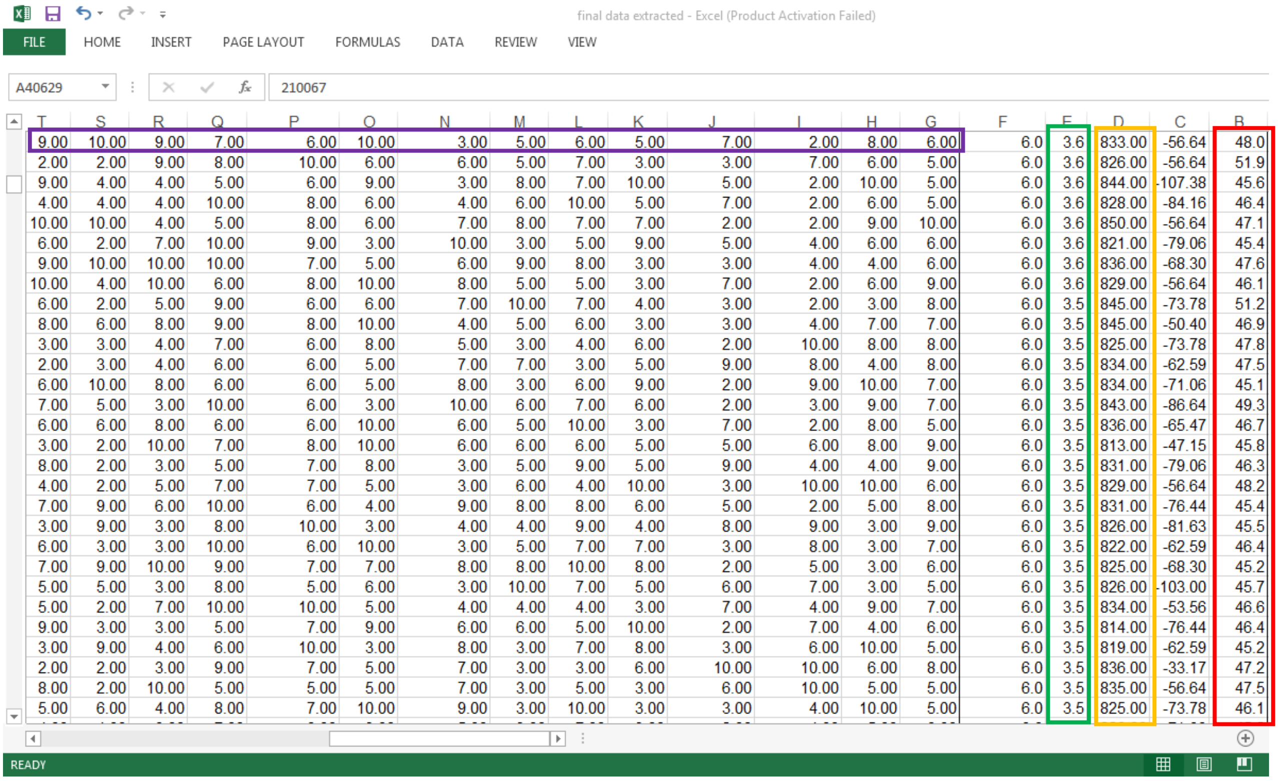


Figure 4.43. A screen shot for bar chart template of activity "C"

3- Maximum entropy analogy template

In this template, two types of an output are generated, the variable output which is the total entropy of the system, and the constant output that is the total resources of the activity and project duration. Moreover, the simulation results are filtered for values with a summation equal to the total number of available resources for the all activities and planned total activity duration as previewed in figure 4.44. Figure 4.45 shows daily resource usage profile before leveling, after leveling using minimum moment algorithm, and after leveling using entropy maximization metric. Figure 4.46 renders the application of the resource usage leveling using entropy maximization metric in LOB graph.



T	S	R	Q	P	O	N	M	L	K	J	I	H	G	F	E	D	C	B
9.00	10.00	9.00	7.00	6.00	10.00	3.00	5.00	6.00	5.00	7.00	2.00	8.00	6.00	6.0	3.6	833.00	-56.64	48.0
2.00	2.00	9.00	8.00	10.00	6.00	6.00	5.00	7.00	3.00	3.00	7.00	6.00	5.00	6.0	3.6	826.00	-56.64	51.9
9.00	4.00	4.00	5.00	6.00	9.00	3.00	8.00	7.00	10.00	5.00	2.00	10.00	5.00	6.0	3.6	844.00	-107.38	45.6
4.00	4.00	4.00	10.00	8.00	6.00	4.00	6.00	10.00	5.00	7.00	2.00	6.00	5.00	6.0	3.6	828.00	-84.16	46.4
10.00	10.00	4.00	5.00	8.00	6.00	7.00	8.00	7.00	7.00	2.00	2.00	9.00	10.00	6.0	3.6	850.00	-56.64	47.1
6.00	2.00	7.00	10.00	9.00	3.00	10.00	3.00	5.00	9.00	5.00	4.00	6.00	6.00	6.0	3.6	821.00	-79.06	45.4
9.00	10.00	10.00	10.00	7.00	5.00	6.00	9.00	8.00	3.00	3.00	4.00	4.00	6.00	6.0	3.6	836.00	-68.30	47.6
10.00	4.00	10.00	6.00	8.00	10.00	8.00	5.00	5.00	3.00	7.00	2.00	6.00	9.00	6.0	3.6	829.00	-56.64	46.1
6.00	2.00	5.00	9.00	6.00	6.00	7.00	10.00	7.00	4.00	3.00	2.00	3.00	8.00	6.0	3.5	845.00	-73.78	51.2
8.00	6.00	8.00	9.00	8.00	10.00	4.00	5.00	6.00	3.00	3.00	4.00	7.00	7.00	6.0	3.5	845.00	-50.40	46.9
3.00	3.00	4.00	7.00	6.00	8.00	5.00	3.00	4.00	6.00	2.00	10.00	8.00	8.00	6.0	3.5	825.00	-73.78	47.8
2.00	3.00	4.00	6.00	6.00	5.00	7.00	7.00	3.00	5.00	9.00	8.00	4.00	8.00	6.0	3.5	834.00	-62.59	47.5
6.00	10.00	8.00	6.00	6.00	5.00	8.00	3.00	6.00	9.00	2.00	9.00	10.00	7.00	6.0	3.5	834.00	-71.06	45.1
7.00	5.00	3.00	10.00	6.00	3.00	10.00	6.00	7.00	6.00	2.00	3.00	9.00	7.00	6.0	3.5	843.00	-86.64	49.3
6.00	6.00	8.00	6.00	6.00	10.00	6.00	5.00	10.00	3.00	7.00	2.00	8.00	5.00	6.0	3.5	836.00	-65.47	46.7
3.00	2.00	10.00	7.00	8.00	10.00	6.00	6.00	6.00	5.00	5.00	6.00	8.00	9.00	6.0	3.5	813.00	-47.15	45.8
8.00	2.00	3.00	5.00	7.00	8.00	3.00	5.00	9.00	5.00	9.00	4.00	4.00	9.00	6.0	3.5	831.00	-79.06	46.3
4.00	2.00	5.00	7.00	7.00	5.00	3.00	6.00	4.00	10.00	3.00	10.00	10.00	6.00	6.0	3.5	829.00	-56.64	48.2
7.00	9.00	6.00	10.00	6.00	4.00	9.00	8.00	8.00	6.00	5.00	2.00	5.00	8.00	6.0	3.5	831.00	-76.44	45.4
3.00	9.00	3.00	8.00	10.00	3.00	4.00	4.00	9.00	4.00	8.00	9.00	3.00	9.00	6.0	3.5	826.00	-81.63	45.5
6.00	3.00	3.00	10.00	6.00	10.00	3.00	5.00	7.00	7.00	3.00	8.00	3.00	7.00	6.0	3.5	822.00	-62.59	46.4
7.00	9.00	10.00	9.00	7.00	7.00	8.00	8.00	10.00	8.00	2.00	5.00	3.00	6.00	6.0	3.5	825.00	-68.30	45.2
5.00	5.00	3.00	8.00	5.00	6.00	3.00	10.00	7.00	5.00	6.00	7.00	3.00	5.00	6.0	3.5	826.00	-103.00	45.7
5.00	2.00	7.00	10.00	10.00	5.00	4.00	4.00	4.00	3.00	7.00	4.00	9.00	7.00	6.0	3.5	834.00	-53.56	46.6
9.00	3.00	3.00	5.00	7.00	9.00	6.00	6.00	5.00	10.00	2.00	7.00	4.00	6.00	6.0	3.5	814.00	-76.44	46.4
3.00	9.00	4.00	6.00	10.00	3.00	8.00	3.00	7.00	8.00	3.00	6.00	10.00	5.00	6.0	3.5	819.00	-62.59	45.2
2.00	2.00	3.00	9.00	7.00	5.00	7.00	3.00	3.00	6.00	10.00	10.00	6.00	8.00	6.0	3.5	836.00	-33.17	47.2
8.00	2.00	10.00	5.00	5.00	5.00	7.00	3.00	5.00	3.00	6.00	10.00	5.00	5.00	6.0	3.5	835.00	-56.64	47.5
5.00	6.00	4.00	8.00	7.00	10.00	9.00	3.00	10.00	3.00	3.00	4.00	10.00	5.00	6.0	3.5	825.00	-73.78	46.1

Entropy values | Total resource of an activity | Activity completion date | Resource assignment /day

Figure 4.44. A screen shot for simulation outcomes of an activity

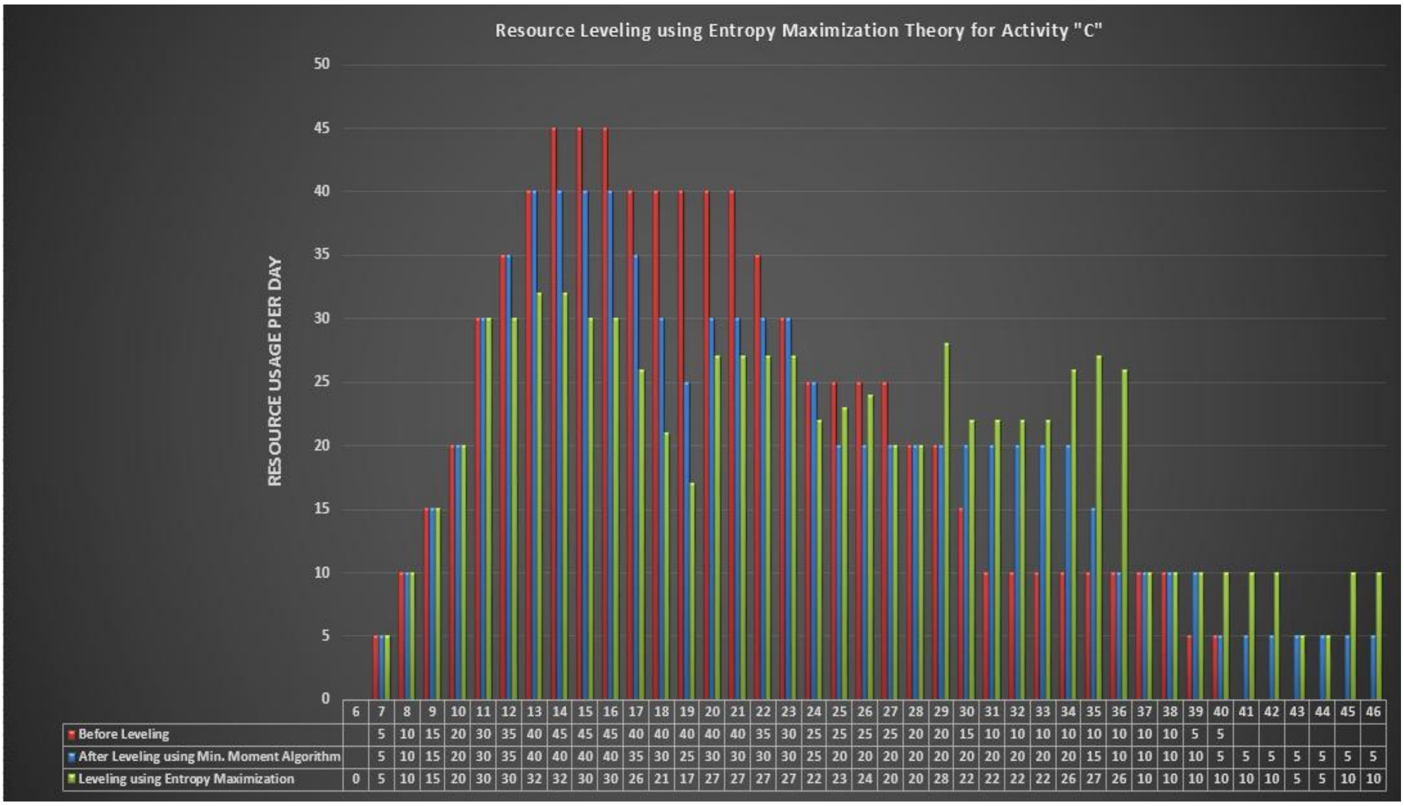


Figure 4.45. Daily resource usage after implementing entropy maximization

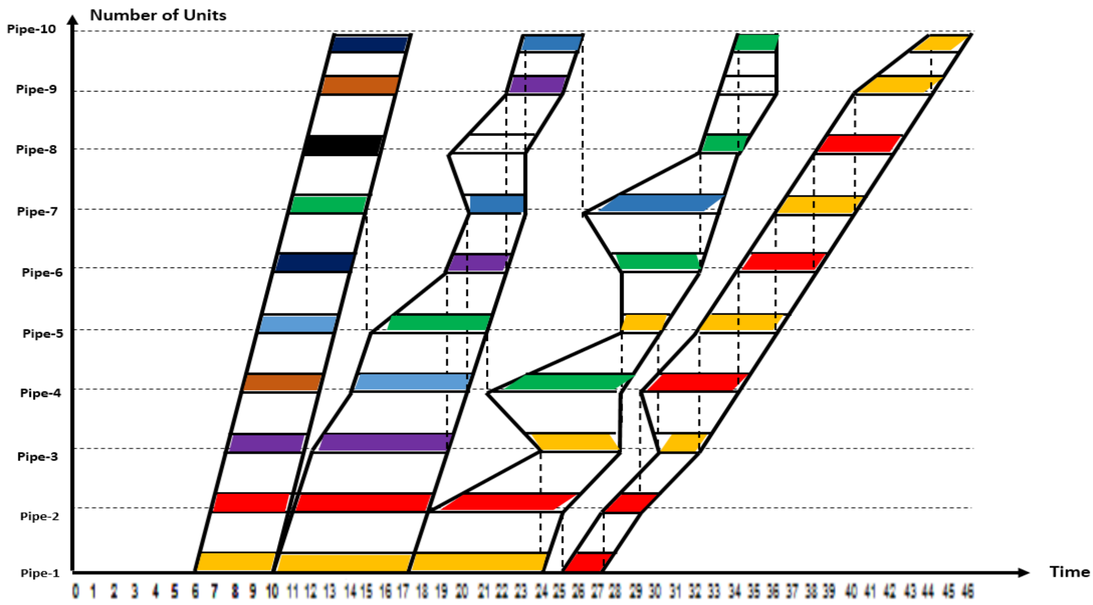


Figure 4.46. LOB graph of activity C after leveling using entropy maximization metric with different production rates among each activity

4.10. Summary and Conclusions of this section

A recap on the minimum moment method was presented, that was implemented to level, to fluctuate resource usage profile and to minimize number of crews utilized. This study presents a flexible simulation model for handling the resource leveling dilemmas for linear construction projects. The proposed model was constructed using crystal ball ribbon based on an entropy-maximization approach. The entropy-maximization method accounts for such possibility of allowing activity to be stretched without affecting total completion date of a project. From the resource leveling perspective, results generated using minimum moment algorithm and proposed model are compared that reveal an enhancement in the resource usage profile, and a reduction in the maximum resource usage per day from 40 to 32 using the proposed simulation model. Moreover the total entropy of the system before applying the developed model is 3.51, where as it became 3.6 after applying the system which reveals the smoothness of the resource usage profile and minimizes daily resource usage per day in case of the occurrence of limitation in resources.

CHAPTER 5 - CONCLUSIONS AND RECOMMENDATIONS

This is the last chapter of the write-up, which summarizes research outcomes reached up to this point. It recaps the limitations that was proposed and was attempted to be remedied in this thesis. Then, it outlines the main findings of this thesis and shows the main contributions to the knowledge. Finally, it highlights doable future research that relates to the topic.

5.1. Research Overview

Scheduling of repetitive projects represents a great challenge for construction scheduler and planner. Traditional CPM analysis does not suit properties of repetitive projects. Although the LOB scheduling technique has been widely used for scheduling linear repetitive construction projects, the fundamental principles of LOB have several shortfalls that raise many concerns about LOB, which need to be attuned and improved in order to comply with the nature of construction projects. The limitations of LOB and solutions are described below.

- Assuming the constancy, identically and linearity of the production rates and amount of work of an activity along the entire units, which is did not correlate well with real life projects.
- Regardless of being an essential tool for project scheduling, LOB technique is imprecise in detecting and pinpointing criticalness and floats; thus, LOB method requires to be developed more to single out critical, non-critical activities and floats.
- In LOB scheduling technique, the perception that crews continuously move in a linear vertical way only may be impractical. Linear repetitive projects encounters resource-constrained problem when there are limits on the availabilities of resources. Hence, LOB needs the occurrence of a mechanism

or an algorithm as a decision making tool to provide an optimum crews routing and distribution and to implement multi-task skilled crews between different activities in different units.

- Construction projects involve circumstances that need the use of visual color coded diagrams or interactive graphs for rendering each crew path to easily pinpoint different crews allocation and to single out concurrent activities attained at same instance.
- The application of the entropy maximization as a metric used to level resources in linear projects has not been previously taken into account.

As a result, there is a need for a practical and effective solution that guarantees a proper road map to accommodate the recent discussed limitation in LOB. The main rationale behind this, is developing a complete coherent framework for planning and scheduling repetitive projects where LOB scheduling technique is utilized. This proposed approach will better handle the following:

- Identifying the practical areas of potential enhancement that can improve the LOB scheduling tool by accounting for the breaking down of activities into sub-activities in order to formulate more precise linear schedules
- Supplementing the repetitive scheduling literature with a new algorithm and a decision supporting system that permits the evolvement and allocation of crews in a spontaneous routing between different activities in different units rather than sequential, and further, the crews working may be switched from linear vertical to spontaneous.
- The flexibility of implementing multi-task skilled crew in linear repetitive construction projects between different activities in different units that can lead to increased productivity, flexibility, and work continuity.

- Conducting a new resource leveling tool based on entropy maximization metric using a simulation model temple by permitting for activity duration to be extended or crunched to ensure minimizing resource fluctuations over time.

In addition, the methodology of breaking down of activities into sub-activities in order to formulate more efficient linear schedules that guarantees a proper criticalness and float analysis in LOB scheduling technique. Furthermore, the proposed framework is capable of minimizing resource usage, identifying optimum crews' route, different crews' allocation, and applying multi-task skilled using MATLAB R2013a, in which an algorithm as an optimization engine was built-in to attain the main objectives of the proposed model. The developed framework was illustrated using a real case study of installing ten identical sewage pipelines. A comparison was done between conventional LOB scheduling and proposed approach in order to track the different in crews' number, their formulation and to improve the efficiency in crews' utilization. The application of the model has shown a tremendous reduction in crews' utilization by approximately 36% from overall required number of crews in term of using traditional method, and representing a new formulation for continuous crews' usage in a spontaneous manner. Moreover, the model allowed the usage of multi-task crew in LOB; hence, cost efficiency of the entire project was enhanced.

Moreover, a computerized model is developed to minimize the total resource usage of a project by allowing the expanding or shrinking of activity durations and having different crews' size. A spreadsheet modeling tool is established using three template (activity and resource flow template, bar chart template, and entropy maximization template). A simulation engine was run using crystal ball ribbon software. The same abovementioned case study was applied to figure out and test the validation of the proposed model

5.2. Conclusion and research contribution.

The new approach for scheduling multi repetitive projects has the potential to revolutionize the way linear schedules are generated and managed. Based on the current development, this research makes a number of contributions:

- Better understanding of linear construction scheduling needs**:** This study has provided an in-depth review of the research reported in literature with respect to the theoretical and practical drawbacks of LOB. Based on these shortfalls, areas in LOB scheduling procedures that require enhancement have been identified.
- Better representation of the intention of activity relationships; as a result, a better identification of criticalness and floats in LOB are attained, and precise critical path is identified.
- Introducing a decision-making, supporting, optimization engine that deals with different crew allocation and formulate the optimum crews routing to attain near optimum crew usage and allocation.
- The usability and extensibility of implementing multi- task skilled crews in linear construction projects between different activities in different units.
- Minimizing the total resource usage of a project, while meeting the requirements for work continuity and the target deadline of each activity by promoting the stretching or crunching of an activity duration and altering crew's sizes.

Recommendation for Future Research

Several aspects of the proposed approach could be improved through further research. The following areas are recommended for further study in order to enhance the capability of proposed approach in scheduling linear projects so that it will be more practical for real construction projects:

- Resource leveling using entropy maximization metric could be converted into a heuristic algorithm that can be implemented without the use of simulation.
- The effects of multiple crew assignments per activity on productivity loss and duration.
- The impact of weather and other global factors on crews' productivity could be incorporated in the entropy model in order to be more realistic, and more effective.
- An algorithm could be developed to accurately forecast the minimum and maximum daily resource usage without out affecting the productivity.
- Features related to financing decisions and project control could be incorporated into the proposed algorithm using MATLAB, such as cash flow analysis, earned value, earned schedule, and productivity analysis.

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APPENDICIES

Appendix A- Calculation Procedures of integrated CPM and LOB

A.1. Calculation of desired rate of delivery

Rd= N-1/Tp-T1+Tf, Where N= number of repetitive units, Tp is the desired Completion date of the whole project, T1 is the completion date of one single unit, and Tf is the total float of noncritical activities to reduce the number of crews employed and to relax production rate of an activity (Suhail and Neale 1994).

A.2. Calculation of number of crews required

- Cdi= di * Rdi, where di is the duration of an activity in one single unit
- Cai =rounded up Cdi

A.3. Calculation of actual production rate

- Rai= Cai / di .Where Cai is the actual number of crew needed to perform a specific repetitive activity, and Rai is the actual rate of progress of an activity

A.4. Calculation of each activity duration

Computing the duration of an activity i over all units (Di), in which STiN = start time of last unit; STi1 = start time of first unit; and Di= duration along all units of activity i. Di =di + STiN − STi1 = di+ (N−1) / Ra.

A.5. Specifying logical relationships

Specifying logical relationships using overlapping activities by comparing the actual progress rate of predecessor and successor activities. If the actual progress rate of Predecessor is greater than actual progress rate of successor, then a start to start relationship will be applied plus buffer time. If the actual progress rate of Predecessor is less than actual progress rate of successor, then a finish to finish relationship will be applied plus buffer time. Finally, if the actual progress rate of Predecessor is equal to actual progress rate of successor, then a start to start relationship will be applied plus buffer time (Ammar, 2013).

A.6. Performing a time scheduling calculations

Performing a time scheduling calculations using CPM. Forward pass calculations are conducted to determine early timings of activities, whereas late timings of activities are determined in the backward pass calculations.

A.7 Calculation Procedures of integrated CPM and LOB for the hypothetical case study using conventional approach

Activity	Duration	TF	Rd	Cd	Ca	Ra	ST_n-ST_1	Days
A	2	0	1.125	2.25	3	1.5	6	8
B	1	0	1.125	1.125	2	2	4.5	5.5
C	16	0	1.125	18	18	1.125	8	24
D	20	0	1.125	22.5	23	1.15	7.82609	28
E	16	4	0.75	12	12	0.75	12	28
F	36	0	1.125	40.5	41	1.138889	7.90244	44
G	4	0	1.125	4.5	5	1.25	7.2	11.2
H	8	46	0.16666667	1.333333	2	0.25	36	44
I	17	46	0.16666667	2.833333	3	0.176471	51	68
J	5	46	0.16666667	0.833333	1	0.2	45	50
K	4	0	1.125	4.5	5	1.25	7.2	11.2
L	3	0	1.125	3.375	4	1.333333	6.75	9.75

Table A-1. LOB calculation of the proposed case study using conventional approach.

Activity	Ra (Act.)	Succ.	Ra (Succ.)	Relation	Lag (days)
A	1.5	B	2	FF	1
B	2	C	1.125	SS	1
		H	0.25	SS	1
C	1.125	D	1.15	FF	20
		E	0.75	SS	16
D	1.15	F	1.138888889	SS	20
E	0.75	F	1.138888889	FF	36
F	1.138888889	G	1.25	FF	4
G	1.25	K	1.25	SS	4
H	0.25	I	0.176470588	SS	8
I	0.176470588	J	0.2	FF	5
J	0.2	K	1.25	FF	4
K	1.25	L	1.333333333	FF	3
L	1.333333333				

Table A-2. Computing the duration of repetitive activities of the case study.

A.8. Calculation Procedures of integrated CPM and LOB for the hypothetical case study using the new approach

Table A-3. LOB calculation of the proposed case study using new approach

ACTIVITY	D_i	TF_{si}	Rd_{si}	C_{di}	C_{ai}	R_{ai}	ST_n-ST_1	Days
A	2	0	1.1538462	2.30769231	3	1.5	6	8
B	1	0	1.1538462	1.15384615	2	2	4.5	5.5
C1	4	0	1.1538462	4.61538462	5	1.25	7.2	11.2
C2	4	4	0.7627119	3.05084746	4	1	9	13
C3	4	8	0.5696203	2.27848101	3	0.75	12	16
C4	4	12	0.4545455	1.81818182	2	0.5	18	22
D1	5	0	1.1538462	5.76923077	6	1.2	7.5	12.5
D2	5	3	0.8333333	4.16666667	5	1	9	14
D3	5	6	0.6521739	3.26086957	4	0.8	11.25	16.25
D4	5	9	0.5357143	2.67857143	3	0.6	15	20
E1	4	1	1.0227273	4.09090909	5	1.25	7.2	11.2
E2	4	5	0.703125	2.8125	3	0.75	12	16
E3	4	9	0.5357143	2.14285714	3	0.75	12	16
E4	4	13	0.4326923	1.73076923	2	0.5	18	22
F1	9	0	1.1538462	10	10	1.11111111	8.1	17.1
F2	9	0	1.1538462	10	10	1.11111111	8.1	17.1
F3	9	0	1.1538462	10	10	1.11111111	8.1	17.1
F4	9	0	1.1538462	10	10	1.11111111	8.1	17.1
G1	1	21	0.3125	0.3125	1	1	9	10
G2	1	14	0.412844	0.41284404	1	1	9	10
G3	1	7	0.6081081	0.60810811	1	1	9	10
G4	1	0	1.1538462	1.15384615	2	2	4.5	5.5
H	8	12	0.4545455	3.63636364	4	0.5	18	26
I	17	12	0.4545455	7.72727273	8	0.47058824	19.125	36.125
J	5	12	0.4545455	2.27272727	3	0.6	15	20
K	4	0	1.1538462	4.61538462	5	1.25	7.2	11.2
L	3	0	1.1538462	3.46153846	4	1.33333333	6.75	9.75

Table A-4. Computing the duration of repetitive activities of the case study.

Activity (Pred)	Rasi (Pred.)	Activity (Succ).	RaSi (Succ.)	Logic Relation	LAG
A	1.5	B	2	FF-2	3
B	2	C1	1.25	SS-2	2
		H	0.5	SS-2	2
C1	1.25	C2	1	SS-4	4
		D1	1.2	SS-4	4
		E1	1.25	SS-4	4
C2	1	C3	0.75	SS-4	4
		D2	1	SS-4	5
		E2	0.75	SS-4	4
C3	0.75	C4	0.5	SS-4	4
		D3	0.8	FF-5	5
		E3	0.75	SS-4	4
C4	0.5	D4	0.6	FF-5	5
		E4	0.5	SS-4	4
D1	1.2	D2	1	SS-5	5
		F1	1.1111111	SS-5	5
D2	1	D3	0.8	SS-5	5
		F2	1.1111111	FF-9	7
D3	0.8	D4	0.6	SS-5	5
		F3	1.1111111	FF-9	7
D4	0.6	F4	1.1111111	FF-9	7
E1	1.25	E2	0.75	SS-4	4
		F1	1.1111111	SS-4	4
E2	0.75	E3	0.75	SS-4	4
		F2	1.1111111	FF-9	7
E3	0.75	E4	0.5	SS-4	4
		F3	1.1111111	FF-9	7
E4	0.5	F4	1.1111111	FF-9	7
F1	1.111111	F2	1.1111111	SS-9	7
		G1	1	SS-9	1
F2	1.111111	F3	1.1111111	SS-9	7
		G2	1	SS-9	1
F3	1.111111	F4	1.1111111	SS-9	7
		G3	1	SS-9	1
F4	1.111111	G4	2	FF-1	1
G1	1	G2	1	SS-1	1
G2	1	G3	1	SS-1	1
G3	1	G4	2	SS-1	1
G4	2	K	1.25	SS-1	1
H	0.5	I	0.4705882	SS-8	9
I	0.470588	J	0.6	FF-5	6
J	0.6	K	1.25	FF-4	5
K	1.25	L	1.3333333	FF-3	5
L	1.333333				

Appendix B- The optimization model using MATLAB Algorithm

B.1. Defining initial input values for activity C (Start, finish date& Act. No.)

Repetitive Activity " C "					
Start Date =		6.0	Activity		
Finish Date =		40.0	Before Leveling		
ID	Activity Code	Activity Duration	ES	EF	Act. No.
1	C1-1	4	6	10	1
2	C2-1	4	7	11	2
3	C3-1	4	8	12	3
4	C4-1	4	9	13	4
5	C5-1	4	10	14	5
6	C6-1	4	10	14	6
7	C7-1	4	11	15	7
8	C8-1	4	12	16	8
9	C9-1	4	13	17	9
10	C10-1	4	14	18	10
11	C1-2	4	10	14	11
12	C2-2	4	11	15	12
13	C3-2	4	12	16	13
14	C4-2	4	13	17	14
15	C5-2	4	14	18	15
16	C6-2	4	15	19	16
17	C7-2	4	16	20	17
18	C8-2	4	17	21	18
19	C9-2	4	18	22	19
20	C10-2	4	19	23	20
21	C1-3	4	14	18	21
22	C2-3	4	15	19	22
23	C3-3	4	17	21	23
24	C4-3	4	18	22	24
25	C5-3	4	19	23	25
26	C6-3	4	21	25	26
27	C7-3	4	22	26	27
28	C8-3	4	23	27	28
29	C9-3	4	25	29	29
30	C10-3	4	26	30	30
31	C1-4	4	18	22	31
32	C2-4	4	20	24	32
33	C3-4	4	22	26	33
34	C4-4	4	24	28	34
35	C5-4	4	26	30	35
36	C6-4	4	28	32	36
37	C7-4	4	30	34	37
38	C8-4	4	32	36	38
39	C9-4	4	34	38	39
40	C10-4	4	36	40	40

B.2. Defining initial input values for activity D (Start, finish date& Act. No.)

Repetitive Activity " D "					
Start Date =		10.0	Activity		
Finish Date =		45.0	Before Leveling		
ID	Activity Code	Activity Duration	ES	EF	Act. No.
1	D1-1	5	10	15	1
2	D2-1	5	11	16	2
3	D3-1	5	12	17	3
4	D4-1	5	13	18	4
5	D5-1	5	14	19	5
6	D6-1	5	14	19	6
7	D7-1	5	15	20	7
8	D8-1	5	16	21	8
9	D9-1	5	17	22	9
10	D10-1	5	18	23	10
11	D1-2	5	15	20	11
12	D2-2	5	16	21	12
13	D3-2	5	17	22	13
14	D4-2	5	18	23	14
15	D5-2	5	19	24	15
16	D6-2	5	20	25	16
17	D7-2	5	21	26	17
18	D8-2	5	22	27	18
19	D9-2	5	23	28	19
20	D10-2	5	24	29	20
21	D1-3	5	20	25	21
22	D2-3	5	22	27	22
23	D3-3	5	23	28	23
24	D4-3	5	24	29	24
25	D5-3	5	25	30	25
26	D6-3	5	27	32	26
27	D7-3	5	28	33	27
28	D8-3	5	29	34	28
29	D9-3	5	30	35	29
30	D10-3	5	32	37	30
31	D1-4	5	25	30	31
32	D2-4	5	27	32	32
33	D3-4	5	29	34	33
34	D4-4	5	30	35	34
35	D5-4	5	32	37	35
36	D6-4	5	34	39	36
37	D7-4	5	35	40	37
38	D8-4	5	37	42	38
39	D9-4	5	39	44	39
40	D10-4	5	40	45	40

B.3. Defining initial input values for activity E (Start, finish date& Act. No.)

Repetitive Activity " E "					
Start Date =		10.0	Activity		
Finish Date =		44.0	Before Leveling		
ID	Activity Code	Activity Duration	ES	EF	Act. No.
1	E1-1	4	10	14	1
2	E2-1	4	11	15	2
3	E3-1	4	12	16	3
4	E4-1	4	13	17	4
5	E5-1	4	14	18	5
6	E6-1	4	14	18	6
7	E7-1	4	15	19	7
8	E8-1	4	16	20	8
9	E9-1	4	17	21	9
10	E10-1	4	18	22	10
11	E1-2	4	14	18	11
12	E2-2	4	16	20	12
13	E3-2	4	17	21	13
14	E4-2	4	18	22	14
15	E5-2	4	20	24	15
16	E6-2	4	21	25	16
17	E7-2	4	22	26	17
18	E8-2	4	24	28	18
19	E9-2	4	25	29	19
20	E10-2	4	26	30	20
21	E1-3	4	18	22	21
22	E2-3	4	20	24	22
23	E3-3	4	21	25	23
24	E4-3	4	22	26	24
25	E5-3	4	24	28	25
26	E6-3	4	25	29	26
27	E7-3	4	26	30	27
28	E8-3	4	28	32	28
29	E9-3	4	29	33	29
30	E10-3	4	30	34	30
31	E1-4	4	22	26	31
32	E2-4	4	24	28	32
33	E3-4	4	26	30	33
34	E4-4	4	28	32	34
35	E5-4	4	30	34	35
36	E6-4	4	32	36	36
37	E7-4	4	34	38	37
38	E8-4	4	36	40	38
39	E9-4	4	38	42	39
40	E10-4	4	40	44	40

B.4. Defining initial input values for activity F (Start, finish date& Act. No.)

Repetitive Activity " F "					
Start Date =		15.0	Activity		
Finish Date =		60.0	Before Leveling		
ID	Activity Code	Activity Duration	ES	EF	Act. No.
1	F1-1	9	15	24	1
2	F2-1	9	16	25	2
3	F3-1	9	17	26	3
4	F4-1	9	18	27	4
5	F5-1	9	19	28	5
6	F6-1	9	20	29	6
7	F7-1	9	21	30	7
8	F8-1	9	22	31	8
9	F9-1	9	23	32	9
10	F10-1	9	24	33	10
11	F1-2	9	24	33	11
12	F2-2	9	25	34	12
13	F3-2	9	26	35	13
14	F4-2	9	27	36	14
15	F5-2	9	28	37	15
16	F6-2	9	29	38	16
17	F7-2	9	30	39	17
18	F8-2	9	31	40	18
19	F9-2	9	32	41	19
20	F10-2	9	33	42	20
21	F1-3	9	33	42	21
22	F2-3	9	34	43	22
23	F3-3	9	35	44	23
24	F4-3	9	36	45	24
25	F5-3	9	37	46	25
26	F6-3	9	38	47	26
27	F7-3	9	39	48	27
28	F8-3	9	40	49	28
29	F9-3	9	41	50	29
30	F10-3	9	42	51	30
31	F1-4	9	42	51	31
32	F2-4	9	43	52	32
33	F3-4	9	44	53	33
34	F4-4	9	45	54	34
35	F5-4	9	46	55	35
36	F6-4	9	47	56	36
37	F7-4	9	48	57	37
38	F8-4	9	49	58	38
39	F9-4	9	50	59	39
40	F10-4	9	51	60	40

B.5. Defining initial input values for activity G4, K and L (Start, finish date& Act. No.)

Repetitive Activity " G4 "					
Start Date =		55.0	Activity		
Finish Date =		61.0	Before Leveling		
ID	Activity Code	Activity Duration	ES	EF	Act. No.
1	G1-4	1	55.00	56.00	1
2	G2-4	1	55.50	56.50	2
3	G3-4	1	56.00	57.00	3
4	G4-4	1	56.50	57.50	4
5	G5-4	1	57.00	58.00	5
6	G6-4	1	57.50	58.50	6
7	G7-4	1	58.00	59.00	7
8	G8-4	1	58.50	59.50	8
9	G9-4	1	59.00	60.00	9
10	G10-4	1	59.50	60.50	10

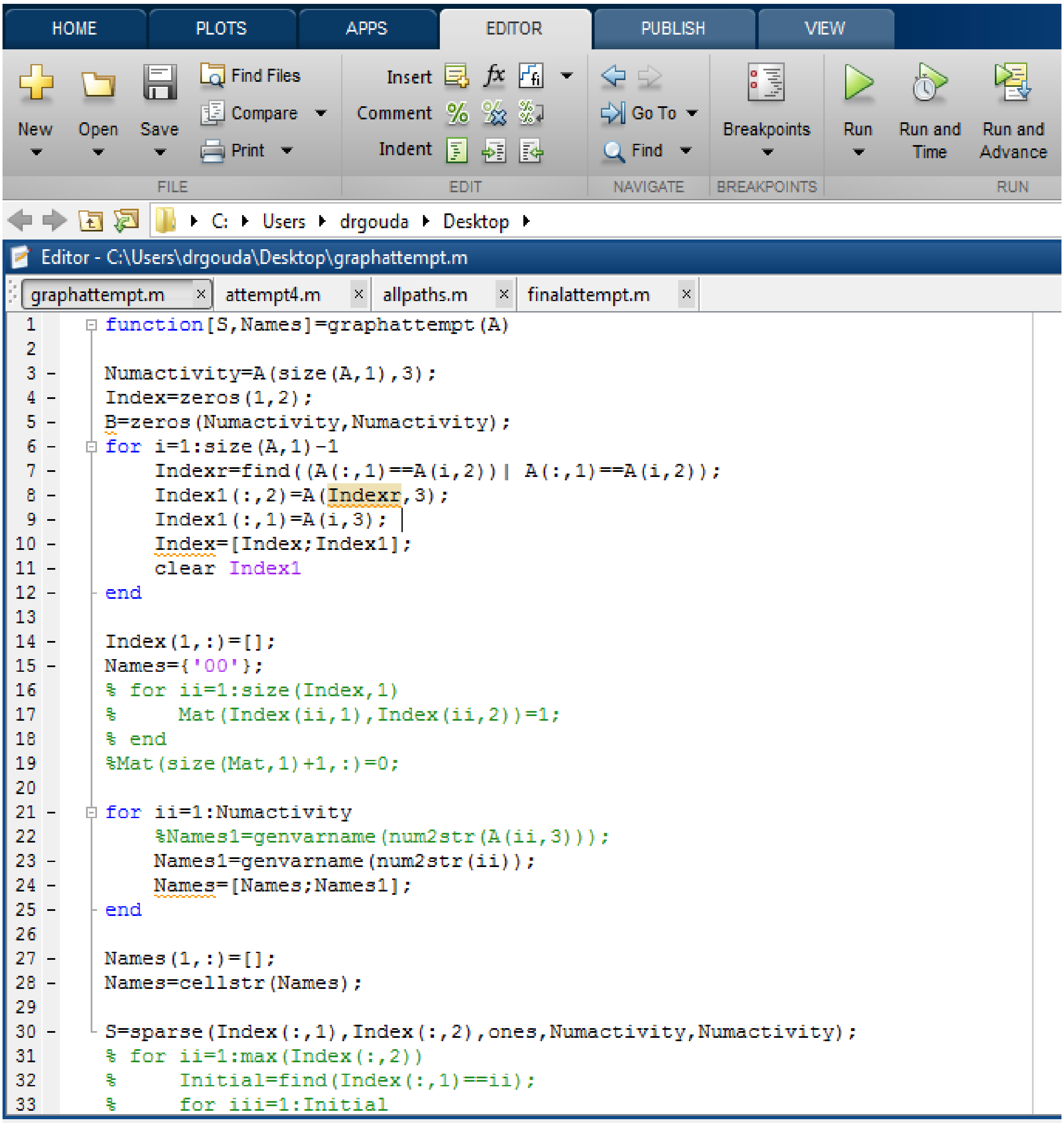
Repetitive Activity " K "					
Start Date =		56.0	Activity		
Finish Date =		68.0	Before Leveling		
ID	Activity Code	Activity Duration	ES	EF	Act. No
1	K-1	4	56.00	60.00	1
2	K-2	4	56.80	60.80	2
3	K-3	4	58.00	62.00	3
4	K-4	4	58.80	62.80	4
5	K-5	4	59.60	63.60	5
6	K-6	4	60.40	64.40	6
7	K-7	4	61.20	65.20	7
8	K-8	4	62.00	66.00	8
9	K-9	4	62.80	66.80	9
10	K-10	4	63.60	67.60	10

Repetitive Activity " L "					
Start Date =		61.0	Activity		
Finish Date =		71.0	Before Leveling		
ID	Activity Code	Activity Duration	ES	EF	Act. No.
1	L-1	3	61.00	64.00	1
2	L-2	3	62.00	65.00	2
3	L-3	3	62.75	65.75	3
4	L-4	3	63.50	66.50	4
5	L-5	3	64.25	67.25	5
6	L-6	3	65.00	68.00	6
7	L-7	3	65.75	68.75	7
8	L-8	3	66.50	69.50	8
9	L-9	3	67.25	70.25	9
10	L-10	3	68.00	71.00	10

B.6. Defining initial input values for activity E (Start, finish date& Act. No.) after leveling using minimum moment algorithm.

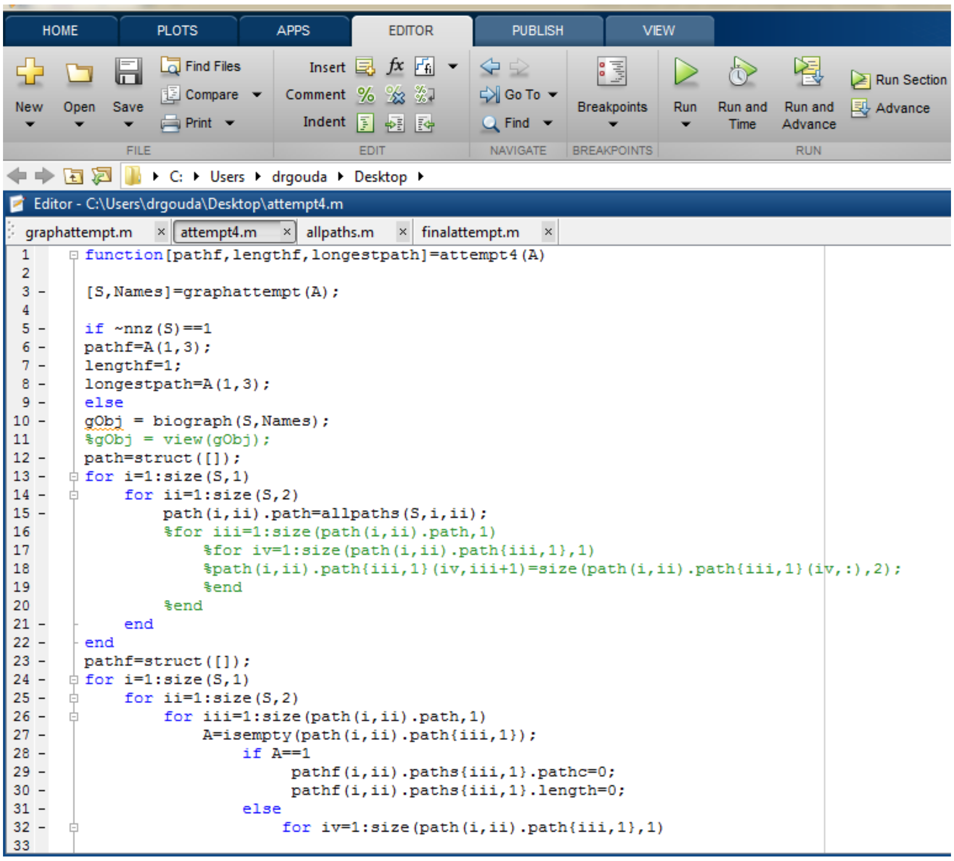
Repetitive Activity " C "					
Start Date =		6.0	Activity After Leveling		
Finish Date =		46.0	Using Min. Moment Alg.		
ID	Activity Code	Activity Duration	ES	EF	Act. No.
1	C1-1	4	6	10	1
2	C2-1	4	7	11	2
3	C3-1	4	8	12	3
4	C4-1	4	9	13	4
5	C5-1	4	10	14	5
6	C6-1	4	10	14	6
7	C7-1	4	11	15	7
8	C8-1	4	12	16	8
9	C9-1	4	13	17	9
10	C10-1	4	14	18	10
11	C1-2	4	10	14	11
12	C2-2	4	11	15	12
13	C3-2	4	12	16	13
14	C4-2	4	14	18	14
15	C5-2	4	15	19	15
16	C6-2	4	16	20	16
17	C7-2	4	18	22	17
18	C8-2	4	19	23	18
19	C9-2	4	20	24	19
20	C10-2	4	22	26	20
21	C1-3	4	14	18	21
22	C2-3	4	15	19	22
23	C3-3	4	18	22	23
24	C4-3	4	19	23	24
25	C5-3	4	22	26	25
26	C6-3	4	23	27	26
27	C7-3	4	26	30	27
28	C8-3	4	27	31	28
29	C9-3	4	30	34	29
30	C10-3	4	31	35	30
31	C1-4	4	19	23	31
32	C2-4	4	23	27	32
33	C3-4	4	26	30	33
34	C4-4	4	27	31	34
35	C5-4	4	30	34	35
36	C6-4	4	31	35	36
37	C7-4	4	34	38	37
38	C8-4	4	35	39	38
39	C9-4	4	38	42	39
40	C10-4	4	42	46	40

B.7. Code or algorithm of MATLAB optimization model

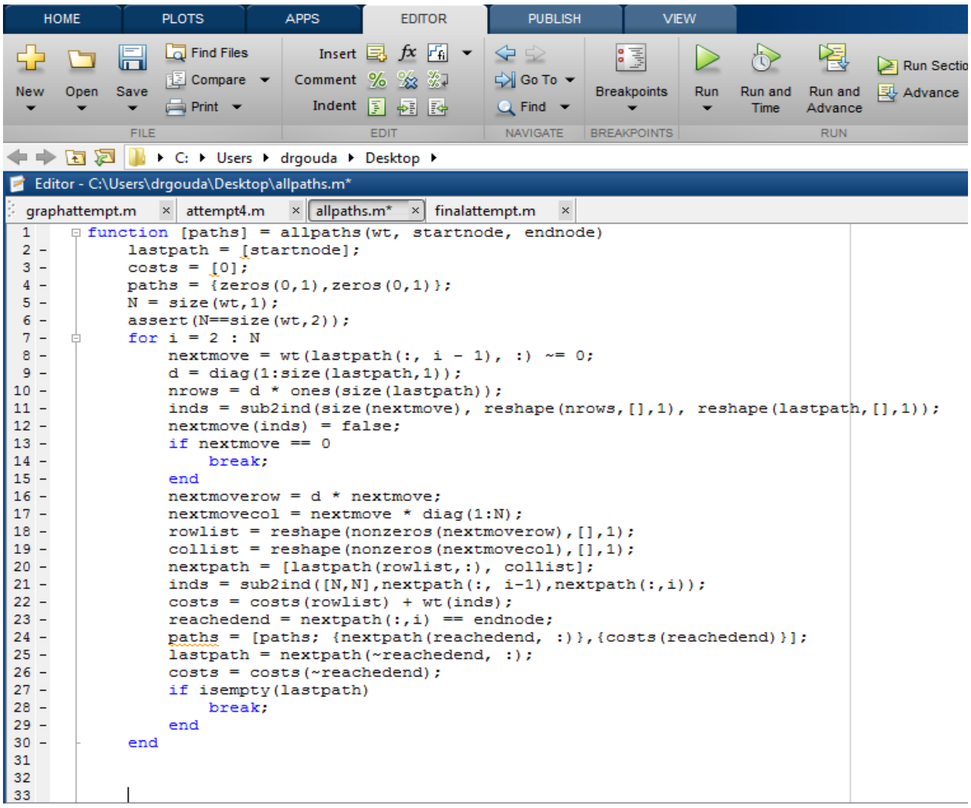



```
function[S,Names]=graphattempt(A)

Numactivity=A(size(A,1),3);
Index=zeros(1,2);
B=zeros(Numactivity,Numactivity);
for i=1:size(A,1)-1
    Indexr=find((A(:,1)==A(i,2))| A(:,1)==A(i,2));
    Index1(:,2)=A(Indexr,3);
    Index1(:,1)=A(i,3);
    Index=[Index;Index1];
    clear Index1
end

Index(1,:)=[];
Names={'00'};
% for ii=1:size(Index,1)
%     Mat(Index(ii,1),Index(ii,2))=1;
% end
%Mat(size(Mat,1)+1,:)=0;

for ii=1:Numactivity
    %Names1=genvarname(num2str(A(ii,3)));
    Names1=genvarname(num2str(ii));
    Names=[Names;Names1];
end

Names(1,:)=[];
Names=cellstr(Names);

S=sparse(Index(:,1),Index(:,2),ones,Numactivity,Numactivity);
% for ii=1:max(Index(:,2))
%     Initial=find(Index(:,1)==ii);
%     for iii=1:Initial
```

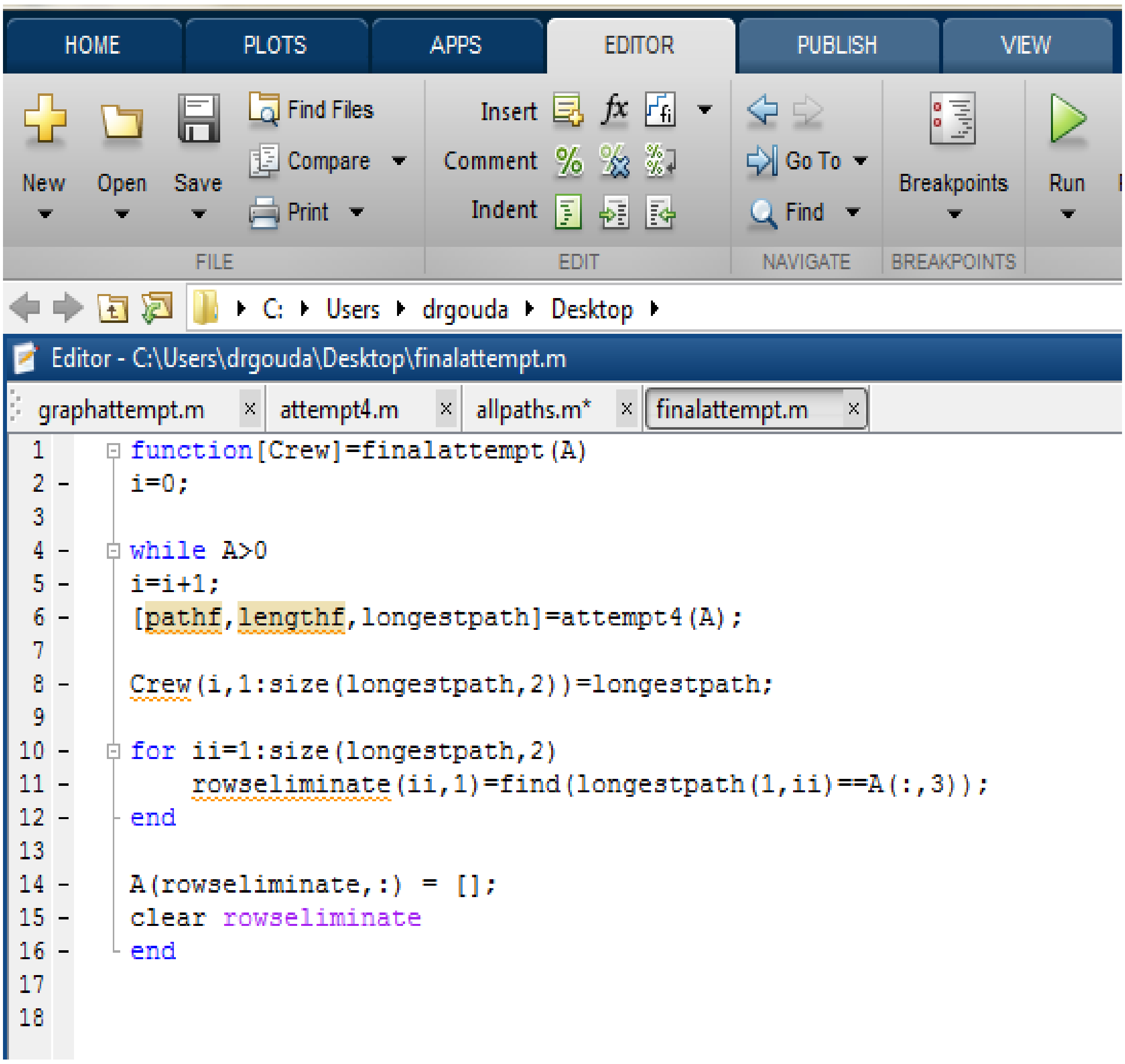
Screen shot for sparse matrix code on MATLAB



Screen shot for graph theory code on MATLAB



Screen shot for structural array code on MATLAB



Screen shot for crew formulation code on MATLAB

Appendix C- Resource leveling using minimum moment algorithm

C.1. Computational procedures of the improvement factors for activity C

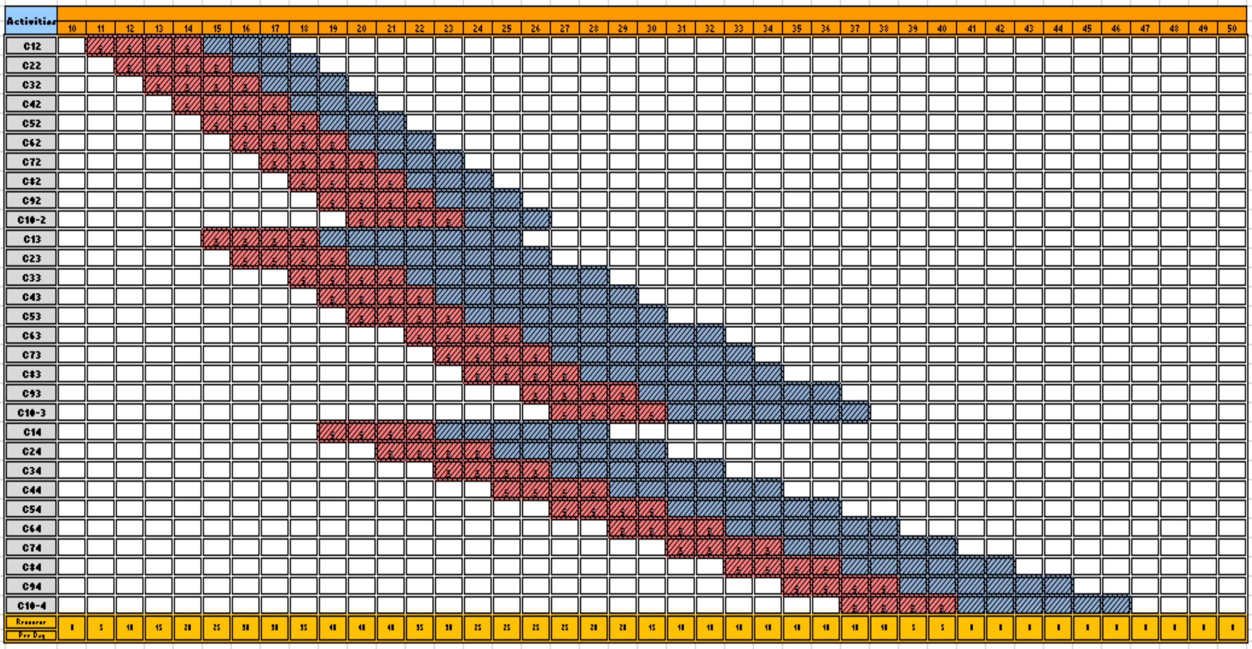
Act	S	r	X	V	m	IF
C12	1	5	50	70	1	-125
C12	2	5	50	90	2	-250
C12	3	5	50	105	3	-350
C22	1	5	70	90	1	-125
C22	2	5	70	105	2	-225
C22	3	5	70	120	3	-325
C32	1	5	90	105	1	-100
C32	2	5	90	120	2	-200
C32	3	5	90	135	3	-300
C42	1	5	105	120	1	-100
C42	2	5	105	135	2	-200
C42	3	5	105	145	3	-275
C52	1	5	120	135	1	-100
C52	2	5	120	145	2	-175
C52	3	5	120	155	3	-250
C62	1	5	135	145	1	-75
C62	2	5	135	155	2	-150
C62	3	5	135	155	3	-175
C72	1	5	145	155	1	-75
C72	2	5	145	155	2	-100
C72	3	5	145	145	3	-75
C82	1	5	155	155	1	-25
C82	2	5	155	145	2	0
C82	3	5	155	130	3	50
C92	1	5	155	145	1	25
C92	2	5	155	130	2	75
C92	3	5	155	115	3	125
C10-2	1	5	145	130	1	50
C10-2	2	5	145	115	2	100
C10-2	3	5	0	105	3	-600

Act	S	r	X	V	m	IF
C13	1	5	120	135	1	-100
C13	2	5	120	145	2	-175
C13	3	5	120	155	3	-250
C13	4	5	120	155	4	-275
C13	5	5	120	145	4	-225
C13	6	5	120	130	4	-150
C13	7	5	120	115	4	-75
C23	1	5	135	145	1	-75
C23	2	5	135	155	2	-150
C23	3	5	135	155	3	-175
C23	4	5	135	145	4	-150
C23	5	5	135	130	4	-75
C23	6	5	135	115	4	0
C23	7	5	135	105	4	50
C33	1	5	155	155	1	-25
C33	2	5	155	145	2	0
C33	3	5	155	130	3	50
C33	4	5	155	115	4	100
C33	5	5	155	105	4	150
C33	6	5	155	100	4	175
C33	7	5	155	95	4	200
C43	1	5	155	145	1	25
C43	2	5	155	130	2	75
C43	3	5	155	115	3	125
C43	4	5	155	105	4	150
C43	5	5	155	100	4	175
C43	6	5	155	95	4	200
C43	7	5	155	90	4	225
C53	1	5	145	130	1	50
C53	2	5	145	115	2	100
C53	3	5	145	105	3	125
C53	4	5	145	100	4	125

Act	S	r	X	V	m	IF
C63	1	5	115	105	1	25
C63	2	5	115	100	2	25
C63	3	5	115	95	3	25
C63	4	5	115	90	4	25
C63	5	5	115	80	4	75
C63	6	5	115	65	4	150
C63	7	5	115	55	4	200
C73	1	5	105	100	1	0
C73	2	5	105	95	2	0
C73	3	5	105	90	3	0
C73	4	5	105	80	4	25
C73	5	5	105	65	4	100
C73	6	5	105	55	4	150
C73	7	5	105	45	4	200
C83	1	5	100	95	1	0
C83	2	5	100	90	2	0
C83	3	5	100	80	3	25
C83	4	5	100	65	4	75
C83	5	5	100	55	4	125
C83	6	5	100	45	4	175
C83	7	5	100	40	4	200
C93	1	5	90	80	1	25
C93	2	5	90	65	2	75
C93	3	5	90	55	3	100
C93	4	5	90	45	4	125
C93	5	5	90	40	4	150
C93	6	5	90	40	4	150
C93	7	5	90	40	4	150
C10-3	1	5	80	65	1	50
C10-3	2	5	80	55	2	75
C10-3	3	5	80	45	3	100

Act	S	r	X	V	m	IF
C14	1	5	155	145	1	25
C14	2	5	155	130	2	75
C14	3	5	155	115	3	125
C14	4	5	155	105	4	150
C14	5	5	155	100	4	175
C14	6	5	155	95	4	200
C24	1	5	130	115	1	50
C24	2	5	130	105	2	75
C24	3	5	130	100	3	75
C24	4	5	130	95	4	75
C24	5	5	130	90	4	100
C24	6	5	130	80	4	150
C34	1	5	105	100	1	0
C34	2	5	105	95	2	0
C34	3	5	105	90	3	0
C34	4	5	105	80	4	25
C34	5	5	105	65	4	100
C34	6	5	105	55	4	150
C44	1	5	95	90	1	0
C44	2	5	95	80	2	25
C44	3	5	95	65	3	75
C44	4	5	95	55	4	100
C44	5	5	95	45	4	150
C44	6	5	95	40	4	175
C54	1	5	80	65	1	50
C54	2	5	80	55	2	75
C54	3	5	80	45	3	100
C54	4	5	80	40	4	100
C54	5	5	80	40	4	100
C54	6	5	80	40	4	100

Act	S	r	X	V	m	IF
C64	1	5	55	45	1	25
C64	2	5	55	40	2	25
C64	3	5	55	40	3	0
C64	4	5	55	40	4	-25
C64	5	5	55	40	4	-25
C64	6	5	55	40	4	-25
C74	1	5	40	40	1	-25
C74	2	5	40	40	2	-50
C74	3	5	40	40	3	-75
C74	4	5	40	40	4	-100
C74	5	5	40	35	4	-75
C74	6	5	40	30	4	-50
C84	1	5	40	40	1	-25
C84	2	5	40	40	2	-50
C84	3	5	40	35	3	-50
C84	4	5	40	30	4	-50
C84	5	5	40	20	4	0
C84	6	5	40	10	4	50
C94	1	5	40	35	1	0
C94	2	5	40	30	2	0
C94	3	5	40	20	3	25
C94	4	5	40	10	4	50
C94	5	5	40	5	4	75
C94	6	5	40	0	4	100
C10-4	1	5	30	20	1	25
C10-4	2	5	30	10	2	50
C10-4	3	5	30	5	3	50
C10-4	4	5	30	0	4	50
C10-4	5	5	30	0	4	50
C10-4	6	5	30	0	4	50



An overview for the bar chart used in leveling resources using minimum moment algorithm

Appendix D- Resource leveling using entropy maximization metric

D.1. Assumptions and Forecasts summary reported from the simulation model using crystal ball ribbon

Crystal Ball Report - Full
Simulation started on 23-Dec-14 at 8:49 PM
Simulation stopped on 23-Dec-14 at 9:51 PM

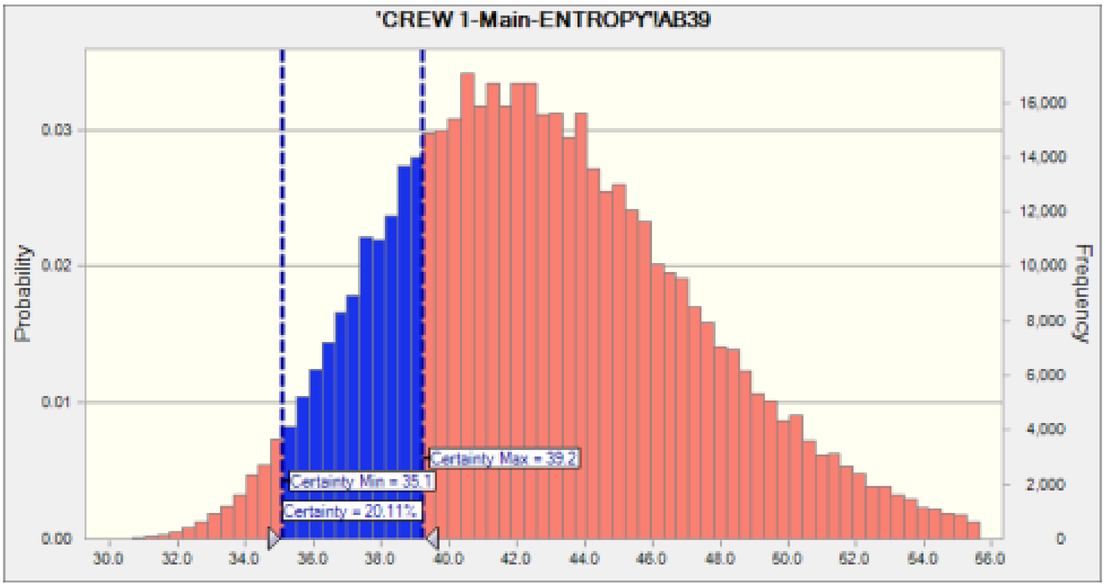
Run preferences:	
Number of trials run	500,000
Extreme speed	
Monte Carlo	
Random seed	
Precision control on	
Confidence level	95.00%
Run statistics:	
Total running time (sec)	3669.50
Trials/second (average)	136
Random numbers per sec	5,450
Crystal Ball data:	
Assumptions	40
Correlations	0
Correlation matrices	0
Decision variables	0
Forecasts	5

D.2. Defining the project completion date as a forecast

Worksheet: [ENTROPY MAXIMIZATION.xls]CREW 1-Main-ENTROPY

Forecast: AB39

Summary:
Certainty level is 20.1142%
Certainty range is from 35.1 to 39.2
Entire range is from 29.3 to 68.9
Base case is 46.0
After 500,000 trials, the std. error of the mean is 0.0

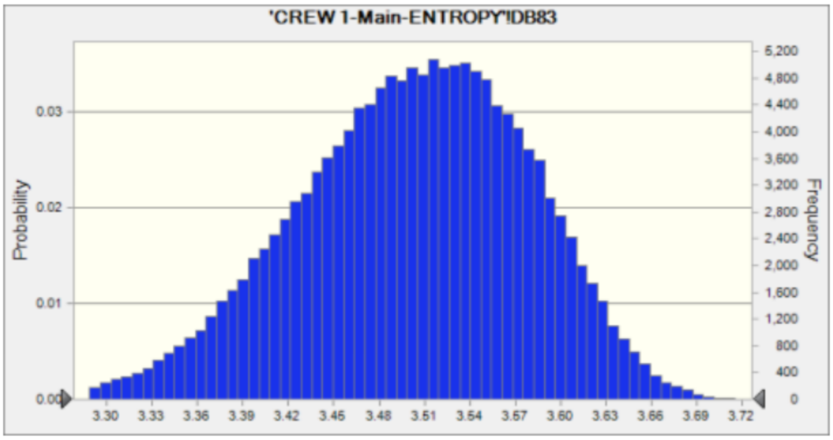


Statistics:	Forecast values
Trials	500,000
Base Case	46.0
Mean	42.8
Median	42.4
Mode	42.2
Standard Deviation	4.6
Variance	21.1
Skewness	0.4978
Kurtosis	3.25
Coeff. of Variation	0.1073
Minimum	29.3
Maximum	68.9
Range Width	39.6
Mean Std. Error	0.0

D.3. Defining the total system entropy as a forecast

Forecast: DB83 **Cell: DB83**

Summary:
Entire range is from 3.10 to 3.77
Base case is 3.52
After 143,263 trials, the std. error of the mean is 0.00



Statistics:	Forecast values
Trials	500,000
Base Case	-73.78
Mean	-75.16
Median	-76.44
Mode	-73.78
Standard Deviation	13.65
Variance	186.32
Skewness	0.0835
Kurtosis	2.87
Coeff. of Variation	-0.1816
Minimum	-133.22
Maximum	-21.19
Range Width	112.03
Mean Std. Error	0.02

D.4. Defining the total number of resources as a forecast

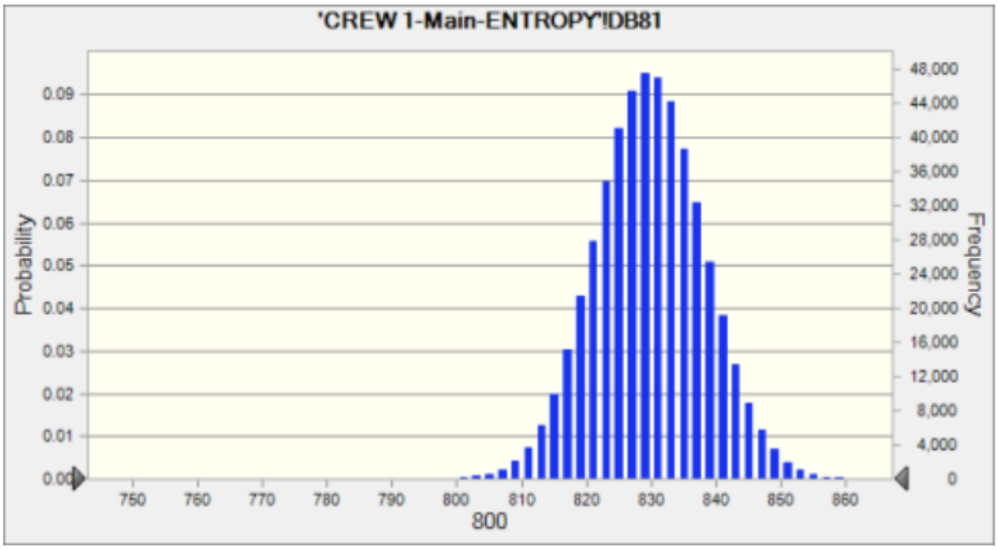
Forecast: DB81 **Cell: DB81**

Summary:

Entire range is from 744.00 to 866.00

Base case is 800.00

After 500,000 trials, the std. error of the mean is 0.01



Statistics:	Forecast values
Trials	500,000
Base Case	800.00
Mean	829.19
Median	829.00
Mode	830.00
Standard Deviation	8.41
Variance	70.66
Skewness	-0.0683
Kurtosis	3.47
Coeff. of Variation	0.0101
Minimum	744.00
Maximum	866.00
Range Width	122.00
Mean Std. Error	0.01

D.5. Resource assignment per day is defined as an assumption with a discrete uniform distribution (minimum and maximum value) based on the total float of each activity

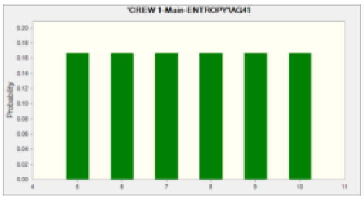
Assumptions

Worksheet: [ENTROPY MAXIMIZATION.xls]CREW 1-Main-ENTROPY

Assumption: AG41 Cell: AG41

Discrete Uniform distribution with parameters:

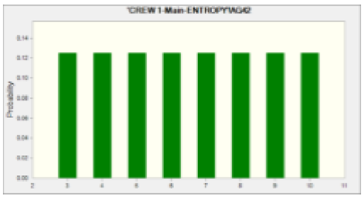
Minimum	5.00
Maximum	10.00



Assumption: AG42 Cell: AG42

Discrete Uniform distribution with parameters:

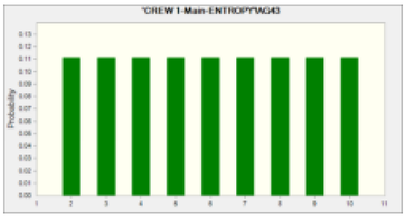
Minimum	3.00
Maximum	10.00



Assumption: AG43 Cell: AG43

Discrete Uniform distribution with parameters:

Minimum	2.00
Maximum	10.00



Assumption: AG44 Cell: AG44

Discrete Uniform distribution with parameters:

Minimum	2.00
Maximum	10.00