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Time-cost Trade-off Analysis for Highway Construction projects

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Time-Cost Trade-off Analysis for Highway Construction Projects.

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Abstract

The Construction industry, which can be in the form of residential building, commercial, public and utility buildings, or civil engineering building, has a huge influence on any nation's economy. Its influence can be either manifested in its contribution to the economy or the service it provides to the community. In order to build any infrastructure project with a balanced cost, time, and quality, project managers search for alternatives that can satisfy these contradicting attributes. The traditional time-cost trade-off was enhanced with the three-dimensional time-cost- quality optimization in the last two decades. The optimization is aimed to minimize the time and cost as much as possible while increasing the quality of the infrastructure to be built. The issue of financing in developing countries has been a bottle neck of success in constructing infrastructure like highway. Many researchers have concluded in their studies the causes of time and cost overrun in high-way construction were, contractors' financial problems, Inflation, progress payments delay by owner, political issues, variations, lack of managemental skills, cost fluctuation of materials during construction, environmental issues, Shortage in equipment, Inadequate contractor experience etc.

The number of studies in the literature that deals with financial optimization and cash-flow analysis to address the problem of financing and inflation are getting more attention. The cash-flow analysis and maximum overdraft to be paid give a good indication to the main participants about the trends toward cost and time overrun. They can also help in making a proper decision right at the beginning.

The purpose of this study is to deal with the optimization of time and profit of highway constructions taking in to consideration the amount of available credit and future value of the cost

of each activity and cash-flow analysis in a comprehensive model. This type of analysis gives the contractor how its profit will be influenced with his allowable credits and the time associated with it. Besides, the model also generates a line of balance scheduling for the project as highways are among the repetitive projects. The cash-flow analysis gives extra information on the overdraft so that it can be optimized to find good combination of execution of the activities which will minimize the overdraft, interest paid to banks and most importantly maximize the profit to be gained by the project using GA approach. This type of analysis also gives alternatives for contractors how much profit would they like to gain by providing different amount of credits. At first the profit and time are optimized individually to get the maximum profit and minimum time for completing the project. Then the multi-objective optimization using goal programing takes place which tries to minimize the deviation from the optimum individual values by assigning importance weight to the individual objectives to find the near optimal solution. The model is tested for different allowable credits and its sensitivity analysis outcomes are plotted to see the relationship between the allowable credits and the profit.

To validate the efficiency of the developed model, it is applied on a project from literature that addresses on scheduling and cost optimization of repetitive projects. It is found that the outcome of the model that maximizes the profit and minimizing the time outlooks the results of the literature with 4.65% and 0.38% improvement in duration and cost of the project respectively.

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Glossary of Abbreviations

ACO	Ant Colony Optimization
AHP	Analytical Hierarchy Process
CPM	Critical Path Method
CP	Constraint Programming
CPS	Critical Path Segments
DC	Direct Cost
DP	Dynamic Programming
DTCTP	Discrete Time Cost Trade-off Problem
EA	Evolutionary Algorithm
EF	Early Finish of an activity
ES	Early Start of an activity
FF	Finish to Finish
FS	Finish to Start
GA	Genetic Algorithm
GP	Goal Programming
IC	Indirect Cost
IP	Integer Programming
LF	Late Finish of an activity
LP	Linear Programming
LS	Late Start of an activity
MA	Memetic Algorithms
Npop	Number of Population of GA
Ngen	Number of Generations of GA
NSGA	Non-dominated Sorting Genetic Algorithm
PCR	Crossover rate
PDM	Precedence Diagram Method
PERT	Program Evaluation and Review Technique
PGA	Pareto Genetic Algorithm
PM	Mutation rate
PSO	Particle Swarm Optimization
QA	Quality Assurance

QC	Quality Control
SF	Start to Finish
SFL	Shuffled Frog Leaping algorithms
SS	Start to Start
TCQT	Time Cost Quality Trade-off
TCT	Time Cost Trade-off
TF	Total Float of an activity
VBA	Visual Basic for Applications
ER	Evidential Reasoning
DTCQTP	Discrete Time–Cost–Quality Trade-off Problems
MOGA	Multi-Objective Genetic Algorithm
KPI	Key Performance Index
iMOO	Integrated Multi-Objective Optimization
GDM	Group Decision Making
FSAWS	Fuzzy Additive Weight System
BOWA	Borda-Ordered Weighted Averaging
AMTCROS	Automatic Multi-objective Typical Construction Resource Optimization System
RCS	Resource Constraints Solution
RCPSP	Resource- Constrained Project Scheduling Problem
M	Mark-up value of the project
B	Incentive value per day if the duration of completion is less than the project duration in the contract
D	the duration of the project in the Contract document.
DA	the actual duration of the project.
L	liquidated damage value per day, if the project is delayed from the contract

	duration.
I	Interest paid in every month of the project.
A	Amount of penalty for additional crews from the pool.
C	Number of crews added to optimize the profit and time
GDP	Gross Domestic Product
GNI	Gross National Income
GFCF	Gross Fixed Capital Formation

CHAPTER 1 Introduction

1.1 Background

Generally, the construction industry includes the construction of "residential buildings, office buildings, stores and other public and utility buildings, farm buildings etc., or the construction of civil engineering works such as motorways, streets, bridges, tunnels, railways, airfields, harbors and other water projects, irrigation systems, sewerage systems, industrial facilities, pipelines and electric lines, sports facilities etc." These works can be constructed either by the owner or contracting to other contractors where contractors can also give a portion of the work for other subcontractors. The construction industry is not only responsible for constructing new one but also repairs buildings and other civil engineering works;(Abi 2007).

The Construction industry has a huge influence on any nation's economy. Even though there is an argument if it has a clear contribution to the economy of any nation, literatures have approved that there is a good correlation with the economic development of one nation. On the other hand, some argue that it can be used for regulating the economy whereas others say it can be influential only for a short period of time. Out of these mentioned above, there are also some literatures saying economic growth drives construction industry instead of being, derived by the construction industry. Regardless of the relationship, which is confusing for many, construction industry is crucially important to provide the necessary infrastructure that any nation need to stimulate economic development. To attain sustainable development, any nation is required to have efficient construction industry process. It is the construction industry which is seen more than once in the economy indicators of a nation such as GDP, GNI, OR GFCF. For example, in Britain the GDP of construction in 2018 was 6%,(Rhodes 2018). In Malaysia the construction industry constitutes about 4.5%(RM50.09 billion) of national GDP in year 2016,(Abd-karim, Suhaimi, and Danuri 2018). In Palestine, the construction sector contributes to 26% of the Palestinian gross domestic product (GDP),(Mahamid, Bruland, and Dmaidi 2012). 4.7% of GDP of Egypt is accounted by the construction industry. This makes it among the most important industries in the economic progress of the country,(El-maaty, El-hamrawy, and Akal 2016).

So, the construction industry is among the important economic sectors for any nation whether developed, underdeveloped or developing;(Olanrewaju and Abdul-Aziz 2015)

The main objective of the management of any project is to get the project done within the desired time, cost, and quality. Because of the cutting-edge era of today's life, the construction industry is imbued with different methods of construction, equipment, materials, resources to be utilized to ensure the project will be finished at the appropriate time, cost and quality. The planning process is the stage where it considers the different methods of construction, materials, equipment, and resources to generate different options for completing the project followed by rigorous evaluation of each option to come up with the most suitable one.

Therefore, the planning process becomes the stage where decisions are made and the selection of the best alternative for the desired purpose is confirmed. The best alternative is selected on the basis of optimization of the project's cost, time, and quality. This means the decision made during the planning process will have a huge impact on the cost, time, and quality of the project. Construction projects are full of uncertainties and variation. The decision made with limited information during the planning process makes it to be very complicated. To have a good decision during this stage, an attempt of optimization of the project is carried out in terms of the cost, time, and quality for all alternatives. It is well established that the three main design and construction objectives are, cost, time, and quality of project construction, (Kazaz et al. 2016).

Highway construction is one of the sectors of the construction industry. It needs a big investment. For example, in Egypt the investments in infrastructure especially highway project reach to US $5.46 billion. It indicates that the national budget on infrastructure development is devoted to highway construction projects, (El-maaty, El-hamrawy, and Akal 2016).

Like all construction industry sectors, it also has to go through all the processes of construction starting from the inception to the completion of the project. The development of the project must pass through the process funding and authorization, location and environmental impact assessment, preliminary and final design and finally awarding. Execution of the preliminary design on site is the next step where it confirms the project is out of the planning stage, (Turochy, Hoel, and Doty 2001).

Cost is the most critical aspect of infrastructure projects. So, cost estimation is a mandatory work to be carried out. Project managers could be helped in choosing the best alternative if they are provided with accurate cost estimation. However, the accurate cost estimation could not be achieved at the early stage due to the uncertain and variable nature of construction industry. If the project is heading towards its end an accurate estimation of cost could be attainable since there is enough detailed information. In spite of how difficult it is to get the preliminary information, data base, updated cost estimating methods, during the conceptual phase, however, it must be carried out, since it is the stage where needs and alternatives are assessed, objective and goals are set and funding is achieved, The duration of a highway project construction is another important factor which has to get huge attention as it hinders smooth movements and activities of a society. On the other hand, increasing the duration of the completion period of a project has also a directly proportional relation to increasing the cost. The factors which affect the magnitude of the completion duration are the number of works, and productivity rate of the crew in the construction. Other than those, the location of construction whether it is rural or urban, features of traffic, type and unique feature of construction are among other factors which have an impact on the duration of the construction. So, when highway construction is on the bid, a reasonable set time to complete the project is included in the contract document. The time set for the completion of the project is estimated from the average individual completion duration of the activities in the project by itself;(Jiang and Chen 2009).

Highways for any country are like the arteries and veins of human body which creates the communication between all the body parts, without them where the body can't get the necessary nutrients and exert the waste material from them.

The dominant mode of transportation in Ethiopia is the road transportation which accounts for about 95% of motorized freight and passenger movements. Its advantages can be manifested in access market for agricultural products, where 85% of the Ethiopian population are engaged in agriculture to produce both domestic and international marketing. Moreover, they are essential for the expanding of education, health service provision and facilitate trades for both locally and globally,(Worku 2011). The Road transportation in Kenya constitutes about 80% of the total internal freight and passenger traffic. The road network is about 160,886 km long, where only 14,000 km is paved. Although it connects all important cities and production centers to enhance the economy and wellbeing of the people, traffic jams are sever in the country,(Magnússon ,2017).

The road transportation is the most widely available form of transport in Ghana. Its economic significance in the country is tremendous as it links not only major cities, towns, villages; but also, agricultural production areas with local, regional and national markets. It carries in excess of 97% of all passenger and freight traffic,(Chileshe and Berko 2010). Egypt's roads network carries out 85% of domestic freight and 60% of passenger movement. It is one of the common transportations means which affects the country's GDP as an industry.,(El-maaty, El-hamrawy, and Akal 2016).

1.2 Problem Statement

Construction and maintenance of highways are not an easy investment. It requires a huge amount of expenditure with foreign currency. Hence, most governments finance road construction and maintenance through loans and aid from other countries and organizations. Besides it always suffers from delay and cost overrun in any country particularly in developing countries.

Cost and time overruns have been key roles in the abandonment and failure of projects in Kenya and Ethiopia, (Labuschagne 2017), which worsens the economic crises of the nations. A number of studies in the public sector show that more than 80% of the highway construction projects are delayed, over-budgeted and suffer with lack of managemental skills in Ethiopia,(Tesfa 2016). While the minimum and maximum time delay are 25% and 264.38% from the contract duration respectively, the cost overrun are 4.11% and 135.06%, (Tadewos and Patel 2018). According to Tesfa, (2016), in his study the main causes of time and cost overrun in high-way construction were, contractors' financial problems, Inflation, progress payments delay by owner.

In Palestine it is found that almost 100% highway projects face cost and time run,(Mahamid and Bruland 2011). The cost overrun reaches up to 76.33% of the original cost estimated, whereas the time delay is about 50%. The main causes of these overruns are, political issues, financial status of the contractor, payments delay by the owner and poor communication between the construction parties, lack of materials,(Mahamid, Bruland, and Dmaidi 2012).

In Jordan highway construction projects suffer from both severe cost and time overrun. The cost overrun ranges from 101% to 600% with an average of 214%, whereas the delay time ranges from 125% to 455% with an average of 226%. The main causes of these overrun are terrain condition, contractor financial problem, material cost fluctuation and managemental problems, (Hazim and Abusalem 2015).

Pakistan is one of the countries which suffers with the time delay and cost over run in the highway construction. Major factors of budget overrun were client interference, Payment problems faced by contractor, Payment problems faced by client from government, changes in design and inexperienced contractor in construction of road projects,(Sohu et al. 2016).

To mitigate this problem, this study will develop a model which helps to generate a cash-flow analysis which will help to understand the trends of time and cost overrun depending on the available allowed credits on hand which is different from the ordinary cost-time-quality optimization. The model will also consider the future value of costs of activities to accommodate the inflation which might strike and will help the decision makers to make decisions whether to take it or not from the beginning. On the other hand, this type of analysis also gives alternatives for contractors how much profit would they like to gain by providing different amount of credits. In this way optimization of profit and time trade-off will be carried on so that cost and time overrun will be mitigated.

1.3 Intended objective(s)

The main objectives of this study are to study the available optimization approaches of cost-time or cost-time- quality in order to develop innovative and practical optimization model for highway construction. The development of such model can help decision makers to supports in the efforts of searching a combination of execution methods of activities which will give good profit and minimum time of construction. These objectives include:

- Developing a model which can optimize time and profit individually alone as well as simultaneously by minimizing the deviation of the individual optimal value and the combination of both objectives.
- Developing a resource driven line of balance scheduling model for the highway construction which can accommodate buffers in the schedule.
- Developing a graphical representing of the schedule so that it would be easy for visualization.
- The optimization and scheduling model are synchronized so that result of optimization model can be manifested in the scheduling model and vice versa.
- Developing a model which integrates the critical path method to calculate the duration of the first unit and line of balance for the whole project.
- Developing the cash-flow analysis model to calculate the maximum overdraft, interest to be paid and actual profit gained.

1.4 Research methodology

To accomplish this research study, the research will go through the following steps as shown in the figure 1-1.

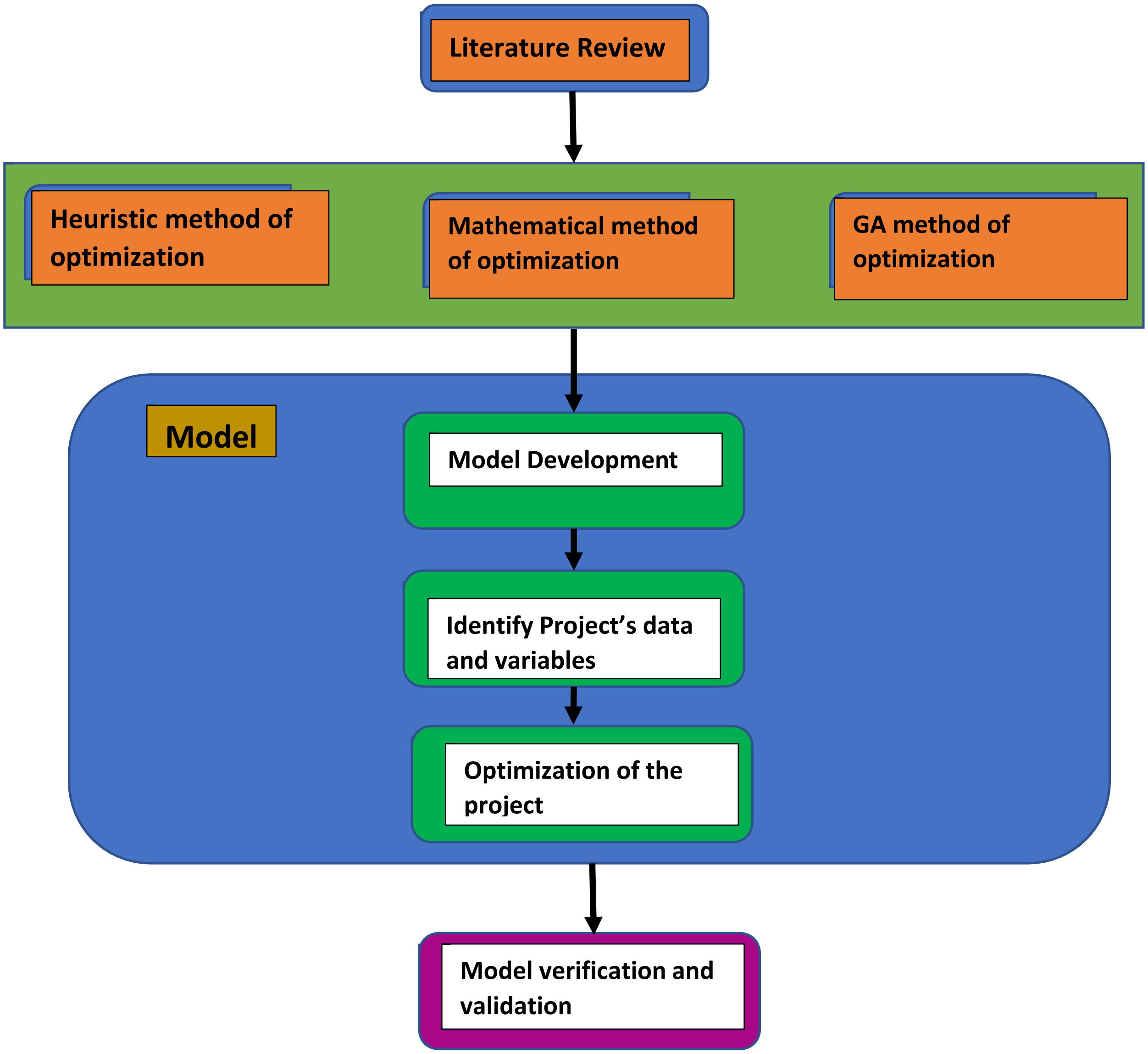

Figure 1-1 Research methodology flow chart.

1.4.1 Conduct a comprehensive Literature review

Through the comprehensive literature review this study will try to investigate the recent research developments in optimization of time-cost trade-off. The study will

1- examine the construction resource utilization methods, currently used models for optimization process.

2- explore available multi-objective genetic algorithms to find the competitive algorithm to carry out for this study by investigating and farther improvement.

1.4.2 Develop a Multi-Objective Optimization Model

This work aims at developing a robust optimization model for the optimal resource utilization plans of a newly constructed highway project. This model can be helpful tool for decision makers in their management job. It will include

1- Examining all the available multi-objective search and optimization tools, and will pick the most suitable and robust one for the present model.

2- Identify relevant decision and function variables of the resource utilization in the construction on hand to carry out the optimization.

3- Formulate optimization objectives/fitness functions that can be used to evaluate the construction time, and profit.

4- formulating the optimization model as a multi-objective genetic algorithm to enable the searching process for the near optimal trade-offs between time and profit.

1.5 Verification of the model:

The model will be checked for its robustness to optimize the time-profit trade-off for the construction of any linear or repetitive project.

1.6 Validation of the model:

The model will Validated for solving time-profit trade-off problem by using a case study project and comparing the result obtained to examine its efficiency.

1.7 Expected significance of the research

This research will have a good contribution for the contractors, managers and the owners of highway construction industry which in turn affects the economy of a nation. According to, (Amare, Quezon, and Busier 2017), 40% of the delays and cost overrun is caused by the contractors, which is due to financial problems, bad planning and scheduling practices and lack of expertise in the management sector. It further states that 23.08% and 26.15% of delay and overrun cost are caused by the owner consultants respectively due to the management problems and lack of awareness on the scheduling and planning phase and financing funds. So, this study will give the awareness to the contractors how their overdraft and profit would be, and which best alternative resource utilization should be followed to have the best alternative to complete the project at near optimal time and affordable funds so that it insures near optimal profit will be gained. The proposed research development is designed to support decision makers to identify near-optimal resource utilization plans for highway construction projects for all the contractor, owner and consultant parties. The application of this research development in planning the construction of highway project holds a strong promise to:

(1) increase the efficiency of resource use in highway construction projects, and thereby producing savings to public expenditures;

(2) reduce construction duration.

(3) maximizing the profit which can be achieved.

1.8 Thesis Organization

This study consists six chapters and references. The first chapter includes the introduction, statement problem, objectives of the research, methodology followed to develop the model, expected contribution of the research and the thesis organization.

In chapter two extensive literature review have been done to see the available way of optimizing the TCT or TCQT problems in the construction industry. Three main techniques of optimization have been covered. These are the Heuristic, mathematical, and evolutionary algorithms methods for solving the aforementioned problems. Genetic Algorithm have thoroughly covered which was used to optimize time, cost, time-cost trade-off, or time-cost-quality trade-off and GA for resource allocation and leveling. Finally, the it will state the gaps in the literature this study is intended to fulfill.

Chapter three deals with the development of the models for both scheduling and optimization. It explains the detail how the models are developed, the available constrains, variables of the models, and the objective functions of the profit and time. It is also accompanied by the flow-chart which indicates the steps and processes to be followed. The fourth chapter is verifying the developed model with fictitious project to maximize the profit and minimize the time individually, and then applying the multi-objective optimization to minimize their deviation from the optimum value of individual so that a near optimal solutions are achieved. Sensitivity analysis have been done with different amounts of allowed credits and maximum profit and near minimal time have been obtained. The fifth chapter is validating the developed model with a project data from literature to see its applicability on practical world. The last chapter but not least was summarizing the thesis with conclusions and recommendations. It states the findings of the research, future studies recommendation and who can use it.

CHAPTER 2 : Literature Review

2.1 Introduction

East Africa had 71 projects valued at US$32.6bn, which accounts for 23.4% of projects on the continent and 10.6% in terms of US dollar value as per 2017. Out of these values the 52.3% in number of projects and 16.6% the projects US dollar value are highways. East Africa's projects in general have substantial risen by a 65.1% between 2016 and 2017 and 10.63% highways in particular. North Africa, and Algeria has a project of motorway for US$8.9 billion, (Labuschagne 2017). This indicates that how fast the construction of roads is progressing with huge amount of money.

Currently Ethiopian Road Authority signed agreements for the construction of a network of roads totaling nearly 724Km for 16.3 billion Br of 10 road projects across Amhara, Oromia, SNNPR, Somalia and Gambella regions in December 2018. It is expected that the constructions will be completed within 4.5 years, where the construction includes bridges and water drainage systems. The Ethiopian government will finance them, except for Gore-Masha-Tepii road project which is 140km and will be financed by the Import and Export Korean bank costing 3.8 billion Br. The contracts are awarded to international and local construction companies, (Temesgen Mulugeta 2018).

The Egyptian government has launched National Roads project in 2014 to boost the country's road-network. The project includes construction of new roads and fixing already existing roads and bridges. It is a value of LE 36 billion which is expected to increase the countries road from 24,000 to 29,000km or 20% of all roads in Egypt. The projects which have been completed till 2017 costed LE 22 billion and the remaining are expected to be completed in 2020. The impact of this highway construction has reduced the annual accidents in Egypt by about 24%, (Lolwa Reda 2019).

Construction of highway which costs $751.2 is about to launch in 2019 between Kenya and Tanzania. The project will be funded 70% by the Development and Business Delivery Office of African Development Bank (AfDB) and the remaining will be funded by the countries. The length of the project is 460-kilometre which begins in Malindi and moves through Mombasa and Lunga on the Kenyan side, before crossing into Tanga, Tanzania. The highway's roll on easing the movement of traffic from both Mombasa and Tanga ports, to neighboring land-locked countries Uganda, Rwanda, Burundi, South Sudan, and DR Congo will tremendous, (John Green 2018).

Eritrea launched an $22.6 million highway project to rehabilitate the road that connects the Eritrean ports and Ethiopian border. The project will be funded by the EU Trust Fund for Africa and through the United Nation's Office for Project Services. The expected completion of the project and the awarded company is not specified yet,(Ryan McGuire 2019).

2.2 Highway Construction Main Activities and their Sequence

The activities of highway construction follow a sequential pattern depending on the type of the highways and their location. After the surveying process takes place which aligns the road way and determine the curvatures and slopes, the activities of construction take place. The activities below are arranged according their sequence of execution.

2.2.1 Clearing, Grubbing and Excavation

Construction of roadway starts with clearing of debris, trees, grass, crops and structures, which fall within the road alignment alongside with grubbing stamps and ruts. Then the excavation work is done to adjust and cut unnecessary embankments in the aligned road way.

2.2.2 Embankment

Embankments are constructed in layers and parallel to the finished grade of the road. The construction of the embankment should have good grade and crossfall which will handle water to run off the embankment allowing construction work to start as soon as possible after rainfall and avoid soft spots forming. Fill material must be free from roots, or any vegetable matter and each layer of fill should be less than 150 mm for compaction purpose,(Haque, Bhaban, and Ramna 2010).

2.2.3 Sub-Grade

The subgrade is an embankment constructed below the pavement. It has to be prepared to give added strength to the pavement. All subgrade material must be free of vegetable matter, debris and other weak materials. The material must have good moisture content so that it can be compacted to form a stable layer. It must be prepared over the full width of the embankment and the shoulders. Drains are to be constructed to ensure water drainage in the pavement.

2.2.4 Sub-base

This is the secondary load spreading layer of the pavement. Its material is either natural or artificial aggregate (or a combination) with no vegetable matter, soft particles or clay. The material should be varying sizes (well graded) of fine and course material which can be compacted easily to produce a close and tight surface texture.

2.2.5 Aggregate Base

The base is the layer below the main surfacing and is the main load spreading layer. It might comprise either a crushed stone or natural to the required size, with sand fillers and treated with bitumen emulsion or cement. It has to be graded well and free of weak material and trees, to insure appropriate compaction,(Mbeki 2008).

2.2.6 Bituminous Layers

Prime coat bituminous is first sprayed on the prepared road base which has to uniformly cover the whole road way. Then a tack coat is applied to make the road surface sticky in order to make bond with the dense bituminous surfacing or carpeting. After tack coat is applied then the carpeting must be placed without taking much time to insure its bondage. After that a primer seal consists of pea gravel material is applied into a cut back bitumen, over the prepared surface. Finally, a dense Bituminous Surfacing consists of graded aggregates, filler, coated with bitumen is applied the surface of the primer seal. It has to be laid in order to insure good compaction to form a dense impervious layer.

2.2.7 Concrete Including Reinforcement

If the highway is not an asphalt, it can be concrete highway. A layer of 75mm thickness blinding concrete must be provided for all concrete structures and is laid directly on the prepared soil. The reinforcements are then placed with adequate cover to protect from corrosion as per design of the surface.

In this chapter an extensive literature review will be conducted to help selecting an appropriate method for the proposed research on hand. This research is motivated by the evolutionary changes in the highway construction industry which imposed the demand for optimization tools tackling the multi-objectives in the utilization of resources and the cost-time trade-off in very complicated and real-life projects. It will investigate the existing traditional and innovative practices on solving both the two and three dimensional; time-cost and time-cost-quality trade-offs. In order to incorporate the appropriate ones in this study, the review will focus on the models developed, optimization techniques and methodologies followed for the different studies. All detailed traditional optimization techniques will be overviewed with their, advantages, and drawbacks. The three main optimization techniques; Heuristic, Mathematical, and Evolutionary will be discussed throughout this chapter.

2.3 Time-Cost Trade-off Analysis

The Critical Path Method (CPM) which is mostly used to schedule the duration of a project completion when the project dead-line is not fixed and the resources are not constrained,(Hegazy and Menesi 2012). However, when. the project deadline is stated, or the project is running out of schedule, TCT will be carried out in the CPM to meet the stated deadline of the project. Some of the activities in the CPM will be replaced with their crashed duration to save the overschedule time. On the other hand, activities on non- critical path are made to be relaxed to save some costs,(Nicolai Siemens 1971). This analysis is done by considering the different parameters like utilization of resources, construction methods, which affect the project duration and cost. The relationships can be shown as in the figure given below, time cost trade-off to get the optimal solution, of time, cost balance,(Hegazy 1999).

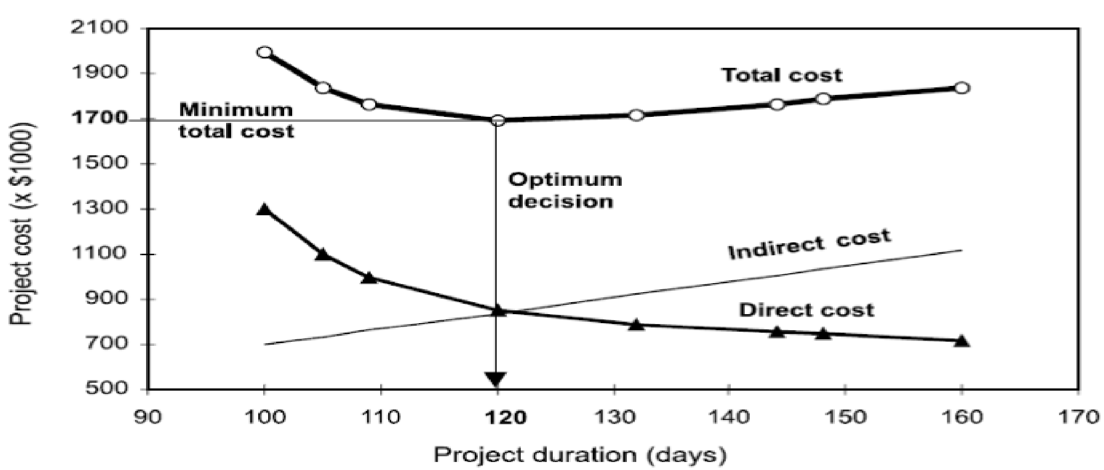

Figure 2-1.Project time cost relationship (Hegazy, 1999)

In the process of TCT analysis activities in the critical path are forced to be crashed so that their cost is increased but the duration is made to be faster. The compressed duration of an activity is known as crashed time whereas the cost associated with this duration is called the crashed cost. Any point of the activity in between the crashed and normal time can be calculated by using the cos-time relationships. Any activity's cost time relationships with its direct cost can be linear, continuous, discrete, or curvilinear as shown the fig below**;**(Liao et al. 2011).

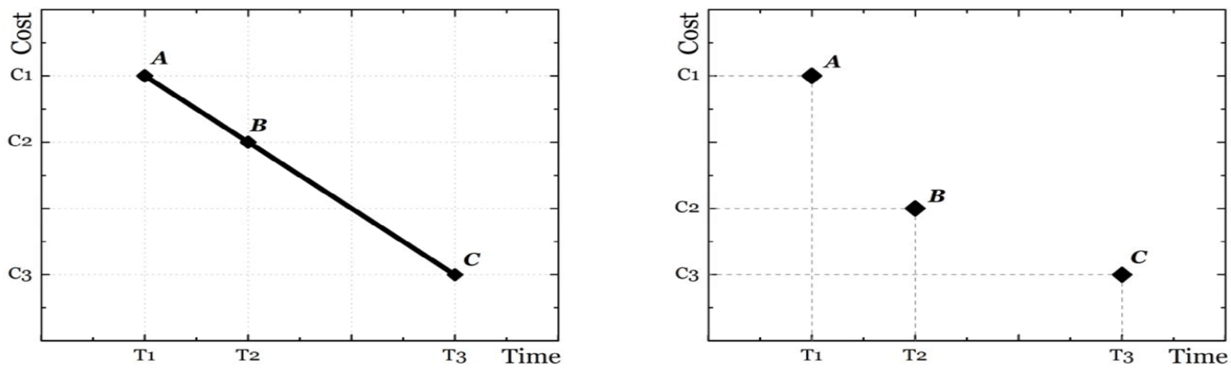

Figure 2-2.Linear and discrete relationships cost and time of an activity, (Hegazy, 1999)

In the early times, it was assumed that the relationship of time-cost trade-off is a linear function of the duration of the activity. The cost bound is from a cost of normal duration to the cost of crashed duration. By assuming a linear function it tries to find any cost in between the normal and crashed duration of any activity, and by doing so it schedules the project duration**;**(Vanhoucke and Debels 2007). However, this relationship is not the representative of real-world projects. It is a discrete relationship between the duration and cost of the project which complies with the real-world projects and is the version which is practically applicable. The discrete time-cost trade-off problem (DTCTP) selects execution modes of the activity from the available options and optimizes either the cost, time or both for the project.

2.4 TCT Optimization Challenges

The process of finding the best solution for a given problem from countless solutions is called Optimization. Trying to calculate the best solution from all feasible solutions in a given project is almost impractical as the total number is an almost exponential function of the resource types which are available for the project. In real-world life, a project may contain thousands of activities with different resource utilization. It is very difficult to come up with best solution of TCT among the possible solutions and is really time-consuming to evaluate each alternative. After trying to find the optimal solution it is the second step to schedule the project and calculate its cost. Even though there are optimization models that can possibly generate near-optimal trade-off between cost and time of a project, they have short comings due to their impractical time requirement for computing in large-scale projects;(El-Rayes and Kandil 2005).

2.5 Techniques for Solving TCT Problems

The most common methods of solving the TCT problem are the heuristic methods, mathematical programming approaches, evolutionary-based techniques and constraint method. The resource utilization process has a huge impact on any project's cost, duration, and quality. Many models have been developed for the optimization of resources utilization in the past years. These decisions, therefore, must be optimized to satisfy the highway construction contracts.

2.5.1 Heuristic Methods

Hegazy and Menesi, (2012), tried to resolve the conflicts that exist between project deadline and resource limits that are common practical constraints in any construction project. Even though it is common in heuristic methods for constrained resource scheduling (CRS) to be available in commercial scheduling software, the inclusion of heuristic time-cost trade-off was overlooked in commercial software which can solve both the CRS and TCT. The paper tried to incorporate both resource constraint schedule and time- cost trade-off optimization using the heuristic method to meet both dead-line of the duration and the resources constraints in a practical real-world. Basically, the proposed method relies on crashing of the activities which have the lowest cost in the critical path, while at the same time resolving any overallocation of resources within each of the TCT cycle. This is a fast, logical and practical approach that can provide a set of possible project duration without violating the resource limitation of the project. This intertwined approach is logical, fast, and provides a set of feasible project durations that do not violate resource limits. It first defines two activity variables, start delay and construction method index which can suit the CRS and TCT decisions. After defining these variables, it proposed a simple heuristic method which can analyzes simultaneously both CRS and TCS for the dead-line duration and resource limitation of the project. The paper has included several case studies to prove its practical application for research and professional use by comparing with other GA optimizing model. It was found that the results are good enough to give an optimal solution. For the sake of practical use, the method has been programmed as an add-in tool to the Microsoft project software.

Bettemir and Talat Birgönül, (2017), developed a model of net-work analysis algorithm that converges very fast on the basis of a minimum cost-slope to find optimum global solutions for a discrete time-cost optimization. The algorithm searches all the feasible crashing options in the project activity which will give the global optimum solution of the optimization. As the number of activities to be crashed in a large project are tremendous, it only selects the activities with less cost on crashing, and this is done by step wise crashing to finally get the global optimal. Network Analysis Algorithm (NAA) also searches the optimum schedule of the project by crashing the activities step-by-step. To accommodate the penalty and reward for delay and early completion of the project, the crashing cost is made to be compared with the summation of reward and indirect cost. After identification of the paths the net-work by the algorithm, critical paths are determined. When there is more than one critical path, the path and activity with least crashing cost is selected. Applying meta-heuristic algorithms for large size project, finding trial of the optimal solution will be increased exponentially, on the other hand computational demand applying NAA increases linearly, which makes heuristic algorithms are more suitable for the optimization of large projects. The model has been tested for 18 and 63 activity sized projects with a deviation of 0.046% and 0.077% respectively from the optimum solution and still is efficient. However, its limitation falls when it is applicable for large sized projects where meta-heuristic approach would be advised.

The heuristic algorithm is not considered as an optimization tool, as it is based on the rules of thumb to find an acceptable optimum solution. They are very easy to understand and can be applied to large problems to find an acceptable solution. They can also be used as a starting point for further optimization using the genetic algorithms.

2.5.2 Mathematical methods

2.5.2.1 Linear programing methods

Burns et al., (1996) formulated an optimization model which hybrids the linear and integral programing together to find an exact solution from all the feasible pool of solutions. The optimization was done through two steps, **A**, the linear programing stage which is used to find the lower bound of the solutions, and **B,** the integral programing stage to find the exact solution. In the first stage, piecewise linear approximation curve is created to the activity cost. Then, points out side the convex hull established (dominated options) are eliminated by considering these options can’t carry out the activity. The established convex hull is then used to construct the constrain in the linear programing model which is used to find the minimum cost of the project by considering the precedence activity constraint. This model will give the lower bound of the time-cost relationship. The second stage is then applied by the integrated programing model for the objective of minimizing the total cost of the project taking into consideration the precedence activity constraints and taking one selected resource utilization options to each of the activities in the project. The model is implemented as Optimum in the Microsoft Excel for friendly enhancement use of the formulation.

2.5.2.2 Non-linear programing methods for time-cost optimization

Klanšek and Pšunder, (2015), presented a study to develop a model for the cost optimization of the time schedules that take into consideration the real project characteristics. Projects naturally have a nonlinear nature relationship between costs and durations. The study also takes into consideration the activities precedence relations in the optimization. Non-linear programing (NLP) model was developed for the cost optimization of the time schedules which accommodate the generalized precedence relations between the project activities to make optimal time-cost decisions applicable to real projects in the project management field. The NLP optimization has applied the generalized reduced-gradient method proposed by Drud (1994). The formulation of the NLP was proposed given below.

Minimize $\mathbf{z = f(x)}$, subject to: $\mathbf{h(x) = 0, g(x) \leq 0}$, where $\mathbf{x \in X = \{x / x \in R^n, x^{LO} \leq x \leq x^{UP}\}}$

Equation 2-1 (Klanšek and Pšunder 2015)

Here x is a vector of the continuous variables, defined within the compact set X. "Functions f(x), h(x) and g(x) are the non or linear functions involved in the objective function z, with their respective signs of the equations. One important criterion in the formation of the equations is that all the functions f(x), h(x) and g(x) are to be continuous and differentiable. The continuous variables in each equation define the schedule parameters such as activity durations, start times, direct costs whereas the objective function determines the total project cost. Equality and inequality constraints and the bounds of the continuous variables represent a rigorous system of the generalized precedence relationship constraints, the activity duration constraints and the project duration constraints of the project scheduling optimization problem."

The total cost of the project was the objective function to be optimized under the constraints of the precedence activity relationships, activities duration constraints and the total project duration constraints. The objective function was given as the equation below.

$$CT = \sum C_i (D_i) + CI(DP) + P(DL) - B(DE), \quad i \in I$$

Equation 2-2 (Klanšek and Pšunder 2015)

"where objective variable CT represents the total project cost, set I comprises the project activities i, i∈I, Ci(Di) denotes the direct cost-duration functions of the project activities i, i∈I, CI(DP) is the project indirect cost-duration function, P(DL) is the penalty-duration function and B(DE) is the bonus-duration function. The variables Di, DP, DL and DE denote the durations of the project activities i, i∈I, the actual project duration, the amount of time - the project is late, and the amount of time - the project is early, respectively." The equation to accommodate all the durations for actual project duration, late duration and early duration and the contract duration are related as below in the given equation. Only one from late and early duration has to be applied in the optimization so, their multiplication must be zero as one of them are to be zero.

$$DP - DL + DE = DT \text{ and } DL * DE = 0$$

Equation 2-3 (Klanšek and Pšunder 2015)

The model was applied to real project which was already tried by Sakellaropoulos and Chassiakos (2004) using the mixed-integer linear programming (MILP) approach and it produced the same result. It presented the minimum cost of the project and optimal time-cost curve of the project. The main weakness of the model lays with its limitations of dealing for deterministic time and cost estimates which include uncertainties.

2.5.2.3 Dynamic Programming Models

There are several formulations which try to address the optimization of resource utilization using dynamic programing. One among these formulations was proposed by**;** (El-Rayes and Moselhi 2001), dynamic programing which tried to minimize the duration and cost of repetitive construction projects by incorporating crew interaction and crew formation parameters, in the scheduling process. This forms interruption algorithm which will be addressed during the scheduling. Crew work continuity assurance in repetitive construction projects is a tool for scheduling the duration. Many formulations which were in use tried to optimize the crew interruption in a repetitive activity. However, it is impractical to bound the sample space of possible interruption of the crew. This model though trying to develop an algorithm that solves this problem on hand and generates a feasible set of non-dominant interruption alternatives which replaces the arbitrary interruption sets selected before scheduling. The model has two stages of algorithm developments namely the scheduling algorithm and the interruption algorithm. Feasible interruptions are first calculated from the scheduling algorithm. These newly generated interruption alternatives go through optimality check where the dominant ones are removed from being considered, whereas the selected once are led to further process to dynamic programing model. The model by itself has two stages, the crew formation, and the interruption option. The model implementation has two stage passes, the back ward and forward passes. The local optimum condition for the project activities' is calculated from the beginning to the end of the project. These results are then checked by the back-word pass for their global optimality.

Moselhi and Hassanein, (2003) also developed a dynamic programing model which optimizes repetitive projects. It is a two-state variable and N-stage dynamic programming formulation to optimize linear and non-linear repetitive construction projects. The model is capable of optimizing **A;** the cost of a project **B;** duration of the project **C;** or combined impact of cost-plus-time bidding, which also known as A+B bidding. The model is a resource-driven which has the capability of optimizing for repetitive and non-repetitive activities, with consideration of transverse obstruction and differences in quantity of work in the repetitive units. The model neither allows crew work interruptions nor tries to optimize them, instead it tries to optimize the crew formation for each activity and work areas are assigned to them. The model is implemented in Microsoft windows where it is coded by object-oriented approach using the program language C++ to store resource data.

2.5.3 Genetic Algorithms

The Genetic algorithm has been developed by many researchers for optimization of the resource utilization in the construction industry. There are different constraints and objectives in construction projects, so different genetic algorithms have been developed to find the optimal objective of the project with the given constraints. The objective function of a given project could be minimizing the cost, time, time-cost optimization, and resource allocation and leveling. Different genetic algorithms for each mentioned problem above have been developed and is continuing to develop nowadays.

2.5.3.1 Genetic Algorithm for cost

Li and Love, (1997) developed a single objective cost optimization of the time-cost trade-off by using the genetic algorithm (GA). It was assumed the duration of the project to be fixed of a certain value and is aimed to search optimum or near optimal solution of the cost of the project from the pool solution. It is applicable to a project where it is running overscheduled. A linear curve relation was assumed for the cost of the activity where its duration is fixed between the expedited and normal values. It was first optimized using a simple GA, well known as basic GA. However, this optimization was demanding in computation which requires a lot of time. Therefore, an improved GA was motivated to modify the basic GA which can result in less time computation. This improved GA made modifications in the cross-over and mutation operators which eliminate solution which are not in the acceptable solution space of the problem. The improved GA outsmarts the basic GA in the speed of calculation to come up with the optimal or near optimal solution. Having a fixed duration, trying to optimize only the cost of the project makes the inefficient, as the solution is far away from optimal solution in reality. Not only the fixing of duration makes the search weak, but also the assumption that the cost of the activity to be linear curve is another deficiency, as it never happened in the real-world.

2.5.3.2 Genetic algorithm for time

Que, (2002) developed GA model that was integrated with the software known as SUGALwhich was written by Dr. Andrew Hunter in 1995. The GA system was written by the SUGAL genetic algorithm, while the primavera planner project(P3) was used for the management system. The chromosome has a sequence of genes which refers to the activities in the project and are arranged according to the schedule of the project using the ID of each activity. However, the activities which are encoded in the chromosome are those which didn't start only. Activities which are already finished are not included in the chromosome since its duration can't be changed. For the sake of simplicity activities which are already started are not included in the chromosome. However, they can be considered as not started for remaining part of the activity. By doing so to determine the completion date of a project, the durations which are in the chromosomes are put in P3 to corresponding activities to get the schedule of the project. The completion date determined by the

P3 displayed in the overview of the project is the date of completion. The P3 has a scheduling parameter like activity relationships, lags, calendars, resources, and progress which can make the project's duration determined by the software to realistic.

2.5.3.3 Genetic Algorithms of time- cost trade-off

Zheng et al., (2004) implemented a multi-objective GA for solving the time-cost trade-off at the same time. To optimize both the time and the cost at the same time, the adaptive weighted approach (AWA) by Pareto was applied. However, to overcome the weakness of the AWA a modification was made to avoid the unit conflicts in the adaptive weight, to have some meaning full concept by changing the sum of the adaptive weight into 1 and changing the value when the criterion maximum and minimum cost and time value have equal value. The chromosome used for the GA is similar the chromosome used by Feng et al. (1997) model. The activities assignment in the chromosome string is also similar to that of Feng et al. (1997). However, the author recommends making more research and effort are to be made to ensure acceptable performance of the model for a large-scale practical project. Another paper followed this paper was developed by using the stochastic approach of multi-objective optimization using the Fuzzy theory.

Toğan and Eirgash, (2018), applied the Teaching Learning Based Optimization (TLBO) algorithm which was first introduced by Rao et al. (2011) on time-cost trade-off optimization problem. Though time-cost-trade-offs have demonstrated by many other optimization methods, but it is for the first time to be carried out by the TLBO as an alternative optimization solver. The TLBO is similar to the metaheuristic algorithms, as it is also a population-based algorithm. In the TLBO algorithm, there are two phases undertaken for the optimization process. These are the teacher phase and the learner phase. During the teacher phase students learn from the teacher while they are also learning from each other by interacting and communicating among themselves. The first mode of TLBO is the Teaching phase, where it creates solutions randomly which are the students or the learners. Then the best qualified students are taken and considered as teacher, gives his insights to the students. This process continues successively until the teacher gives what he knows to the students until they get his level in that way the knowledge is dispersed small by small until it gets all the search space of the learners. When every learner reaches the level of the teacher then it is considered as a teacher. Here the analogy of the students is the size of the population, and the different subject to be taught are the design variables of the optimization process. According to the result of the students the fitness of the optimization problem is evaluated and the students with the best results are considered to the best solutions to the fitness function or the objective function. The model was programed in MATLAB software with the application of the Modified Adaptive Weight Approach proposed by Zheng et al. (2004) to deal with the pareto front. So, the model is known to be MAWA-TLBO which is capable of computing with the other time- cost optimization methods. To see its capability four examples from technical literature was tested and demonstrated a very good power of optimization. The limitation with this approach was that for a large project with large number activities it showed a large deviation from their minimum values of the objective functions.

Magalhães-mendes, (2015), presented an approach that combines a genetic algorithm, a schedule generation scheme and a local search procedure where each of them has different responsibility in the optimization. The priority of the activities is produced by the genetic algorithm. Any chromosome has to go through four different phases which are the transition, prioritizing of activities, schedule construction, and schedule improvements. For each chromosome the following four phases are applied: 1) Transition parameters - this phase is responsible for the process transition between first level and second level; 2) Schedule parameters - this phase is responsible for transforming the chromosome supplied by the genetic algorithm into the priorities of the activities and delay time; 3) Schedule generation - this phase makes use of the priorities and the delay time and constructs schedules; 4) Schedule improvement- this phase makes use of a local search procedure to improve the solution local search procedure to improve the solution obtained in the schedule generation phase.

2.5.3.4 Genetic Algorithm for resource allocation and leveling

Hussain et al., (2007) used the MATLAB software to implement the GA for resource allocation and leveling. The GA starts its work by generating a random collection of population and are represented in a string called chromosome. Each chromosome is considered as a solution which can be best or worst of the available population. The objective function is the point where it evaluates the fitness of each solution performance. After the chromosomes change information either by cross-over or mutation, a new offspring is produced and evaluated to replace the parent population which are lower in fitness. The resource fluctuation in the activities is represented by Mx and the resource utilization is represented by My. So, whenever the combined sum of these moments is small, it is considered the resources are utilized efficiently. So, the optimization is processed by the considering the random priority of activities and minimum combined moments.

Chan et al., (1996) by using the GA created a method that can be used for allocation and leveling of resources on a project. The first formulation that he put was aiming to minimize the difference between the available and required resources. The chromosome string has two important variables, the priority of the activity in its schedule and the percentage of the float that the activity can have. The implementation of the model has the GA engine for the operation of selection, mutation, cross-over for the solution generation, the scheduler builder to construct schedules which do not make confusion with activities' relations and constraints, and fitness chromosome checking by evaluating the function to minimize the difference in resource acquired and availability of each activity. There was activity mapping to the gene of the chromosome string which was done in two methods. The first one was the activity mapping to the chromosome by arbitrary method. The other one was an advanced method where it arranges activities according to their precedence and then are mapped like that to chromosomes. It is reported that the structured mapping gives better outcomes than the arbitrary mapping.

This model outcome was compared with other heuristic methods results and it was found it gives a shorter duration of the project with evenly distributed resources. The best outcome GA is that it doesn't have the shortcomings of heuristic methods have for large projects

Parveen and Saha, (2012) implemented a model by using a GA approach in a MATLAB software. He used the multi-objective approach for the time-cost trade-off by using time-resource trade-off as an input. The model also applied the modified adaptive weight approach (MAWA) which can help in coming with the output of the best optimal solution and the Pareto front, that will give freedom for the planner for effective time-cost trade-off decision. It aims at minimizing the twin target of time and cost. In its formulation first, it considers the total cost of the project is the summation of the direct cost of each activity with their respective resource and the indirect cost. If any activity requires resources which are not available, a premium cost for the extra resource is implemented in the calculation of the direct cost. Penalties for delay of the completion date of the project is also incorporated in the model for indirect cost. The string of the chromosome contains many sections, the gene which contain the duration of each activity. After the process of cross-over and mutation takes place a new off-springs are produced which can replace the original population according to their fitness performance. The model was compared to other literatures results ;(Zheng, Ng, and Kumaraswamy 2004) and was found much better both in terms of cost and duration.

Sonmez and Gürel, (2016), proposed advanced hybrid optimization method for planning and scheduling in large construction projects which have multiple modes of execution and as a result of that, having different duration to finish the projects and resource constraints (MRCPSP). It embraces both heuristic and genetic algorithm where the heuristic is used for the scheduling with regarding to efficient resource utilization whereas the genetic algorithm is used for farther improvements of the quality of optimum solutions which already are found from the heuristic method. This study is committed to solve the resource- constrained project scheduling problem (RCPSP) in a large-scale project and satisfying both at the same time. The start time of each activity is to be assigned after accommodating of both the constrains, and the objective function is made to be minimizing of the total duration of the project. scheduling problem (RCPSP) considers the resource limits along with the precedence constraints. This study has a big contribution on savings during planning and scheduling of large projects with multi-mode execution and resources limitations with few minutes of computation. Although this method has the aforementioned merits however, it requires large amount of time for computation to achieve good quality of solution for large projects.

Damci et al., (2016), took the initiation to investigate how the LOB schedules get impacted by different objective functions for leveling the resources used to complete a project. It used the optimum crew size and natural rhythm principles in the genetic algorithm-based model. To construct this model the steps taken were “(1) identifying the objective functions that are used in resource leveling of network-based and linear schedules, (2) defining the basic principles of “optimum crew size” and “natural rhythm” that are used in resource leveling of LOB schedules,

(3) defining the steps of developing a genetic algorithm-based model for leveling resources in LOB schedules, (4) investigating the impacts of using different objective functions in resource leveling of LOB schedules." To illustrate the model created for demonstration it was applied to a pipeline project of 26 km which is supposed to be completed in 65 days. Here one km is considered to be a unit production and has seven repetitive activities to be completed consecutively. This project was tested for different objective functions in leveling the resources in LOB schedules. The principles of natural rhythm mean to shift the start time of an activity at different rates by changing the number of crews, however, it doesn't affect the duration of the activity and conflict with the precedence relationships between the activities. The study was done against ten functions to level the resources other than LOB and it was found the histogram for all the cases to be the same.

2.5.3.5 Genetic algorithm for time- cost- quality trade-offs

Monghasemi et al., (2015) introduced the application of evidential reasoning (ER) in to a project scheduling by taking the best solutions from the pareto front in the optimization of discrete time–cost–quality trade-off problems (DTCQTPs). Multiple modes of each activity were determined taking in to consideration the constraints which affect the activity. These constraints may include resource limitations and usage plans, technology limitations, construction methods, which have huge impact for the duration and cost of an activity. The multi-objective genetic algorithm (MOGA) with NSGA-II procedure was the key to guide the algorithm to converge the global Pareto optimal front. Their merit study has formulated a DTCQTP modeling skeleton which interacts with a multi-objective genetic algorithm (MOGA), which in turn handles systematically multi-criterion assessment. After having applied the NSGA-II procedures to find the solutions of the pareto front, the ER approach was utilized to rank these solutions according to their optimality. The normalized weight of each objective function (e.g., time, cost, and quality) was obtained by the Shannon's entropy technique method. On the other hand, these weights were used to evaluate the overall performance criterion by creating hierarchical structure. This way the ER approach was examined by the DMs to choose the best solution by assigning utility scores inactive of their degree satisfaction with each alternative solution. To see the applicability, compatibility, and ability of the proposed approach, it was made to solve a case study of DTCQTP problem for highway construction. It was also compared to the research done by Mungle et al. (2013). and the results indicated that the ER approach is more efficient in ranking the Pareto solutions and enables the DMs to decide on an optimal solution with more confidence. However, the approach is not applicable for large projects with large number of activities.

Heravi and Faeghi, (2014) presented a model which seeks the optimal resource utilization in construction projects by optimizing the time, cost, and quality at the same time by a model they called a group decision making framework. It considers all the uncertainty that might be available in any construction project while building the group decision making (GDM) framework to solve the time-cost-quality problem optimization. It basically accumulates the needs and preference of individual decision makers (DMs) for the same problem with different alternative solution to make the most appropriate decision, which gives opportunity to the decision makers free of choosing their own and produce optimal solution. The paper used Monto Carlo Simulation to measure the stochastic time and cost and Fuzzy Additive Weight System (FSAWS) for the stochastic estimation of quality and finally Borda-Ordered Weighted Averaging (BOWA) for searching the optimum resource utilization considering the time-cost- quality trade-offs simultaneously using the GDM. The group decision makers are considered the individual objectives of the project to be optimized and these are the time, cost, and quality. The actual value of cost and time can't be known before construction so there is uncertainty on them and to accommodate the uncertainty the study used the Monto Carlo Simulation approach which will embrace it with confidence level and probability. The formula used for the optimization of each objective function are as the follows.

$$\text{Minimize Project Time} = \sum_{i=1}^{L} T_i^n$$

Equation 2-4 (Heravi and Faeghi 2014)

T_i^n= duration of activity i on the critical path using resource utilization n, and L = number of activities.

$$\text{Minimize Project Cost} = \sum_{i=1}^{L} C_i^n$$

Equation 2-5 (Heravi and Faeghi 2014)

where $\boldsymbol{C_i^n}$= cost of activity i using resource utilization n and L = number of activities.

$$\text{Maximize Overall quality} = \sum_{i=1}^{L} wt_i \sum_{i=1}^{K} wt_{i,k} Q_{i,k}^n$$

Equation 2-6 (Heravi and Faeghi 2014)

where $\boldsymbol{Q_{i;k}^n}$ = performance of quality indicator k in activity (or zone) I, $\boldsymbol{wt_{i;k}}$ = weight of quality indicator k compared to other indicators in activity i representing the relative importance of this indicator to others ,$\boldsymbol{wt_i}$= weight of activity i compared to other activities in the project (illustrating the importance and contribution of the quality of this activity to the overall quality of the project), and K = number of quality indicators. The framework was applied in the real-world construction of Namroud Dam, a rock-fill dam with clay core, which is in the central area of Iran and it proved its capability. However, the frame work has integrated different tools for optimizing each of the objective function which makes prone to mistakes and high computation works.

Abd ElRazek et al., (2010), developed a practical software system which is named as the Automatic Multi-objective Typical Construction Resource Optimization System (AMTCROS). Its main aim was to support decision makers in searching the efficient way of resource utilization so that the cost and duration of the project will be minimum, and the quality will be maximum. The method integrates both the concept of Line of Balance, and Critical Path Method and the multi objective search engine of genetic algorithm. It was coded using the Java programing and the software has user graphic interface (GUI) where the planner can input his inputs of the project description, activities list, activities relationships, resource utilization for each activities, duration of each resource utilization, holidays, weekends, exceptional dates, genetic algorithm parameters, and the output phase where he can inter the weights of his objectives. The formulations for quantifying the quality of the activities and project was taken from (Heravi and Faeghi, 2014). The cost of the project also includes the indirect cost of project which was assumed to be 500 EGY pound. The software has tested to see its capability to demonstrate the optimization on real construction of Semoha in Alexandria that has about 23 repetitive activities with 15 floors.

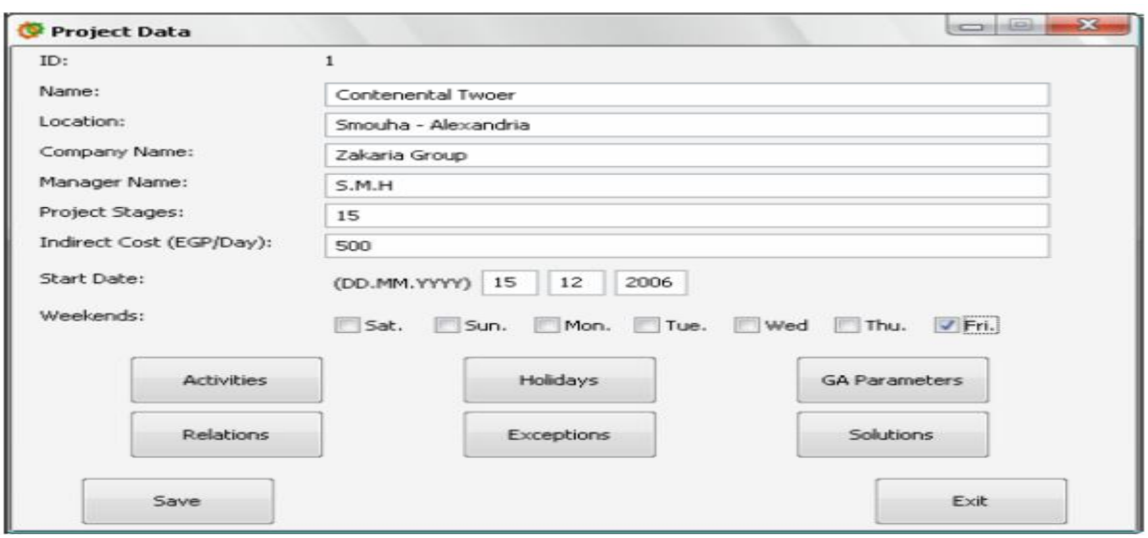

Figure 2-3.Project input details form (Abd ElRazek et al. 2010)

Kazaz et al., (2016), came with idea of introducing a new two-step methodology, for the time-cost-quality trade-off problems by considering different construction materials alternatives to be involved in the formation of data for optimization. The study more fits for building as high variety of construction materials can be utilized in buildings. It argues that technical specifications of different alternative materials have directly impact on the TCQ of an activity and project as whole. It states as an example, that "using gas concrete bricks instead of clay bricks will shorten the duration of the wall building activity by 40% in turkey." The study also gave an emphasis that the material to be used affects the direct and indirect cost of an activity as well as the project besides the maintenance cost. However, the quality impact attributed by each material used can't be overlooked on the project as well as the activity. The study argues that alternative construction materials must involve in the resource utilization formation instead of only focusing on crew formation and policy. Hence a two-step optimization method was introduced to the TCQ optimization. In the first step alternative construction materials effect is checked on the TCQ optimization under same conditions of crew formation and policy. On this stage which material to be used will be determined and at the same time the expected quality of the activity and the project with the selected material will also be estimated. After determining the quality at this early stage, quality as parameter has not to be optimized in the second stage. Then the second step can take place if and only if it is required to crash the duration or minimize the cost of the construction schedule, where it can involve different alternatives of crew formation and policy. At this point time-cost optimization can be processed at the same time using different optimization methods found in the literatures. However, the study doesn't show which optimization method it has used, and the results compared with other literature.

2.6 Gap in the Literature

Time-cost trade-off or time-cost- quality trade-offs were the focus of optimization in the past two decades. They deal with trade-offs these contradicting parameters to strike a balance among them where it will result minimum time, and cost and maximum quality. However, studies which include cash-flow analysis in researches and literatures are not as common as the Time-cost trade-off as per the author's knowledge which studies to the time and cost as the credit get changed. The cash-flow analysis has double advantage to contractors, as it gives information about the trend of financing in each month, and how much credits should be provided to get the targeted profit from the project. It also gives a big clue whether to take the project or not at its early stage by knowing your allowable credits. So, this study tried to optimize time and profit with different amount of allowable credits, using the commonly used optimizing engines.

CHAPTER 3 MODEL DEVELOPMENT

3.1 Introduction

This chapter will cover some important concepts and procedures for the development of the models. It starts with the brief explanation of the nature of highway construction to the detailed development of the two models; the scheduling and optimization models for highways construction. The detailed steps for the optimization of the profit, time and multi-objective optimization will be elaborated in this chapter.

3.2 Repetitive projects

Projects that are characterized by their repetitive activities are called linear or repetitive projects. The activities of these projects get repeated each time in each unit of the project. They are known for their repetition natures and can be classified as (1) horizontal repetitive which is resulted due to their location and layout like highway, multi-bay single story building, pipelines which are generally called linear projects; (2) vertical repetitive which are called due to their repetition their activities in the vertical direction as high rising building and (3) repetitive projects which integrated both the horizontal and vertical repetitive projects like multi- high rising building, (Agrama 2011).

Linear projects generally constitute large percentile of the construction industry. All highways, tunnels, pipeline including repetitive buildings cover large portion of construction. However, these projects are difficult to get them scheduled due to their repetitive behavior and are always challenging to the project managers. This resulted from their nature that they can't be scheduled using the mostly used critical path method, rather they require schedule that is capable of resource continuity and ensure un-interruption in the movements from one unit to the other unit keeping the logical dependency constraints. The traditional commonly used scheduling method; the critical path method doesn’t suit for the scheduling of repetitive projects. As a result, a resource driven technique of scheduling like the Line of Balance (LOB) is used which accommodates the resource continuity and the logical dependency constraints of the activities. The LOB is basically a graphical representation technique which doesn’t have the CPM qualities in scheduling of a project,(Ammar 2013). This research is integrating the CPM and LOB to schedule the project as highway construction is one of the repetitive projects.

The purpose of this chapter is to show the development of the models for scheduling of a repetitive activities and the optimization of the profit and time for a given project. The two models have different work where the scheduling model gives the schedule of the activities in each unit depending up on the model for the optimization of the profit and time associate with the different methods of execution of each of an activity. The optimization model searches for a near optimal solutions of maximum profit and minimum time by changing the method of execution for each activity in each unit. The scheduling method on the other hand takes the output of the optimization model and schedules each activity in each unit. These models are implemented using the software excel spreadsheet where it is a common and easily used by practitioners in the field of management. For optimization purpose the add-in tool called the Evolver is used. It is an efficient tool for optimization of multi-objective; so, it is used for the optimization of the profit and time of a given project simultaneously. The two models developed are:

1. Scheduling model
2. Optimization model for the profit and time of the project.

3.3 Scheduling Model

The scheduling model is a presentation of the line of balance of the repetitive activities in a project. The basic representation of the LOB is described briefly and is shown in the figure below.

It is a graphical representation of the schedules where it lacks the merits of CPM and has its own attributes. The bar of the LOB represents an activity and its width is the duration of that activity. The units of each activity are represented by the y- axis where are the activity of each unit is represented by the x-axis. On the other hand, the duration of the project is on the horizontal axis and number of units of the project are on the vertical axis. The assumption in the scheduling is that, each unit of the project have the same amount of work to be accomplished which in reality would be different, however, it gives realistic scheduling outcome. Any horizontal line drawn will cut the activities bar at its start and finish point of the unit.

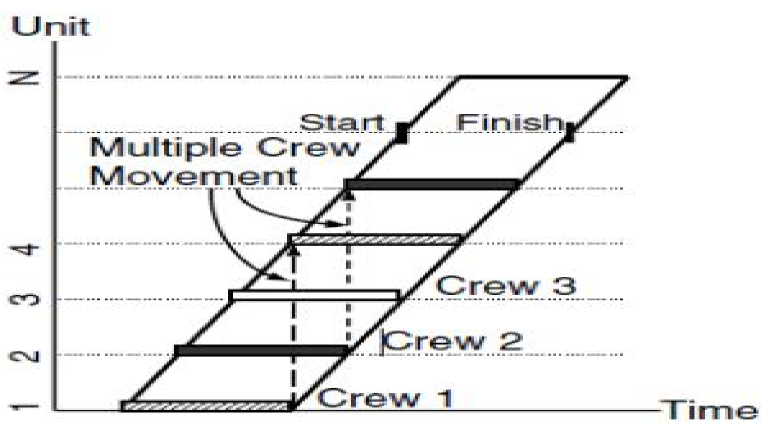

Figure 3-1 basic representation of line of balance for repetitive activities (*Hegazy T* 2002)

Whereas any vertical line from the end one unit to the other tells where the crew can start after finishing the first unit. It can be shown from the figure above that multiple crews can be utilized in the same activity. However, it is always recommended that work continuity must be maintained to avoid or mitigate the amount of disruption and maximize the output production rate of the units. This representation allows for multiple crew usage in the same activity, as shown in the figure 3-1. The steps for the calculation of the line of balance are explained below in detail.

3.3.1 LOB Calculations

The basic aim of LOB scheduling is to produce a schedule which is a resource driven and balances the number of crews employed in each activity. Then units will be delivered with some rate of production in a such a way that meets the prespecified deadline of the work with the work continuity being maintained. The process assumes that only one crew can work in a single unit and spends time equal to the duration of the activity. Then that crew can move to the next unit where it is not being worked by other crew if the activity has more than one crew. To make sure the project will be completed in the prespecified deadline, a desired rate of production to deliver the work must be formulated. Generally, the LOB undergoes the following tasks to complete the scheduling process. These steps are applied in the developed model to give the scheduling of any project according to its user inputs.

- Crew synchronization and work continuity equation;
- Computation of a project delivery rate that meets a given deadline duration;
- Calculating resource needed for critical and non-critical activities; and
- Drawing the LOB schedule.

3.3.1.1 Crew Synchronization and Work Continuity Equation.

To attain a crew synchronization and work continuity, it is necessary to drive an equation which incorporates duration taken by a crew to complete a unit of activity and number of crews which can be used to complete the whole units of an activity. Looking at the figure below, it will be easy to derive the relationship between the duration of an activity in a unit and number of crews required to accomplish all units of that activity.

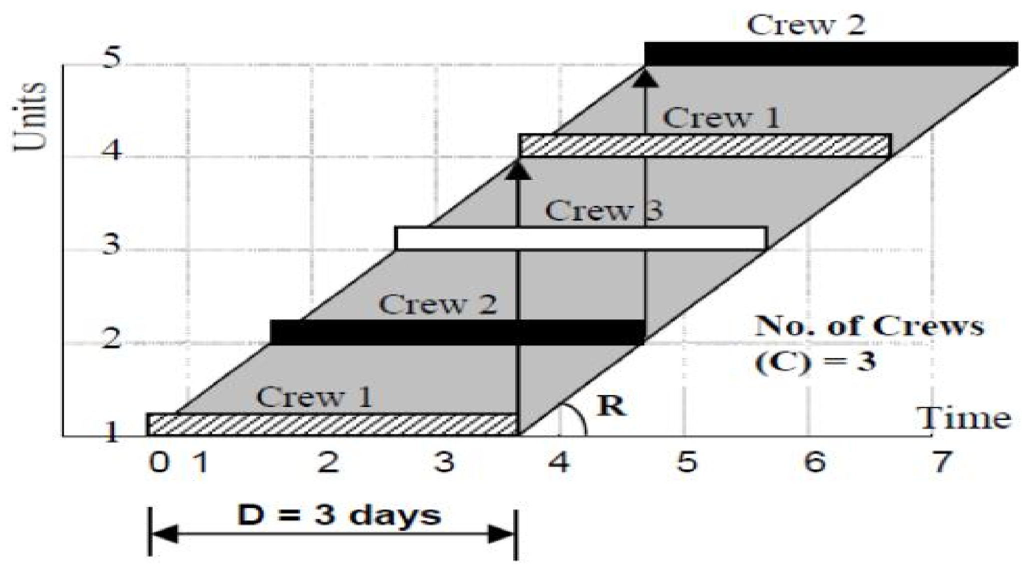

Figure 3-2 crew synchronization (Hegazy T 2002))

In the figure 3-2 above the 5 units are worked with three crews. Every crew moves to the next unit after it finishes the first unit and is always assumed that only one crew can work on a single unit and spends time (D). It is possible now to schedule the movement of each of the crew in the units without causing any interruption with a constant rate of production(R). For creating the work synchronization, the simple equation below can be applied.

$NUMBER\ OF\ CREWS(C) = D\ x\ R$ *Equation 3-1 (Hegazy T 2002)*

Where C= number of crews

D= duration of one-unit R= rate of production

From the figure 3-3, below shown driving the relationship of Equation 3.1 is simple. It is first the duration (D) is divided among the number of crews (C), then the slope of the shaded triangle can be used to apply the Pythagoras theorem and the slope which is (R) can be calculate.

R= 1/(D/C)

D/C= 1/R *Equation 3-2*

We can come up with the former equation C= D x R from both the later equations. It also can be seen the start of the next unit is D/C or 1/R away from the previous unit. This has a big advantage in the scheduling, and it is always good to remember that crews have time which they don't have to share, and on these moments, they may utilize equipment or machines which are fixed in number in the project like crane. So, it is possible to adjust the rate of delivery by changing the number of crews and duration of the activity in the unit.

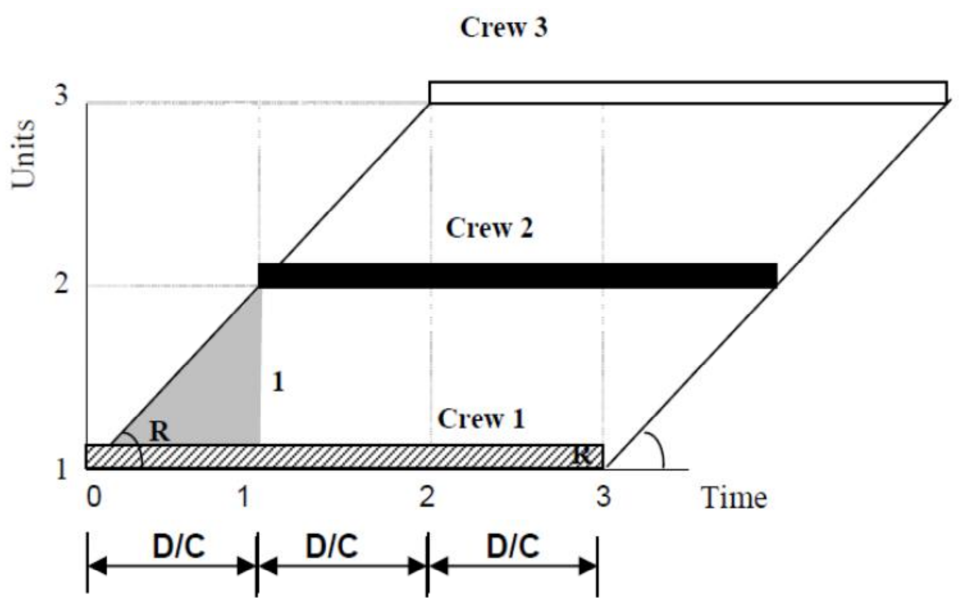

Figure 3-3 rate of production calculations for activities (Hegazy T 2002)

The model has incorporated these rules and formulas to maintain the crew synchronization.

Rate	Theortical # Of Crews	Actual # Of Crews
0.168674699	=AS26*AH26	2
0.168674699	1.012048193	2
0.168674699	2.024096386	3
0.168674699	0.674698795	1
0.168674699	0.506024096	1

Figure 3-4 part of the model where number of crews is the product of duration of the activity and the rate of production.

Where cell AS26 is the rate of production of any activity and cell AH26 the duration of that activity.

3.3.1.2 Computation of a project delivery rate that meets a given deadline duration

To meet the desired deadline of the project the activities have to be delivered at a certain rate so that the project will not be delayed. The desired rate (R_d) at which every activity is delivered to meet the project duration can be done using the equation 3-3 below by referencing to figure 3-4. This desired rate is a theoretical rate of output and is measured and expressed in number of units per unit time.

$$R_d = \frac{N-1}{T_P - T_1} \qquad \textit{Equation 3-3}$$

Where N= number of units Tp= total project duration T1= CPM duration of one unit.

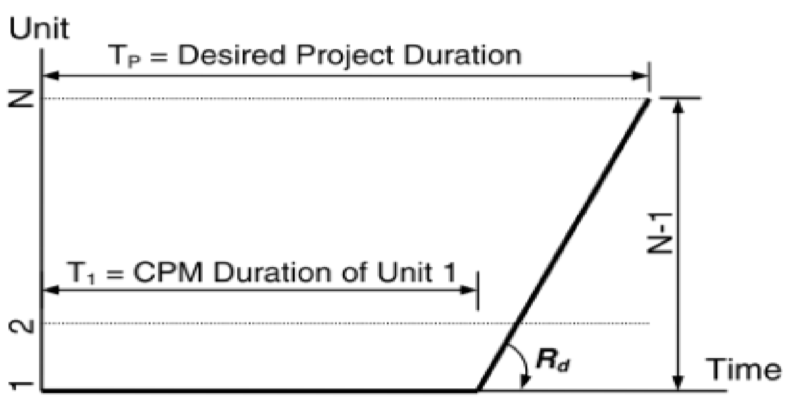

Figure 3-5 Calculating a desired rate of delivery (*Hegazy T 2002*)

To apply this formula in the model the main user inputs are number of units (N), and total project duration. However, the duration of a critical path method of the first unit is calculated by the optimization model. So, having all these inputs the ideal rate can be calculated.

Description	Value
Number of Units	**15**
Deadline of The Project (Months)	**120**
Duration of One unit (Months)	**37**

Table 3-1 user inputs of number of units and project deadline with calculated duration of one unit

3.3.1.3 Calculating resource needed for critical and non-critical activities

The delivery rate determined from Equation 3.3 is the minimum rate to be applied in order to meet the desired deadline. If we increase the rate of delivery it will shorten the duration of the project. However, it will need more crews which can result for more cost. After having the minimum rate of delivery (Rd), we apply it on the schedule of the repetitive activities in order to find the resource needed to complete the project on time. Equation 3.3 is then firmly applied to activities which are critical having the longest path in CPM network of each unit. However, activities which are not critical have float times and it is not necessary to apply equation 3.3. we can relax them and that means subsidizing the increase in cost. So, to accommodate any activity in a project Equation 3.3 can be modified as

$$R_i = \frac{N-1}{(T_P - T_1) + T_{F_i}}$$ *Equation 3-4*

After having the desired rate of production for each activity using equation 3.4, the number of crews required to complete the project without delay can be expressed as

$$C_i = D_i \times R_i$$ *Equation 3-5 modified equation of 3.1*

The calculated number of crews from equation 3.5 might not be integer number as the rate is most of the time a decimal value. So, to change the number of crews as integers where there can't be fraction of number of crews, the result of the equation is rounded up and as a result actual number of crews (Ca_i) can be attained. However, the rate of delivery will be also changed as the result of rounding up the number of crews, so, adjustment to the actual rate of delivery of the activities is needed.

$$Ca_i = Roundup\ (C_i) \qquad \textit{Equation 3-6}$$

$$Ra_i = Ca_i / D_i \qquad \textit{Equation 3-7}$$

$Ca_i <= Cm_i$ where Cm_i is the maximum number of crews available for each activity.

The developed optimization model does these works and are utilized by the scheduling model. The equation 3.4 can also cause more relaxation of activities which are not in the critical path method, which can cause these activities to be changed in to critical activities and violate the precedence relationships. To avoid that it is advisable to change the total float in to free float of the activities which really doesn't create any of the aforementioned problems,(Hegazy and Wassef 2001). Sample of the equations from the optimization model can be seen in the figure 3-6 below.

BUFFER OF LOB	Rate	Theortical # Of Crews
=(AS4-1)/(AS5-AS6+AP26)		
	0.168674699	1.012048193
	0.168674699	2.024096386

Figure 3-6 a formula for calculating the desired rate of production incorporating the free float.

The cells AS4 is number of units of the project, AS5 the total project duration, AS6 duration of one unit from the critical path method, AP26 is free float of the given activity.

3.3.1.4 Drawing the LOB Schedule

3.3.1.4.1 Calculating Activity Duration

Duration of activity in each unit is considered to be the same. So, the duration of an activity in all units can be calculated as:

$$Di = di + STiN - STi1 \qquad Di = di + (N-1)/R_{ai} \qquad \text{Equation 3-8}$$

in which STiN = start time of last unit; STi1 = start time of first unit; and Di = duration along all units of activity I; di= duration of one unit.

3.3.1.4.2 Specifying Logical Relationships using Overlapping Activities

The rate of progress of different activities is the determinant factor of their logical dependency relationships among them. The developed model is capable of determining the relationship among the different activities according to the rate of progress as well as preserving the precedence relationship of each activity. Farther more it also maintains the work continuity. To determine the relationships the actual rate progress of each activity is compared with that of its successors. If R_{ai} and R_{as} are the actual rate of production of precedent activity i and its succeeding activity s, respectively, three scenarios of the following can be encountered.

- Case 1. Rai > Ras, in this case the two activities are divergent where activity i is faster than its succeeding activity s. As a result, the finish of the first unit of activity i controls the start of the first unit of activity s. Therefore, a start-to-start (SS) relationship can be specified.

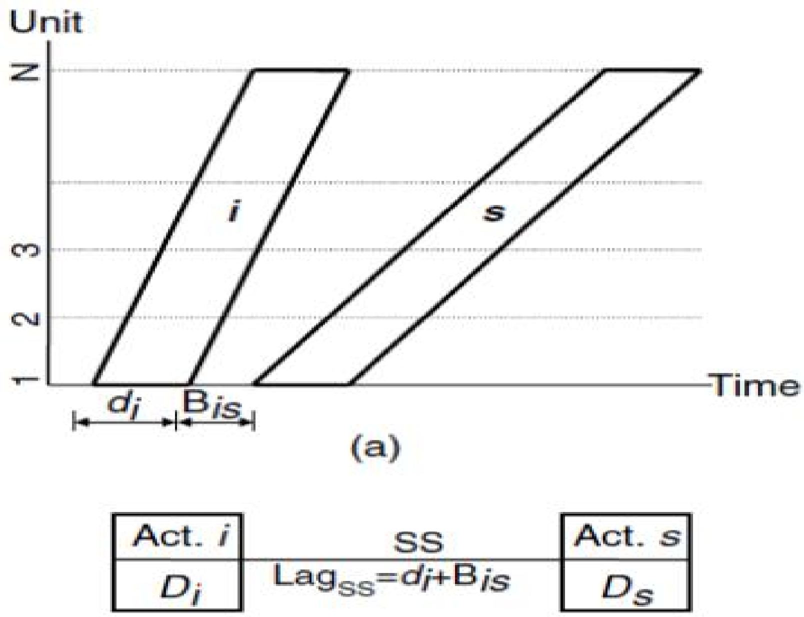

*Figure 3-7 S-S relationship of activities for **Rai > Ras*** (*Hegazy T 2002*)

The lag associated with the SS relationship (LagSS) can be calculated as the equation given below.

LagSS *= di +Bis* *Equation 3-9*

Bis = minimum buffer time between activities i and s. Buffer time is usually used in LOB scheduling to absorb the effect of any unforeseen effects that may delay project completion. The model developed on this study also allows to put the user amount of buffer of his will, which it takes in to its scheduling of the project.

- Case 2. Rai < Ras, this case represents a scenario of conflicting of the two activities may happen as they are converging activities. Since, the s activity is faster than the ith activity the finish of the last unit of the ith activity controls the start of the last unit of the s activity. Then the finish-to-finish (FF) relationship is utilized. The associated lag with FF relationship (LagFF) can be calculated by Equation 3.10 in which ds = unit duration of the succeeding activity s.

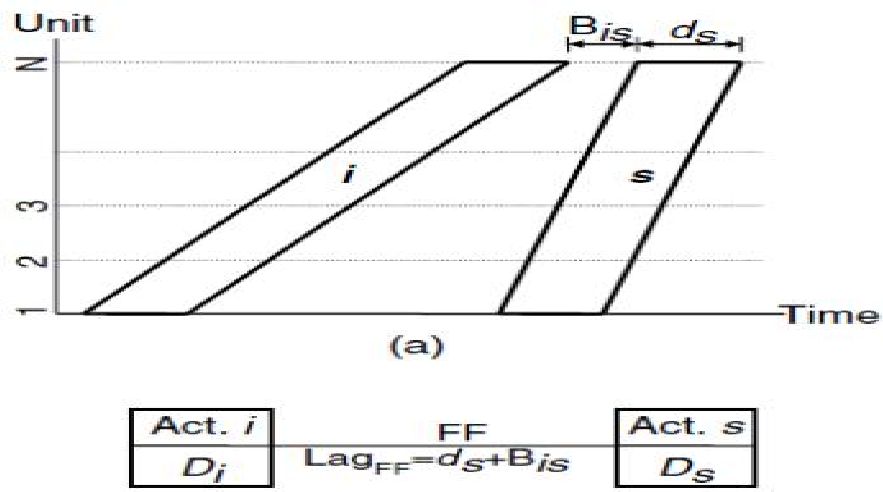

Figure 3-8 F-F relationship of activities for ***Rai < Ras*** *(Hegazy T 2002)*

$$LagFF = ds + Bis \qquad \text{Equation 3-10}$$

- Case 3. When the rate of both activities is the same it possible to use any of the above cases.

3.3.1.4.3 Time Scheduling

After the LOB calculations are performed and the relationship type among consecutive activities are determined with their associated lags, then similar to the CPM, time analysis can be easily performed. Forward pass to determine the early timings of all activities are conducted on the other hand backward pass to determine the late timings are also performed.

For SS relationship

$$ES_{i1} = MAX\ (ES_{P1} + LagSS_{ip})\ P = 1,2,3,\ldots\ldots\ldots\ldots P(N) \qquad \text{Equation 3-11}$$

$$EF_{IN} = ES_{i1} + D_i \qquad \text{Equation 3-12}$$

where ESi1 = early start time of the first unit of activity i; ESp1 = early start time of the first unit of its predecessor p; NPi = number of its predecessors; and EFiN = early finish time of the last unit of activity i.

For FF relationship

$$ES_{iN} = MAX\ (EF_{PN} + LagFF_{ip})\ P = 1,2,3,\ldots\ldots\ldots\ldots P(N) \qquad \textit{Equation 3-13}$$

$$ES_{I1} = EF_{In} - D_i \qquad \textit{Equation 3-14}$$

If the early start and finish times of the first and last units of an activity are determined, then the early start and finish times of all the units of that activity can be easily determined using the equation 3-15

$$ES_{iN} = Es_{i1} + (n-1)/Ra_i \qquad \textit{Equation 3-15}$$

$$Ef_{iN} = Es_{i1} + di \qquad \textit{Equation 3-16}$$

where ESin and EFin denote early start and early finish times of any unit n in activity i, respectively (n = 1,2,3……..N).

Depending on the type of relationships determined which basically was function of the production rate of each activity, the scheduling model gives the days of start of each unit for each activity. It also takes in to consideration the precedence relationships be never violated. Accordingly, it generates the schedule for any number of units and activities given by the user.

Sample of the model which generates the early start of each unit and finish of each unit is shown in the figure 3-9 and 10 below.

ACTIVITIES	Start1	Start2	Start3	Start4	Start5	Start6	Start7	Start8	Start9	Start10	Start11	Start12	Start13	Start14	Start15	Start16
A	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	
B	0	3	6	9	12	15	18	21	24	27	30	33	36	39	42	
C	0	4	8	12	16	20	24	28	32	36	40	44	48	52	56	
D	24	28	32	36	40	44	48	52	56	60	64	68	72	76	80	
E	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	
F	12	17	22	27	32	37	42	47	52	57	62	67	72	77	82	
G	28	33	38	43	48	53	58	63	68	73	78	83	88	93	98	
H	9	13	17	21	25	29	33	37	41	45	49	53	57	61	65	
I	38	42	46	50	54	58	62	66	70	74	78	82	86	90	94	
J	61	64	67	70	73	76	79	82	85	88	91	94	97	100	103	
K	17	22	27	32	37	42	47	52	57	62	67	72	77	82	87	

Figure 3-9 scheduling model which generates start time of each of unit with every activity.

1st unit finish	2nd unit finish	3rd unit finish	4th unit finish	5th unit finish	6th unit finish	7th unit finish	8th unit finish	9th unit finish	10th unit finish
10	15	20	25	30	35	40	45	50	55
6	9	12	15	18	21	24	27	30	33
12	16	20	24	28	32	36	40	44	48
28	32	36	40	44	48	52	56	60	64
9	12	15	18	21	24	27	30	33	36
17	22	27	32	37	42	47	52	57	62
33	38	43	48	53	58	63	68	73	78
17	21	25	29	33	37	41	45	49	53
45	49	53	57	61	65	69	73	77	81
67	70	73	76	79	82	85	88	91	94

Figure 3-10 scheduling model which generates finish time of each of unit with each activity.

3.4 Optimization Model

The model's main objective is to identify and select the appropriate execution method of construction for each activity of the project within the number of options of execution with each activity, in such a way it will maximize the profit of the project and minimize the time to complete it. This means it searches a combination of execution of the activities to have near optimal profit and time for completion the project. This proposed model is implemented in Microsoft Excel software which is well-known and used by many practitioners. For the optimization purpose the add-in tool in Microsoft excel called evolver is used. It has genetic algorithm engine which is used for this research. The outcome of this model will provide planners and decision makers in the highway construction: (1) generating optimal/near optimal resource utilization plans for highway construction projects that optimizes construction time and profit; (2) visualizing 2-dimensional representation of the trade-offs among project time, and profit. The optimization consists of four tasks.

1. Modeling of construction decision variables;
2. Formulation of objective functions;
3. Model implementation;
4. Model testing and validation.

These tasks will be described in more details in the following sections.

3.4.1 The Proposed Approach and Methodology

In order to develop the models, identification of the parameters involved in the scheduling and optimization are indispensable. The parameters, tools and steps of developing the models will be explained and covered in the sub-sequent topics.

3.4.1.1 Decision Variables

The decision variables are factors which have an impact on the project in any of the project attribute. These attributes can either of the projects cost, time, quality, profit, environmental impact, and risks. The variables of any project may include materials used, equipment, construction methods, crews' formation, or crews' overtime policy. For the study on hand the above-mentioned variables are summed up as a construction method or resource utilization which will have an associated cost and time for each activity of the project. Then each activity in return within a project may have several methods of execution to accomplish that activity. The execution method of each activity will have a specific production rate which will affect the direct cost and time of completion of that activity as well as the project as a whole, since its effect can be manifested on the duration and cost of the project. So, each resource utilization option of an activity will create different values on the project's profit as well as the time for the completion of the project. This means the profit and time of completion of the project is a function of the options of execution methods of the activities in the project. Having this in hand the objective of the model is to identify and select an index for each activity which will give near maximum profit and near minimum duration of the project. These indices are the genes of a chromosome to be changed to achieve the intended objective.

The variables(genes) of the study on hand are the method of execution of each activity and the additional crews to get near optimal time and near optimal profit.

COSTRUCTION METHOD CHOOSEN			
INDEX	COST	DURATION	CREW
1	19284	10	6
1	20000	6	8
1	38000	12	4
1	34928	4	6
1	50000	3	4
1	25000	5	8
1	20610	5	4
1	22574	8	6
1	40000	7	6
1	47000	6	4
1	31000	5	10
1	34000	9	10
1	26494	8	4
1	66000	5	10
1	24000	4	8

Figure 3-11 screen shot of the index of using different execution method variables

Actual # Of Crews	Actual Rate	Additional Crews	Revised # of Crews
2	0.2	0	2
2	0.333333333	0	2
3	0.25	0	3
1	0.25	0	1
1	0.333333333	0	1
1	0.2	0	1
1	0.2	0	1
2	0.25	0	2
2	0.285714286	0	2
2	0.333333333	0	2
1	0.2	0	1
2	0.222222222	0	2
2	0.25	0	2
1	0.2	0	1
1	0.25	0	1

Figure 3-12 screenshot of additional crew's variables to optimize the model for profit and time.

3.4.2 Optimization Constraints

Optimization constraints are constraint which will never be broken by any means. For any optimization project to be valid, it must optimize the objective function by satisfying the given constraints. Depending on the optimization objective the constraints can be different for different projects. However, for the study on hand the optimization constrains are as the following.

- The total duration of the project must be greater than the duration of one unit of activities which can be found from critical path method (CPM) analysis.

Description	Value
Number Of Units	15
Deadline of The Project	120
Duration Of One unit	37

Figure 3-13 screen shot of project duration and duration of one unit of the model.

- The maximum allowable crew numbers can't be greater than the maximum available crews in each activity.

- The number of crews to be added must be integer and zero, not fraction.

- The maximum over draft of the cash flow should not greater than the available credit permit.

Credit limit	**$**	**(1,750,000)**
Maximum Overdraft	**$**	**(1,941,362)**

Figure 3-14 screen shot of credit and overdraft of the optimization model.

- The value of the index number of the execution method should be integer and ranges between the minimum and maximum options available on each activity.

3.4.3 Total Project Cost

The direct and indirect costs of a project constitute the project cost. The direct cost of the project is the sum of all the costs of each activity in the given project according to each execution method chosen to each activity; Whereas the indirect cost is the cost incurred daily for the duration of the project as a whole. The indirect cost is in direct relationship with the duration of the project, which can be assumed to be a fixed value per time measure. If a contract document has a stipulation on early finish incentive and late finish liquidate damage, then these values can be added to the total cost which will either increase or decrease the project's cost according to the time it finished to complete the project.

For the study on hand the target is to maximize the profit and minimize the time for completion of the project. The model is intended to find the combinations of execution methods of the activities by adding crews to the construction in such a way it will attain near minimal time of completion and near optimal profit for the given project. The model considers incentives for early completion and liquidated damage for late completion of the project from contract duration of the given project.

Table 3-2 screen shot of table which shows the incentive, and liquidated damage and other costs from the model

Description	Value
Number Of Units	15
Deadline of The Project (Da	120
Duration Of One unit (Days)	37
Working days per week	6
Early Completion Bonus/day	$ 2,000
Liquidated Damages/day	$ 1,500
Indirect Cost/day	$ 1,000
Interruption Penalty	$ 1,750
Additional Cost/Crew	$ 2,000

The component of the profit of the project includes the summation of all interest paid, the contract markup of the project, incentive money if the projected is completed in duration lower than the contract duration of the project, the addition cost for the additional number of crews and liquidated damage if the project completion is delayed. The direct and indirect costs are incorporated in the cashflow analysis. If the cash-out flow is greater than the cash-in flow, there will be an overdraft from pocket or to be paid from loan which will in-force to pay interest money for the loan. So, the equation 3.17 given below can illustrate all the component of the profit.

Month	Total Direct Cost	Monthly direct& indirect Expenses	Cumulative Expenses Cash-Out/Month	Expected money/Month	Advanced payment to be Reduced	Retention	Payable Amonunt of Money	Payment Received	Month	cumulative Cash In	Overdraft before interest	Interest	Overdraft
0													
1	$ 8,430	$ 38,974	$ 38,974	$ 42,872	$ 4,288	$ 5,145	$ 33,439	$ 3,435,965	0	$3,435,965	$ 3,396,991		$ 3,396,991
2	$ 8,430	$ 39,527	$ 78,501	$ 43,479	$ 4,348	$ 5,218	$ 33,913	$ -	1	$3,435,965	$ 3,357,465		$ 3,357,465
3	$ 8,430	$ 40,087	$ 118,588	$ 44,095	$ 4,410	$ 5,292	$ 34,393	$ 33,439	2	$3,435,965	$ 3,350,818		$ 3,350,818
4	$ 11,764	$ 44,181	$ 162,769	$ 48,600	$ 4,860	$ 5,832	$ 37,908	$ 33,913	2	$3,469,404	$ 3,340,550		$ 3,340,550
5	$ 14,931	$ 48,205	$ 210,974	$ 53,026	$ 5,303	$ 6,364	$ 41,359	$ 34,393	3	$3,469,404	$ 3,326,739		$ 3,326,739
6	$ 16,860	$ 50,987	$ 261,961	$ 56,086	$ 5,609	$ 6,731	$ 43,746	$ 37,908	3	$3,503,317	$ 3,313,660		$ 3,313,660
7	$ 33,527	$ 70,101	$ 332,062	$ 77,111	$ 7,712	$ 9,254	$ 60,145	$ 41,359	4	$3,503,317	$ 3,284,918		$ 3,284,918
8	$ 33,527	$ 71,094	$ 403,156	$ 78,203	$ 7,821	$ 9,385	$ 60,997	$ 43,746	4	$3,537,710	$ 3,257,570		$ 3,257,570
9	$ 36,694	$ 75,696	$ 478,851	$ 83,265	$ 8,327	$ 9,992	$ 64,946	$ 60,145	5	$3,537,710	$ 3,242,020		$ 3,242,020
10	$ 39,516	$ 80,016	$ 558,868	$ 88,018	$ 8,802	$ 10,563	$ 68,653	$ 60,997	5	$3,575,617	$ 3,223,002		$ 3,223,002

Figure 3-15 screen shot of cash-flow analysis from the model

3.4.4 The Fitness Function

The fitness function for maximizing the profit of the project is given by the equation 3-17. If the contract has stipulation for incentives if the project is finished before its contract time and liquidated damage if it gets delayed, then the formula below will be incorporate in equation 3-17.

$$F = \begin{cases} B * (D_C - D_A) & if\ D_C > D_A \\ L * (D_A - D_C) & if\ D_C < D_A \end{cases}$$

Equation 17

$$Maximize\ Profit = M + F - \sum I - A * \sum C \qquad \text{Equation 3-17}$$

Where

M = the mark up value of the project

F= the incentive or liquidated damage of the project depending the completion duration.

B = incentive value per day if the duration of completion is less than the project duration in the contract.

D_C = the duration of the project in the contract document.

D_A= the actual duration of the project.

L= liquidated damage value per day, if the project is delayed from the contract duration.

I= interest paid in every month of the project.

A= amount of penalty for additional crews from the pool.

C= number of crews added to optimize the profit and time.

3.4.5 Total Project Duration

In calculating the total duration of the project, the first step is to perform the CPM approach for the first unit. Forward pass is first done to find the early start and finish times of the activities. The following equations indicate the formulas used to calculate the early start, early finish, late start and late finish, total float and free float of each activity.

Early Start (ES) = latest Early Finish of the activity's predecessors or project start date. Equation 3-18

Early Finish (EF) = Early Start + Duration. Equation 3-19

Late Finish (LF) = Earlies Late start of the successors. Equation 3-20

Late Start (LS)= Late Finish- Duration. Equation 3-21

Total Float (TF) = LS – ES = LF – EF. Equation 3-22

Free float (FF) = ES start of the successors – Early finish (EF) Equation 3-23

An ES time of zero is assigned to an activity if it is the start of the project. The EF time of any activity is calculated using Equation 3-19. The ES time of a successor activity taken as the maximum early finish of its predecessors. For the start of an activity its late start and early start are the same which also applies the same for the end activity of the project. The end activity of a project also has the same early finish and late finish and is considered as the duration of the project. Application of the backward path is used to determine late finish times of activities. The LS time of any activity is calculated using Equation 3-21. To find the LF time of any predecessor activity, it is taken as the smallest LS value of its successors. The TF value of any activity is calculated as the difference of late finish minus early finish or late start minus early start as is shown in equation

3-22. Free float of an activity on the other hand is the time an activity can be delayed without affecting the early start of its successors and is calculated as equation 3-23. This can be shown as figure given below.

ES	EF	LS	LF	TOTAL FLOAT	successor's min. START	FREE FLOAT
0	10	0	10	0	10	0
0	6	2	8	2	6	0
0	12	0	12	0	12	0
10	14	10	14	0	14	0
6	9	8	11	2	9	0
12	17	12	17	0	17	0
14	19	14	19	0	19	0
9	17	11	19	2	17	0
17	24	17	24	0	24	0
19	25	19	25	0	25	0
17	22	19	24	2	24	2
24	33	24	33	0	33	0
25	33	25	33	0	33	0
22	27	28	33	6	33	6
33	37	33	37	0	1000	0

Figure 3-16 screen shot of the calculations of ES, EF, LS, LF, TF, FF using the critical path method for the first unit

However, the calculation of the total time of the project on this study is not only dependent on the critical path method duration rather it is a linear scheduling which depends on the line of balance. Its final duration is found from the scheduling model after integrating with the optimization model to start with the critical path method of the first unit. To calculate the total duration of the project, it is needed to go through the whole process explained under the scheduling model. The fitness function of the time is given by equation 3-24.

Minimize Time= $\sum_1^n T$ *Equation 3-24*

where n= number of units

T = time of each unit in the critical path.

3.4.6 Optimization Approach

The optimization approach is a genetic algorithm application approach where the evolver add-in package in excel is used.

- The first optimization is to maximize the profit subjected to deadline of the project, allowable credit, and limited number of crews.
- Minimizing the total project time subjected to allowable credit, and limited number of crews.
- And over all optimization of profit and time subjected to allowable credit, and limited number of crews.

In the overall optimization of both the profit and time an importance weight is selected according to the user preference for the profit and time. The process of the multi-objective optimization for both the profit and time is done as discussed below.

3.4.7 Optimization Tool

The modeling is based on the genetic algorithm (GA) optimization, so, a tool which incorporates genetic algorithm has to be utilized where Evolver was the suitable match for the study on hand and is an excel spread sheet add-in package. For this study purpose the trial version of Evolver has been used, where it doesn't have any limitation from the commercial evolver except it expires after certain weeks. The use of excel as modeling media has many advantages as it is the most widely used software in the management field and can be understood by any of practitioner. It is also very easy software to model the project. The Evolver which is considered as one of the most powerful optimization software packages is capable of finding the global solutions of any complicated non-linear problems. According to the corporation who developed the evolver, best attributes of the software include finding better solutions, ease of use, dealing with large numbers of variables and constraints, and its accuracy. Before doing any optimization the steps to set the evolver are as the follows.

Step 1. The model has to defined, by telling it whether the optimization is minimizing or maximizing and specify also the cell to be minimized or maximized. On the model definition log, all the adjustable cells and constraints are also defined with ordering what type increasing is required for your model. All the adjustable cells have an option of selecting the range, maximum and minimum values and also the values if they have to be integer, decimal or discrete which increase with steps as shown in the figure 3-18.

Step 2. The setting of the evolver also allows to choose the type of engine, runtime setting whether it has to be stopped by time or number of iterations. This can be illustrated in the figure 3-19. For the study on hand the genetic algorithm engine is utilized with 100 number of population and .5 cross over and .1 mutation, where the two latest are default setting of the engine.

Step 3. After all settings are set by the user, then the start Run Butten is pressed to start the optimization.

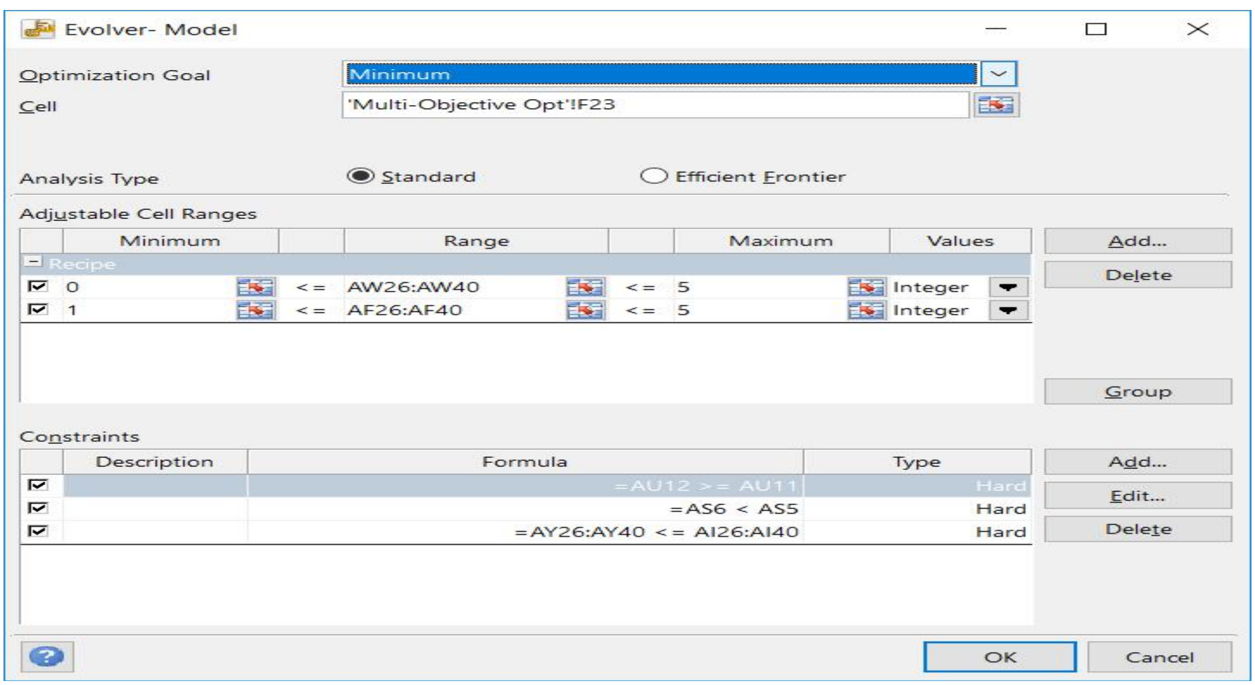

Figure 3-17 screenshot of the model definition of the evolver.

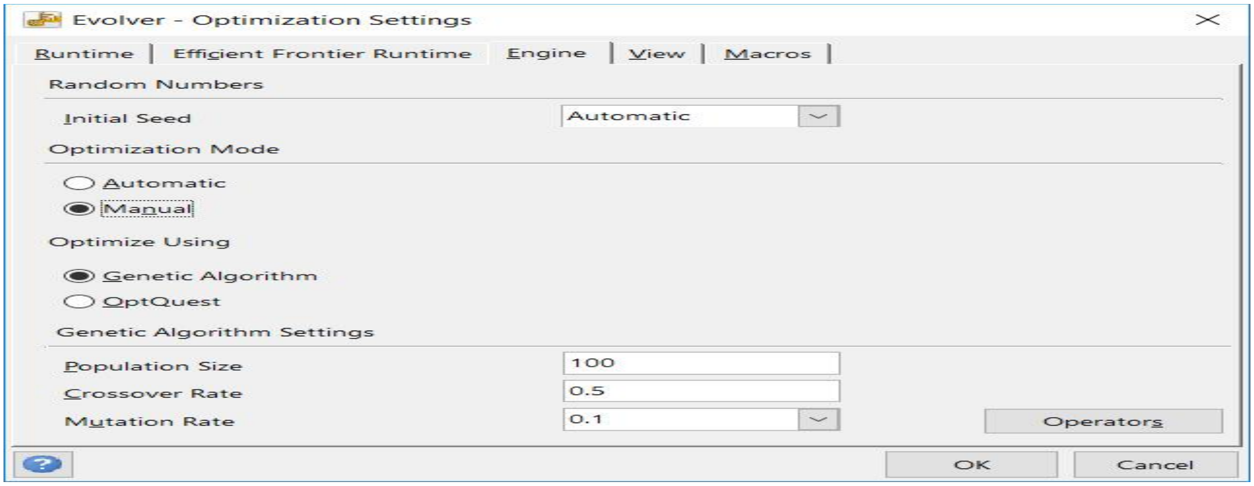

Figure 3-18 screenshot of the setting of the evolver and setting of this optimization model.

3.5 Model Description and Organization

The optimization model has two parts which are the input model and the output model. They are not two different models but are found together. However, it has a distinction method of color code. For the input cells, it is a grey color, for the variables it is a yellow color where as for the output cells in the model is white.

3.5.1 Flow chart of the genetic algorithm process

This model works genetically and have number of genes in a chromosome which indicate the options of execution methods and have a number of chromosomes which refer to the number of populations. The process of selection, cross-over and mutation takes place in order to satisfy the constraints and objective function and continues until near optimal solution is reached. For the model on hand the there are two types of chromosome, the chromosome for the method of execution and number of crews to be added during the optimization. The figure below shows the execution method of each activity. So, the model has to search for optimal combination of execution of the activities and added number of crews from the available limited number of crews to carry the optimization.

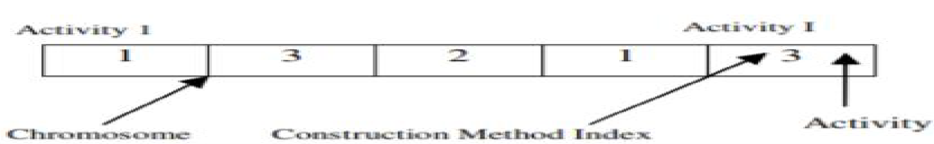

Figure 3-19 chromosome with genes of execution method of different activities.

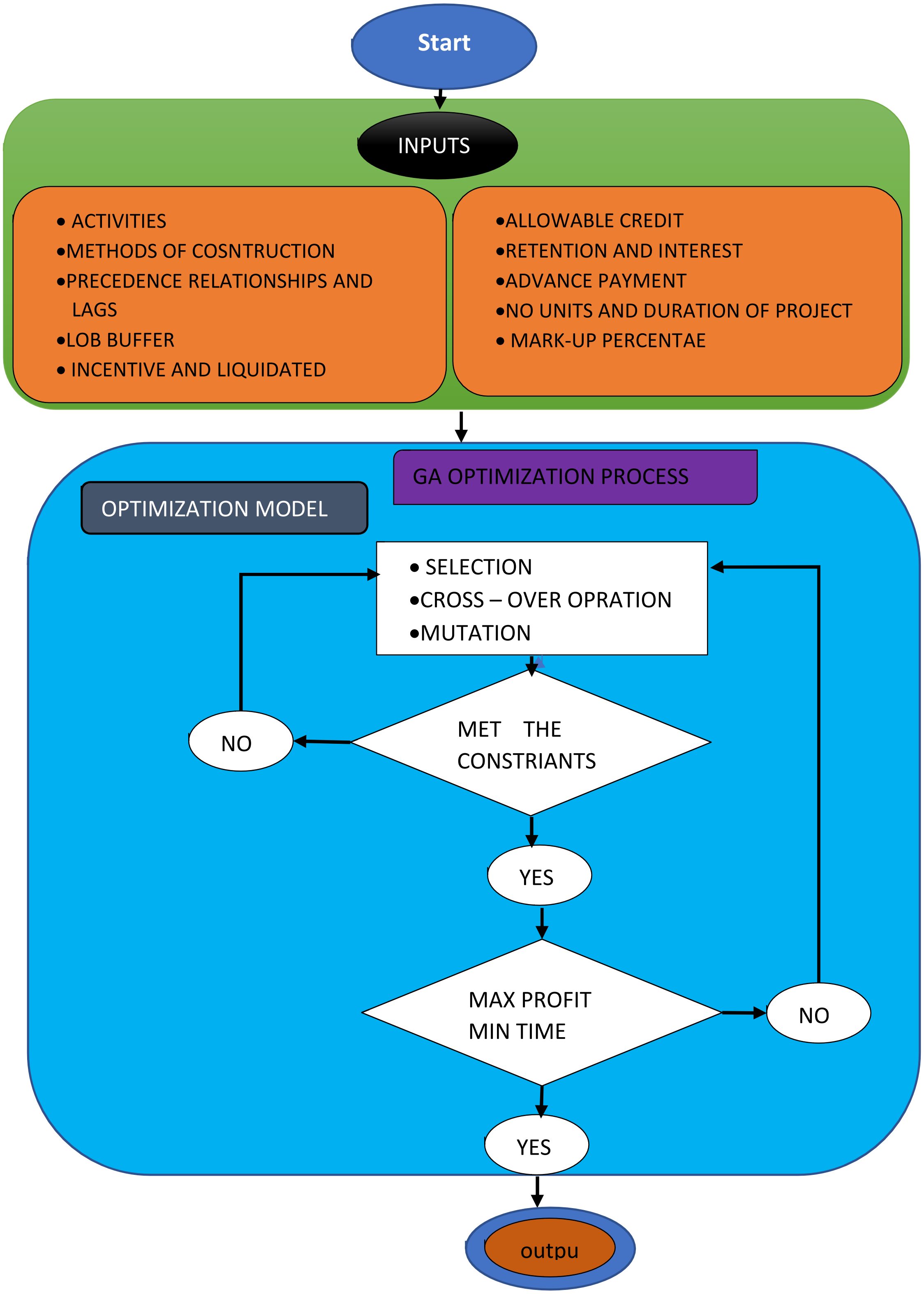

Figure 3-20 flow chart of operation of the genetic algorithm to reach optimal solution.

3.5.2 Input Module

The input part of the model consists of the following where the user has to input to facilitate the optimization and scheduling of the project.

- General activities data, including ID and description of each activity.
- Scheduling data, including predecessors of each activity.
- Execution options data, including duration, direct cost, and number of crews.
- Project constraints and contractual data, including the project deadline, allowable credits
- Number of units, indirect cost, a penalty of late completion, and a bonus of early completion.
- Mark-up percentage, interest percentage, retention percentage, and advanced payment.
- Lags of predecessors from the start of successors.
- Buffers for the scheduling of line of balance.

	Construction Methods														
Activity	1			2			3			4			5		
	Cost1	Duration1	Crews1	Cost2	Duration2	Crews2	Cost3	Duration3	Crews3	Cost4	Duration4	Crews4	Cost5	Duration5	Crews5
A	$ 19,284	10	3	$50,000	4	4	$61,600	3	1	$61,480	7	5	$67,216	6	5
B	$ 20,000	6	4	$49,504	12	5	$62,000	11	6	$56,288	4	5	$35,000	4	4
C	$ 38,000	12	2	$85,000	8	2	$17,232	5	2	$27,009	3	1	$64,667	5	4
D	$ 34,928	4	3	$61,045	3	5	$45,000	2	6	$35,000	4	3	$15,000	2	4
E	$ 50,000	3	2	$24,638	2	3	$67,543	10	3	$85,000	7	3	$60,000	8	2
F	$ 25,000	5	4	$80,000	4	2	$55,159	8	6	$60,000	3	5	$47,000	3	3
G	$ 20,610	5	2	$54,550	5	1	$31,773	4	2	$69,928	3	4	$46,151	9	5
H	$ 22,574	8	3	$55,000	7	1	$62,085	9	6	$50,231	5	2	$30,000	10	4
I	$ 40,000	7	3	$31,000	12	4	$42,602	4	6	$48,199	12	1	$57,000	7	3
J	$ 47,000	6	2	$64,162	11	2	$54,112	3	3	$29,000	10	1	$64,899	8	2
K	$ 31,000	5	5	$61,544	4	5	$42,373	10	5	$59,291	4	5	$42,852	11	3
L	$ 34,000	9	5	$65,488	5	1	$17,224	6	3	$53,644	12	3	$49,023	4	4
M	$ 26,494	8	2	$68,148	3	5	$42,534	3	2	$39,000	2	6	$32,000	5	5
N	$ 66,000	5	5	$56,092	8	5	$ 8,419	9	5	$37,000	5	5	$54,723	4	5
O	$ 24,000	4	4	$19,000	7	5	$33,449	4	3	$61,892	3	1	$69,858	2	4

Figure 3-21 input table of the construction methods of the project

PRED 1	LAG1	PRED 2	LAG2	PRED 3	LAG3	PRED 4	LAG4	PRED 5	LAG5
A		B							
B									
B		C							
D		E							
E									
F									
G		H							
H		E							
K		I							
K		J							
K									
L		M		N					

Figure 3-22 input table of predecessors and their lags.

Table 3-3 user input table of interest, retention, advanced and number of construction methods from the model.

Description	Value	BUFFER OF LOB
Number Of Units	15	
Deadline of The Project	120	
Working days per week	6	
Early Completion Bonus/day	$ 2,000	
Liquidated Damages/day	$ 1,500	
Indirect Cost/day	$ 1,000	
Interruption Penalty	$ 1,750	
Additional Cost/Crew	$ 2,000	
days allowed for incentive	15	
Max days allowed of delay	20	
Number of activities	15	
Credit limit	$ (1,750,000)	
Markup	10%	
Retention	12%	
Advance Payment	10%	
Number Of Construction Methoc	5	
Intrest Rate/Year	17%	
Cost Weight	0.6	
Time Weight	0.4	

3.5.3 profit Maximization

After the user has input all the necessary data for the optimization process, Profit maximization optimization is first carried out to find the maximum profit possible with the given allowable credit without considering the time of the project. The optimization approach is a genetic algorithm application approach where the evolver trial version add-in package in excel is used. Projects with fifteen and fifty activities and five to three method of execution have been used to verify the developed model.

For example, for allowable credits of $1750000 to the fifteen activities project and $2562000 to the fifty activities project which have five to three methods of execution with different number of crews for each activity, can be taken as an example to show how the profit optimization is carried out.

Table 3-4 user-input and result of the optimization model before optimization for 15 activities project.

Description	Value	Description	Value
Number of activities	15	Markup	10%
Project Completion	135	Retention	12%
Early Completion Bonus		Advance Payment	10%
Delay Penalty		Number Of Construction Methods	5
Total Indirect Cost	$ 135,000	Intrest Rate/Year	17%
Total Interruption Cost	$ -	Total Interest Paid	$ (556,544)
Total Crew Cost	$ -	Planned Profit	$ 3,123,604
Credit limit	$ (1,750,000)	Actual Profit	$ 2,567,004
Maximum Overdraft	$ (1,941,362)	Time	135
Cost Weight	0.6	Maximizing profit	$ 2,514,504
Time Weight	0.4		

Table 3-5 user-input and result of the optimization model before optimization for 50 activities project.

Description	Value	Description	Value
Number of activities	50	Markup	10%
Project Completion	174	Retention	12%
Early Completion Bonus		Advance Payment	10%
Delay Penalty		Number Of Construction Methods	5
Total Indirect Cost	$ 174,000	Intrest Rate/Year	17%
Total Interruption Cost	$ -	Total Interest Paid	$ (651,382)
Total Crew Cost	$ -	Planned Profit	$ 4,025,826
Credit limit	$ (2,670,000)	Actual Profit	$ 3,374,382
Maximum Overdraft	$ (2,522,410)	Time Minimization	174
Cost Weight	0.6	Maximizing profit	$ 3,290,382
Time Weight	0.4		

Number of activities, cost and time weights, mark-up, retention, advanced payment, interest, and method of executions are user inputs. The total interest, planned profit, actual profit, Maximum overdraft are values calculated by the cash-flow analysis model.

The total interest paid is the summation of interest paid throughout the project duration when the overdraft is negative. The planned profit is the mark-up of the project cumulative cost. Actual profit is the profit the contractor gets from project which is the difference between the planned cost and total interest.

The profit is the parameter to be maximized by optimization and the fitness function equation is given as:

$$\textit{Maximize Profit} = \boldsymbol{M + F - \sum I - A * \sum C} \qquad \textit{Equation 3-25}$$

Where

M = the mark up value of the project

F= summation of the liquidated damage and incentive.

B = incentive value per day if the duration of completion is less than the project duration in the contract.

D_C = the duration of the project in the contract document.

D_A= the actual duration of the project.

L= liquidated damage value per day, if the project is delayed from the contract duration.

I= interest paid in every month of the project.

A= amount of penalty for additional crews from the pool.

C= number of crews added to optimize the profit and time.

The constraints of the optimization of the profit are

- Allowable credit on hand; it can be seen from table 3-4, and 3-5 that the maximum over-draft can be greater or less than the allowable credit, when all the method of execution of the activities were set to be 1. So, the model has to search for method of execution where the maximum overdraft is less than the allowable credit limit.
- Number of crews available; during the optimization the crews to be added must be not greater than the available number of crews in each activity.
- The duration of the project has to be greater than the duration of one unit which can be found from the critical path method.

After setting the evolver for optimization with constraints and limits of the optimization to maximize the profit the results of the table in 3-4 and 3-5 get changed and all the models of cash-flow analysis, index of the method of execution, scheduling models and number of crews added get changed depending on the values of the maximized profit.

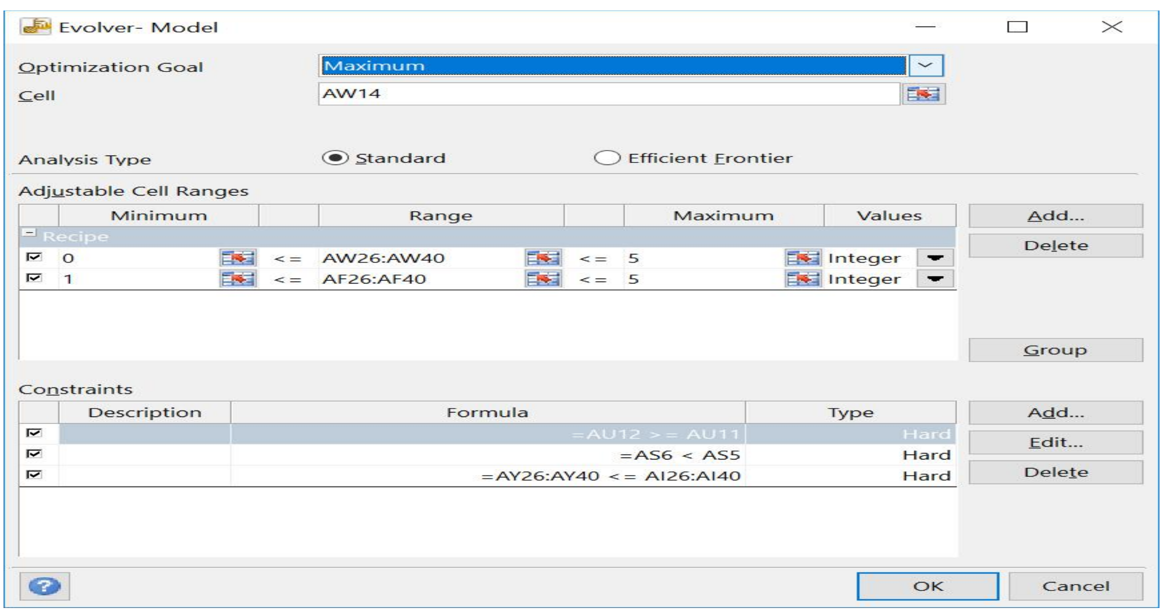

Figure 3-23 setting up of the evolver for the profit maximization.

The tables below show that the results get changed in values from the optimization in the table.

Table 3-6 values changed after optimization of the profit in table 3-4.

Description	Value	Description	Value
Number of activities	15	Markup	10%
Project Completion	114	Retention	12%
Early Completion Bonus		Advance Payment	10%
Delay Penalty		Number Of Construction Methods	5
Total Indirect Cost	$ 114,000	Intrest Rate/Year	17%
Total Interruption Cost	$ -	Total Interest Paid	$ (377,159)
Total Crew Cost	$ 60,000	Planned Profit	$ 2,857,671
Credit limit	$ (1,750,000)	Actual Profit	$ 2,480,470
Maximum Overdraft	$ (1,723,677)	Time Minimization	114
Cost Weight	0.6	Profit maximization	$ 2,432,470
Time Weight	0.4		

Table 3-7 values changed after optimization of the profit in table 3-5.

Description	Value	Description	Value
Number of activities	50	Markup	10%
Project Completion	178	Retention	12%
Early Completion Bonus		Advance Payment	10%
Delay Penalty		Number Of Construction Methods	5
Total Indirect Cost	$ 178,000	Intrest Rate/Year	17%
Total Interruption Cost	$ -	Total Interest Paid	$ (681,278)
Total Crew Cost	$ 24,000	Planned Profit	$ 4,275,193
Credit limit	$ (2,670,000)	Actual Profit	$ 3,593,856
Maximum Overdraft	$ (2,665,861)	Time Minimization	178
Cost Weight	0.6	Maximizing profit	$ 3,471,856
Time Weight	0.4		

It can be noted that, the maximum over draft is less than the allowable credit in both cases.

However, while our intention was to maximize the profit, it gets reduced instead for the first project. The reason why this happened is actually, the intention was looking for a maximum profit for the given limited credit. So, the value $2432470 is the best solution for the combination of execution methods and crew added of the activities shown in table 3-6 with credit limit of $1750000. The maximum overdraft became $1723677 which is less than $1750000. However, on the other hand for the second project the allowable credit was greater than the maximum overdraft. So, it finds the maximum profit for the project with that allowable credit.

The index of the execution method of the activities and added crews are given below in the table for the optimized time.

Table 3-8 method of execution index and number of crews added to maximize the profit of the fifteen activity project.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Index	1	4	4	1	1	2	3	3	2	1	1	1	4	2	1
Added crew	3	3	1	0	0	0	2	1	1	1	4	3	2	5	4

3.5.4 Time optimization

The time optimization also follows the same procedure as the profit optimization. The only difference is that the profit is made to be maximized and the time is made to be minimized.

Given all the user input as shown in the table below, the optimization is made to minimize the duration of the project. The allowable credit limits are $1750000 and $2670000 for the two projects.

Table 3-9 user-input and results of the optimization model before optimization for the fifteen activities project.

Description	Value	Description	Value
Number of activities	15	Markup	10%
Project Completion	135	Retention	12%
Early Completion Bonus		Advance Payment	10%
Delay Penalty		Number Of Construction Methods	5
Total Indirect Cost	$ 135,000	Intrest Rate/Year	17%
Total Interruption Cost	$ -	Total Interest Paid	$ (556,544)
Total Crew Cost	$ -	Planned Profit	$ 3,123,604
Credit limit	$ (1,750,000)	Actual Profit	$ 2,567,004
Maximum Overdraft	$ (1,941,362)	Time	135
Cost Weight	0.6	Maximizing profit	$ 2,514,504
Time Weight	0.4		

Table 3-10 user-input and results of the optimization model before optimization for the fifty activities project.

Description	Value	Description	Value
Number of activities	50	Markup	10%
Project Completion	174	Retention	12%
Early Completion Bonus		Advance Payment	10%
Delay Penalty		Number Of Construction Methods	5
Total Indirect Cost	$ 174,000	Intrest Rate/Year	17%
Total Interruption Cost	$ -	Total Interest Paid	$ (651,382)
Total Crew Cost	$ -	Planned Profit	$ 4,025,826
Credit limit	$ (2,670,000)	Actual Profit	$ 3,374,382
Maximum Overdraft	$ (2,522,410)	Time Minimization	174
Cost Weight	0.6	Maximizing profit	$ 3,290,382
Time Weight	0.4		

Number of activities, cost and time weights, mark-up, retention, advanced payment, interest, and method of executions are user inputs. The total interest, planned profit, actual profit, Maximum overdraft are values calculated by the cash-flow analysis model.

The total interest paid is the summation of interest paid throughout the duration of the project when the overdraft is negative. The planned profit is the mark-up of the project cumulative cost. Actual profit is the profit the contractor gets from the project which is the difference between the planned cost and total interest.

The time minimization optimization is given by the objective function:

Minimize Time= $\sum_{1}^{n} T$ *Equation 3-25*

where n= number of units

T = time of each unit in the critical path.

The constraints for the optimization of the time is the same as the constraints of the profit maximization optimization.

- Allowable credit on hand; it can be seen from table 3-4, that the maximum over-draft is greater than the allowable credit, when all the method of execution of the activities were set to be 1. So, the model has to search for method of execution where the maximum overdraft is less than the allowable credit limit. However, in the second case the maximum overdraft is already less than the allowable credit.
- Number of crews available; during the optimization the crews to be added must be not greater than the available number of crews in each activity.
- The duration of the project must be greater than the duration of one unit which can be found from the critical path method.

The setting of the evolver was made to minimize the time as shown in the figure 3-24.

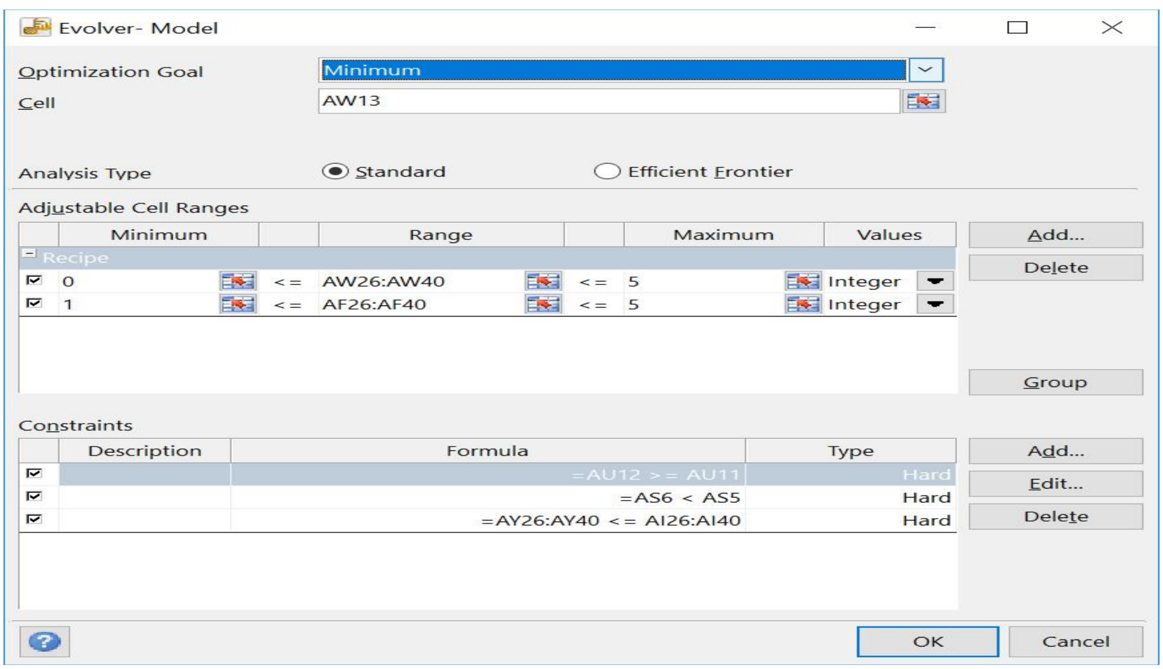

Figure 3-24 evolver setting for the time optimization.

After the optimization the time to finish the project was 65 months. The result of the optimization can be shown in the tables.

Table 3-11 result and changed values of the table 3-9 after time minimization optimization.

Description	Value	Description	Value
Number of activities	15	Markup	10%
Project Completion	65	Retention	12%
Early Completion Bonus		Advance Payment	10%
Delay Penalty		Number Of Construction Methods	5
Total Indirect Cost	$ 65,000	Intrest Rate/Year	17%
Total Interruption Cost	$ -	Total Interest Paid	$ (373,291)
Total Crew Cost	$ 82,000	Planned Profit	$ 2,050,156
Credit limit	$ (1,750,000)	Actual Profit	$ 1,676,820
Maximum Overdraft	$ (1,196,915)		
Cost Weight	0.6	Time Minimization	65
Time Weight	0.4	profit optimization	$ 1,624,820

Table 3-12 result and changed values of the table 3-10 after time minimization optimization

Description	Value	Description	Value
Number of activities	50	Markup	10%
Project Completion	163	Retention	12%
Early Completion Bonus		Advance Payment	10%
Delay Penalty		Number Of Construction Methods	5
Total Indirect Cost	$ 163,000	Intrest Rate/Year	17%
Total Interruption Cost	$ -	Total Interest Paid	$ (590,382)
Total Crew Cost	$ 18,000	Planned Profit	$ 3,568,169
Credit limit	$ (2,670,000)	Actual Profit	$ 2,977,720
Maximum Overdraft	$ (2,230,451)	Time Minimization	163
Cost Weight	0.6	Maximizing profit	$ 2,914,220
Time Weight	0.4		

The time has reduced to less than half with the profit. However, the profit at this point is not a concern. Our constraint, the maximum overdraft is satisfied along with the number of crews to be added.

The index of the execution method of the activities and added crews are given below in the table for the optimized time for the first project.

Table 3-13 method of execution index and number of crews added for the minimized time for the fifteen activities project.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Index	2	5	5	3	1	3	4	4	1	3	4	5	5	1	3
Added crew	2	3	3	2	1	5	1	3	1	1	5	4	5	3	2

3.5.5 Multi-objective Optimization of time and profit

The multi-objective optimization is made to run, after the individual runs were made to maximize the profit and minimize the time. It is based on the Goal programing using the genetic algorithm.

- The first optimization is to maximize the profit subjected to allowable credit, and limited number of crews, the duration of the project is greater than the duration of one unit.
- Minimizing the total project time subjected to allowable credit, and limited number of crews, the duration of the project is greater than the duration of one unit.

In the overall optimization of both the profit and time an importance weight is selected according to the user preference for the profit and time. This optimization is also subjected to allowable credit, and limited number of crews and the duration of the project is greater than the duration of one unit like the profit and time optimization.

After finding the optimal values of the profit and duration, final optimization of both profit and time take place simultaneously to get the near optimal solution for both profit and time.

Before optimization of either the profit, time or both simultaneously the method of execution(index) of each activity is initialized to be one or the first method of execution. Then the model will give a profit and time of completion of the project for these methods of execution. Having the values from the initialization and results of the profit maximization and time minimization, the multi- objective optimization tries to minimize the deviation between them using the goal programing. The values of the profit and duration of the project for initialized value can be seen from the table 3-10.

Table 3-14 user-input and results of the optimization model before optimization for the fifteen activities project.

Description	Value	Description	Value
Number of activities	15	Markup	10%
Project Completion	135	Retention	12%
Early Completion Bonus		Advance Payment	10%
Delay Penalty		Number Of Construction Methods	5
Total Indirect Cost	$ 135,000	Intrest Rate/Year	17%
Total Interruption Cost	$ -	Total Interest Paid	$ (556,544)
Total Crew Cost	$ -	Planned Profit	$ 3,123,604
Credit limit	$ (1,750,000)	Actual Profit	$ 2,567,004
Maximum Overdraft	$ (1,941,362)	Time	135
Cost Weight	0.6	Maximizing profit	$ 2,514,504
Time Weight	0.4		

Table 3-15 user-input and results of the optimization model before optimization for the fifty activities project.

Description	Value	Description	Value
Number of activities	50	Markup	10%
Project Completion	174	Retention	12%
Early Completion Bonus		Advance Payment	10%
Delay Penalty		Number Of Construction Methods	5
Total Indirect Cost	$ 174,000	Intrest Rate/Year	17%
Total Interruption Cost	$ -	Total Interest Paid	$ (651,382)
Total Crew Cost	$ -	Planned Profit	$ 4,025,826
Credit limit	$ (2,670,000)	Actual Profit	$ 3,374,382
Maximum Overdraft	$ (2,522,410)	Time Minimization	174
Cost Weight	0.6	Maximizing profit	$ 3,290,382
Time Weight	0.4		

The optimized profit and time of the projects for $1750000 and $2670000 are given from the individual optimization as in the tables 3-11,12, 13 and 14 below.

Table 3-16 the optimized maximum profit for 1750000 allowable credit of the fifteen activities project.

Description	Value	Description	Value
Number of activities	15	Markup	10%
Project Completion	114	Retention	12%
Early Completion Bonus		Advance Payment	10%
Delay Penalty		Number Of Construction Methods	5
Total Indirect Cost	$ 114,000	Intrest Rate/Year	17%
Total Interruption Cost	$ -	Total Interest Paid	$ (377,159)
Total Crew Cost	$ 60,000	Planned Profit	$ 2,857,671
Credit limit	$ (1,750,000)	Actual Profit	$ 2,480,470
Maximum Overdraft	$ (1,723,677)	Time Minimization	114
Cost Weight	0.6	Profit maximization	$ 2,432,470
Time Weight	0.4		

Table 3-17 result of the optimized minimum time for 1750000 allowable credit for the fifteen activities project.

Description	Value	Description	Value
Number of activities	15	Markup	10%
Project Completion	65	Retention	12%
Early Completion Bonus		Advance Payment	10%
Delay Penalty		Number Of Construction Methods	5
Total Indirect Cost	$ 65,000	Intrest Rate/Year	17%
Total Interruption Cost	$ -	Total Interest Paid	$ (373,291)
Total Crew Cost	$ 82,000	Planned Profit	$ 2,050,156
Credit limit	$ (1,750,000)	Actual Profit	$ 1,676,820
Maximum Overdraft	$ (1,196,915)		
Cost Weight	0.6	Time Minimization	65
Time Weight	0.4	profit optimization	$ 1,624,820

Table 3-18 the optimized maximum profit for 2670000 allowable credit of the fifty activities project.

Description	Value	Description	Value
Number of activities	50	Markup	10%
Project Completion	178	Retention	12%
Early Completion Bonus		Advance Payment	10%
Delay Penalty		Number Of Construction Methods	5
Total Indirect Cost	$ 178,000	Intrest Rate/Year	17%
Total Interruption Cost	$ -	Total Interest Paid	$ (681,278)
Total Crew Cost	$ 24,000	Planned Profit	$ 4,275,193
Credit limit	$ (2,670,000)	Actual Profit	$ 3,593,856
Maximum Overdraft	$ (2,665,861)	Time Minimization	178
Cost Weight	0.6	Maximizing profit	$ 3,471,856
Time Weight	0.4		

Table 3-19 result of the optimized minimum time for 2670000 allowable credit for the fifty activities project.

Description	Value	Description	Value
Number of activities	50	Markup	10%
Project Completion	163	Retention	12%
Early Completion Bonus		Advance Payment	10%
Delay Penalty		Number Of Construction Methods	5
Total Indirect Cost	$ 163,000	Intrest Rate/Year	17%
Total Interruption Cost	$ -	Total Interest Paid	$ (590,382)
Total Crew Cost	$ 18,000	Planned Profit	$ 3,568,169
Credit limit	$ (2,670,000)	Actual Profit	$ 2,977,720
Maximum Overdraft	$ (2,230,451)	Time Minimization	163
Cost Weight	0.6	Maximizing profit	$ 2,914,220
Time Weight	0.4		

The setting of the process and equation for the multi-objective optimization follow some procedures and can be shown for the fifteen activities project.

First the deviations of the objectives are calculated as

- deviation from optimum Values profit or time = Absolute (Value of the initial profit or time – Optimum value of profit or time from individual optimization) / Optimum value of profit or time from individual optimization.

For example, for profit to find the deviation we take abs **($2,514,504 - $ 2,432,470)/ $ 2,432,470**

= 0.033724568

For time abs **(135-65)/65** = **1.07692**

Where $2,514,504 and 135 are the initial values of profit and time and $2,432,470 and 65 are the optimum values of individual optimization.

- Weighted Deviation = Deviation from Optimum Value profit or time * profit or time Optimization Weight.

The weights of profit and time are 0.6 and 0.4 respectively for this study. So, the weighted deviation for profit = **0.6* 0.033724568 = 0.020234741**

Deviation for time **= 0.4* 1.07692 = 0.43077.**

- Multi-Objective Optimization Value = Sum of Weighted Deviation.

0.020234741+ 0.43077 = 0.451003972

After finding the sum of the weighted deviation, the optimization is run to minimize this sum of weighted deviations. The setting and constrains of the model remain the same as for the individual optimization. The same procedure is applied to the project with fifty activities.

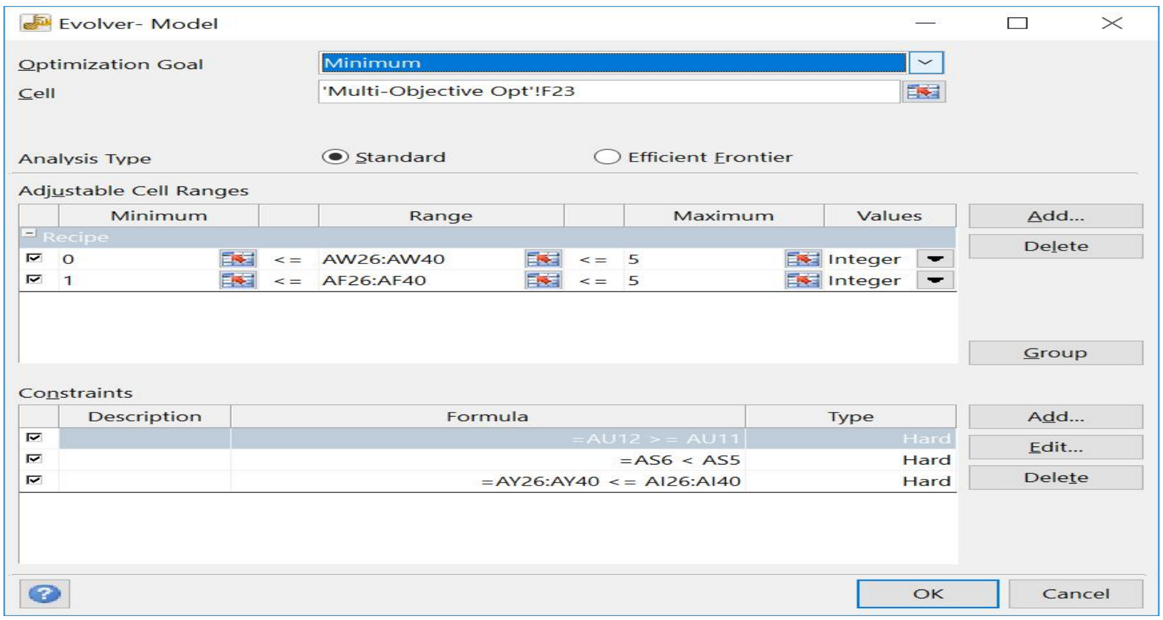

Figure 3-25 evolver setting for the multi-objective optimization of the project

PROFIT AND TIME OPTIMIZATION			
Initial values		PROFIT	TIME
		$ 2,514,504	135
INDIVIDUAL NEAR OPTIMIZED VALUE			
		PROFIT	TIME
		$ 2,432,470	65
DEVIATION FROM OPTIMUM			
		PROFIT	TIME
		0.033724568	1.07692
WEIGTHS OF INDIVIDUAL FOR OPTIMIZATION			
		PROFIT	TIME
		0.6	0.4
WEIGTHED DEVATION			
		PROFIT	TIME
		0.020234741	0.43077
MULTI OBJECTIVE OPTIMIZATION			
		0.451003972	

Figure 3-26 Multi-objective optimization value and set up for the fifteen activities project.

PROFIT AND TIME OPTIMIZATION	
PROFIT	TIME
3290382	174
INDIVIDUAL NEAR OPTIMIZED VALUE	
PROFIT	TIME
$ 3,471,856	162
DEVIATION FROM OPTIMUM	
PROFIT	TIME
0.052270025	0.07407
WEIGTHS OF INDIVIDUAL FOR OPTIMIZATION	
PROFIT	TIME
0.6	0.4
WEIGTHED DEVATION	
PROFIT	TIME
0.031362015	0.02963
MULTI OBJECTIVE OPTIMIZATION	
0.060991645	

Figure 3-27 Multi-objective optimization value and set up for the fifty activities project.

By minimizing this summation of the weighted deviation, the individual optimum value for the profit get decreased and the time get increased. The figure below shows the changes in time and profit by minimizing the deviation of the summation of the profit and time.

PROFIT AND TIME OPTIMIZATION	
PROFIT	TIME
2211762	74
INDIVIDUAL NEAR OPTIMIZED VALUE	
PROFIT	TIME
$ 2,432,470	65
DEVIATION FROM OPTIMUM	
PROFIT	TIME
0.09073411	0.13846
WEIGTHS OF INDIVIDUAL FOR OPTIMIZATION	
PROFIT	TIME
0.6	0.4
WEIGTHED DEVATION	
PROFIT	TIME
0.054440466	0.05538
MULTI OBJECTIVE OPTIMIZATION	
0.109825081	

Figure 3-28 Result of the optimized profit and time by minimizing the deviation for the fifty activities project.

PROFIT AND TIME OPTIMIZATION	
PROFIT	TIME
3471024	176

INDIVIDUAL NEAR OPTIMIZED VALUE	
PROFIT	TIME
$ 3,471,856	162

DEVIATION FROM OPTIMUM	
PROFIT	TIME
0.000239641	0.08642

WEIGTHS OF INDIVIDUAL FOR OPTIMIZATION	
PROFIT	TIME
0.6	0.4

WEIGTHED DEVATION	
PROFIT	TIME
0.000143785	0.03457

MULTI OBJECTIVE OPTIMIZATION
0.034711686

Figure 3-29 Result of the optimized profit and time by minimizing the deviation for the fifty activities project.

The results of the multi-objective optimization for the profit decreased to $2,211,762 from the optimum value $2,432,470 whereas the duration of the project get increased to 74 months from 65 month.

The method of execution of each activity and number of crews added are as given in figure 3-28.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Index	5	4	5	3	1	2	4	3	3	5	2	5	2	1	1
Added crew	3	2	1	1	1	0	4	4	2	2	3	3	2	5	2

Figure 3-30 method of execution of each activity and added crew after the multi-objective optimization for the fifty activities project .

3.5.6 Output Module

This module gives the output of the input values put by the user. These outputs are samples from the project which contain 15 activities. The output of the model includes:

- CPM calculations depending up on the selected method of execution, including ES, EF, LS, LF, FF, and TF for all the project activities, and critical activities identification for the first unit figure 3-29.
- Rate of production of each of the activities in the project.
- Number of crews required for each of the activities in the project so that there will not be interruptions between the activities in progress, figure 3-29.
- Duration of the project by applying the output of the optimization model, and the scheduling model.
- The most important part of the model is producing the cash-flow analysis and produces the maximum overdraft, theoretical profit, actual profit, amount of money paid as interest, total indirect cost, amount of liquidated damage, figure 3-31.
- After optimization to maximize the profit, it gives the new profit, and associate duration for the whole project as well as the first unit using the critical path method with the chosen method of execution.
- Results time minimization optimization with associated duration for the whole project as well as the first unit using the critical path method with the chosen method of execution.
- Result of multi-objective optimization for maximizing profit as well as minimizing the time.

ON METHOD CHOOSEN													
INDEX	COST	DURATION	CREW	ES	EF	LS	LF	TOTAL FLOAT	FREE FLOAT	BUFFER OF LOB	Rate	Theortical # Of Crews	Actual # Of Crews
5	67216	6	10	0	6	5	11	5	0		0.157303371	0.943820225	1
4	56288	4	10	0	4	0	4	0	0		0.157303371	0.629213483	1
5	64667	5	8	0	5	10	15	10	0		0.157303371	0.786516854	1
3	45000	2	12	6	8	11	13	5	0		0.157303371	0.314606742	1
1	50000	3	4	4	7	4	7	0	0		0.157303371	0.471910112	1
2	80000	4	4	5	9	15	19	10	0		0.157303371	0.629213483	1
4	69928	3	8	8	11	13	16	5	5		0.14893617	0.446808511	1
3	62085	9	12	7	16	7	16	0	0		0.157303371	1.415730337	2
3	42602	4	12	9	13	19	23	10	7		0.145833333	0.583333333	1
5	64899	8	4	16	24	16	24	0	0		0.157303371	1.258426966	2
2	61544	4	10	16	20	18	22	2	0		0.157303371	0.629213483	1
5	49023	4	8	20	24	23	27	3	3		0.152173913	0.608695652	1
2	68148	3	10	24	27	24	27	0	0		0.157303371	0.471910112	1
1	66000	5	10	20	25	22	27	2	2		0.153846154	0.769230769	1
1	24000	4	8	27	31	27	31	0	0		0.157303371	0.629213483	1

Figure 3-31 screenshot of the output module after input values are done by the user for the project with fifteen activities.

Month	Total Direct Cost	Monthly direct& indirect Expenses	Cumulative Expenses Cash-Out/Month	Expected money/Month	Advanced payment to be Reduced	Retention	Payable Amount of Money	Payment Received	Month	cumulative Cash In	Overdraft before interest	Interest	Overdraft
0													
1	$ 8,430	$ 38,974	$ 38,974	$ 42,872	$ 4,288	$ 5,145	$ 33,439	$ 3,435,965	0	$ 3,435,965	$ 3,396,991		$ 3,396,991
2	$ 8,430	$ 39,527	$ 78,501	$ 43,479	$ 4,348	$ 5,218	$ 33,913	$ -	1	$ 3,435,965	$ 3,357,465		$ 3,357,465
3	$ 8,430	$ 40,087	$ 118,588	$ 44,095	$ 4,410	$ 5,292	$ 34,393	$ 33,439	2	$ 3,435,965	$ 3,350,818		$ 3,350,818
4	$ 11,764	$ 44,181	$ 162,769	$ 48,600	$ 4,860	$ 5,832	$ 37,908	$ 33,913	2	$ 3,469,404	$ 3,340,550		$ 3,340,550
5	$ 14,931	$ 48,205	$ 210,974	$ 53,026	$ 5,303	$ 6,364	$ 41,359	$ 34,393	3	$ 3,469,404	$ 3,326,739		$ 3,326,739
6	$ 16,860	$ 50,987	$ 261,961	$ 56,086	$ 5,609	$ 6,731	$ 43,746	$ 37,908	3	$ 3,503,317	$ 3,313,660		$ 3,313,660
7	$ 33,527	$ 70,101	$ 332,062	$ 77,111	$ 7,712	$ 9,254	$ 60,145	$ 41,359	4	$ 3,503,317	$ 3,284,918		$ 3,284,918
8	$ 33,527	$ 71,094	$ 403,156	$ 78,203	$ 7,821	$ 9,385	$ 60,997	$ 43,746	4	$ 3,537,710	$ 3,257,570		$ 3,257,570
9	$ 36,694	$ 75,696	$ 478,851	$ 83,265	$ 8,327	$ 9,992	$ 64,946	$ 60,145	5	$ 3,537,710	$ 3,242,020		$ 3,242,020
10	$ 39,516	$ 80,016	$ 558,868	$ 88,018	$ 8,802	$10,563	$ 68,653	$ 60,997	5	$ 3,575,617	$ 3,223,002		$ 3,223,002

Figure 3-32 cash-flow analysis output as the result of the input for the fifty activities project .

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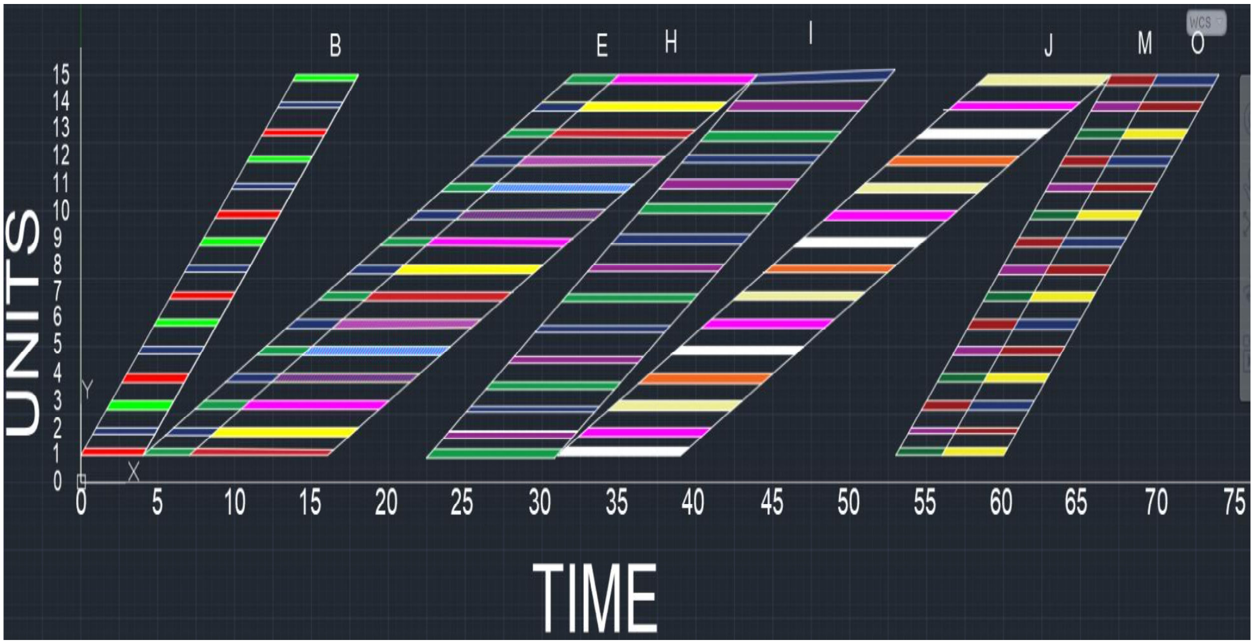

Figure 3-33 sample of schedule of the output for the whole project with only critical activities shown ***for the fifty activities project .***

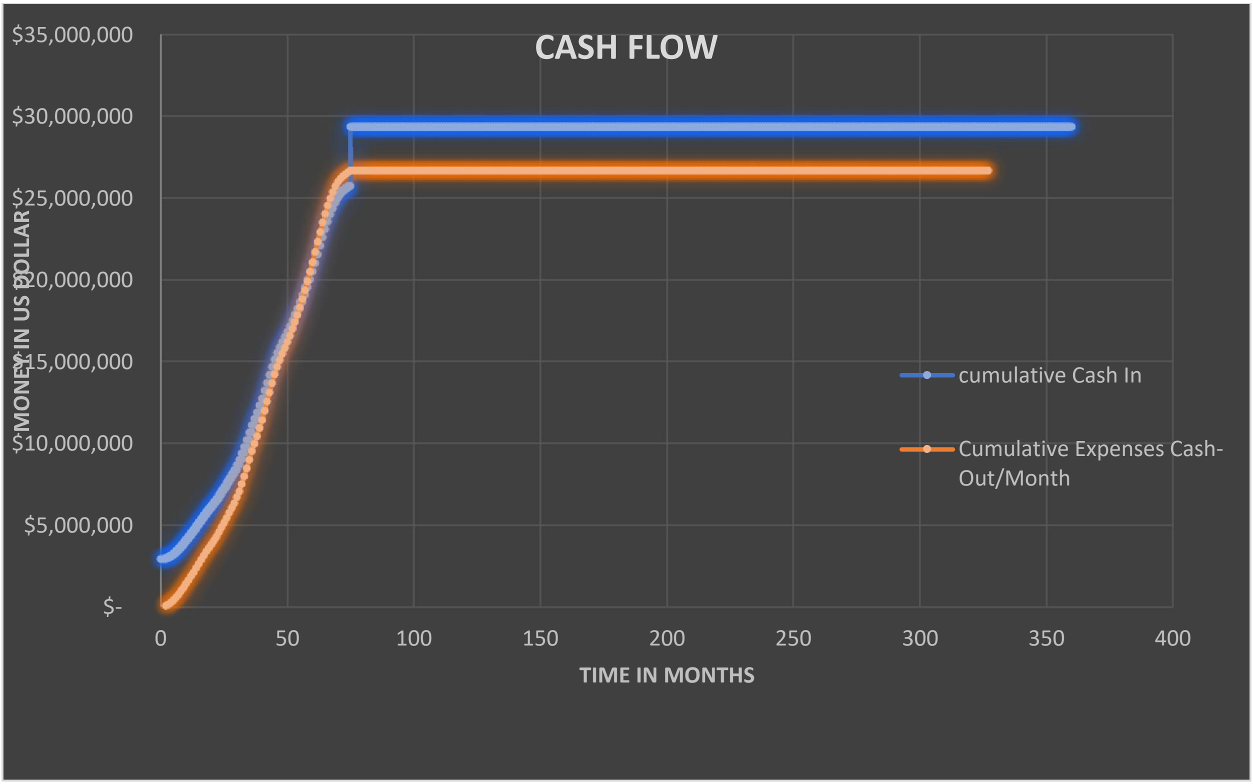

Figure 3-34 screenshot of the cash-flow analysis of the project in months ***for the fifty activities project .***

CHAPTER 4 Verification and sensitivity analysis

To verify the model's capability, it was tested on projects which have 15 units and 15 activities and 10 units and 50 activities. The projects have five to three option of method of execution and different number of crews for each activity.

To run for the multi-objective optimization, first individual runs were made to maximize the profit and minimize the time as explained in chapter 3 for a specific allowable credit. The allowable credit is assumed to be the total money of the loan and its interest.

- The first optimization is to maximize the profit subjected to an allowable credit, and limited number of crews. The duration of the project also must be greater than the duration of one unit.
- Minimizing the total project time is made subjected to allowable credit, limited number of crews, and the duration of the project is made to be greater than the duration of one unit.

In the overall optimization of both the profit and time an importance weight is selected according to the user preference for the profit and time. Then its intention is to minimize the summation of the deviation from its optimum value for both the profit and time using the goal programing as detailed in chapter 3 under the multi-objective optimization.

4.1 Sensitivity Analysis

To see the effect of availability of different allowable credits, for maximizing profit, minimizing time, and both profit and time simultaneously of a given project, several runs were made with different credits. The amount of credit is the total money barrowed and its interest. It was tested for seven different allowable credits for the projects which have 15 and 50 activities keeping the respective constraints the same for all of the credits. The initialization of the models for the first time is made for all the activities to be executed using the first method, without adding crews. Then the model will give the maximum overdraft from the cash-flow analysis model. Then to make the sensitivity analysis the start of the allowable credit to be tested is made to be about 70% of the maximum over draft from the first initialization for the first project and 90% for the second project for it couldn't find any combination that yields 70% of the maximum overdraft. The increase in the allowable credit was made by 50,000 to both of them until finding a point where there will not be any big change in the profit.

4.1.1 Profit Sensitivity Analysis

The models were run several times with different allowable credits to optimize the profit and see the effect of increasing allowable credit. All models were run for 45 minutes. The optimization process was exactly like profit optimization as in chapter 3. It only increases the credit by $50,000. At this point the time was not a concern. However, its effect already added to the profit as incentive or liquidated damage.

It was found that there are a nearly linear relationships between the profit and the allowable credit. The maximum profit gets increased as the credits increase. However, at some point, increasing the allowable credit doesn't create much difference in the profit and it becomes stable.

Table 4-1 maximum profits for different allowable credits for the project with fifteen activities.

ALLOWABLE CREDITS	OPTIMIZED MAXIMUM PROFIT
$ 1,650,000	$ 2,315,179
$ 1,700,000	$ 2,335,244
$ 1,750,000	$ 2,432,470
$ 1,800,000	$ 2,500,444
$ 1,850,000	$ 2,618,984
$ 1,900,000	$ 2,784,859
$ 1,950,000	$ 2,794,907

Table 4-2 Maximum profits for different allowable credits for the project with fifty activities.

ALLOWABLE CREDITS	MAXIMUM PROFIT
$ 2,520,000	$ 3,276,140
$ 2,570,000	$ 3,307,210
$ 2,620,000	$ 3,345,225
$ 2,670,000	$ 3,471,856
$ 2,720,000	$ 3,501,100
$ 2,770,000	$ 3,580,674
$ 2,820,000	$ 3,605,700

The results of the optimization of the profit for different credits can be summarized as shown in table 4-1and 2.

The graphical representation of the profit and the different credits are shown in figure 4-1and 2.

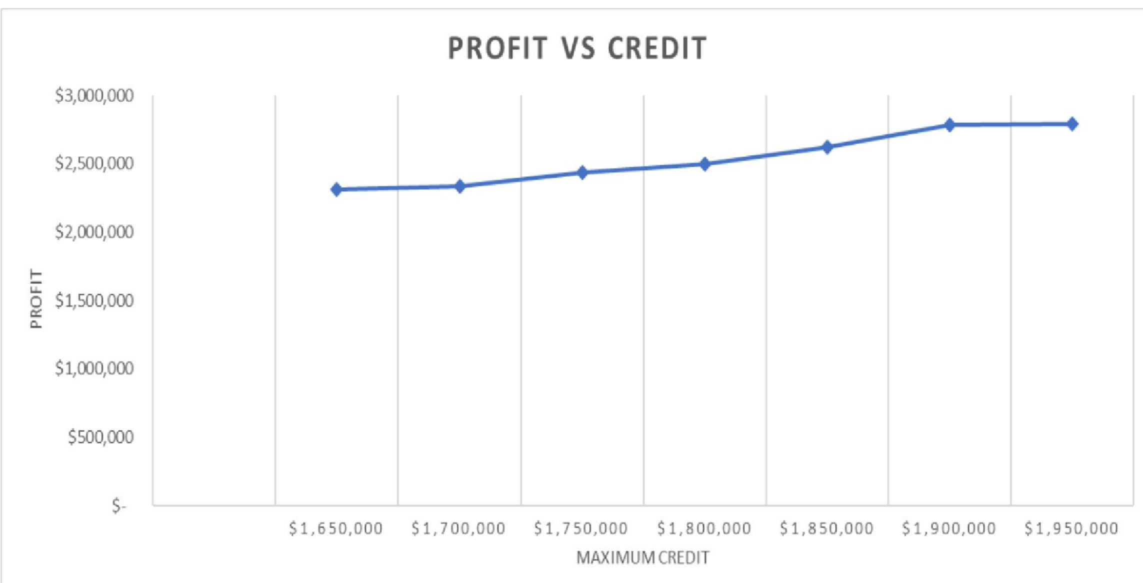

Figure 4-1 graph showing the increase of profit with increase in allowable credits for the project of 15 activities.

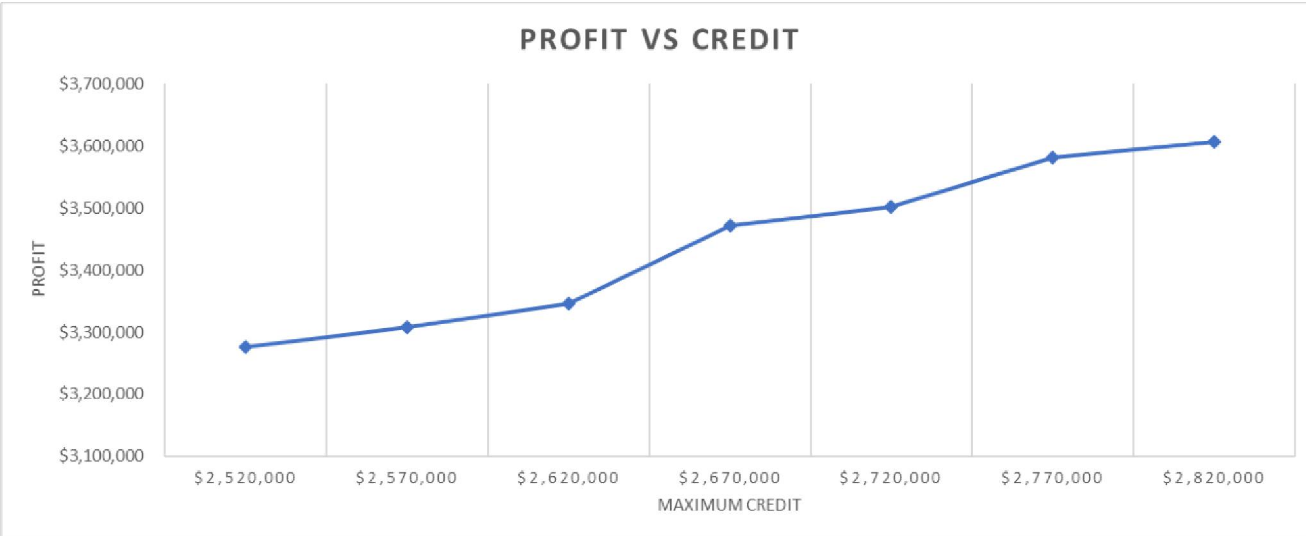

***Figure 4-2** Graph showing the increase of profit with increase in allowable credits for the project of 50 activities.*

The cost of all the sensitive analysis carried out for the profit was also tabulated to see if there is any correlation between the cost and variation of the allowable credit. It is found that there is a good linear relationship, where increase in credit result in increase in cost.

***Table 4-3** cost of the project for different allowable credit of the project with 15 activity.*

PROFIT OPTIMIZATION	
CREDIT	COST
$ 1,650,000.00	$ 28,238,449.66
$ 1,700,000.00	$ 28,423,768.47
$ 1,750,000.00	$ 28,576,710.51
$ 1,800,000.00	$ 29,819,611.99
$ 1,850,000.00	$ 31,540,339.67
$ 1,900,000.00	$ 33,795,574.01
$ 1,950,000.00	$ 33,842,566.23

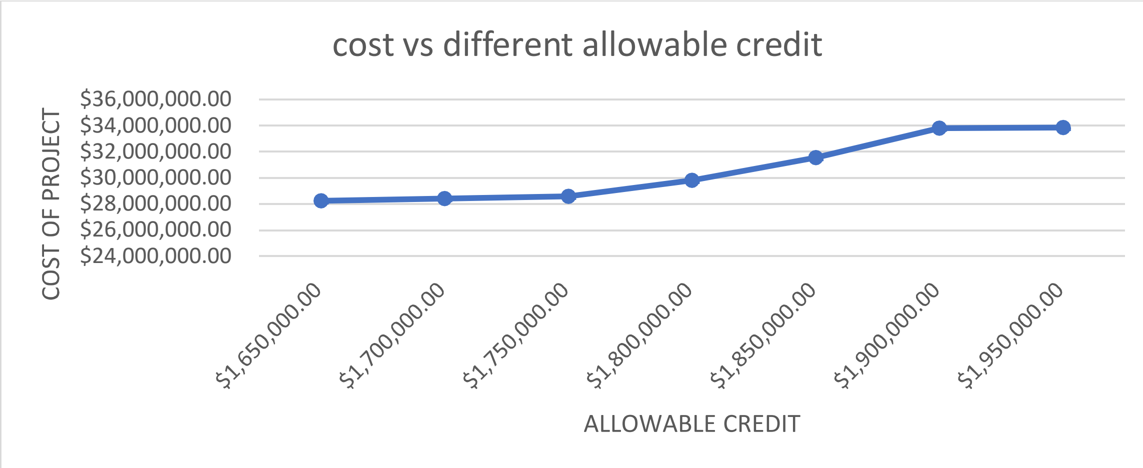

Figure 4-3 graph of cost of the project with different allowable credit of 15 activities project.

Table 4-4 Cost of the project for different allowable credit of the project with 50 activity.

PROFIT OPTIMIZATION	
CREDIT	COST
$ 2,520,000	$ 40,322,007.00
$ 2,570,000	$ 40,673,157.00
$ 2,620,000	$ 41,186,556.00
$ 2,670,000	$ 42,751,934.00
$ 2,720,000	$ 43,237,936.00
$ 2,770,000	$ 44,268,905.00
$ 2,820,000	$ 44,586,673.00

Figure 4-4 graph of cost of the project with different allowable credit of 50 activities project.

4.1.2 Time sensitivity Analysis

The effect of different credits on the minimal duration of the project was tested by running many optimizations with different credits. Each run time was made to be forty-five munities. In this optimization the constraints remain the same as that of the optimization of maximum profit for different allowable credits. The different credit allowable are made to be the same as for the profit optimization. The minimum time found were 65 and 162 months with an allowed credit of $1750000 and $2670000 dollars for both projects. However, it was found that there was no any correlation between the minimum time and increasing the allowable credits.

Table 4-5 minimum time for different allowable credits for the project with fifty activities.

ALLOWABLE CREDITS	MINIMUM TIME FOR EACH CREDIT
$ 1,650,000	68
$ 1,700,000	71
$ 1,750,000	65
$ 1,800,000	70
$ 1,850,000	108
$ 1,900,000	66
$ 1,950,000	107

Table 4-6 Minimum time for different allowable credits for the project with fifty activities.

ALLOWABLE CREDITS	MINIMUM DURATION
$ 2,520,000	168
$ 2,570,000	162
$ 2,620,000	172
$ 2,670,000	163
$ 2,720,000	166
$ 2,770,000	173
$ 2,820,000	172

Not only the time, but also the cost of the projects for the optimization of time for different allowable credits don't show any relationship with the variation of the allowable credits.

Table 4-7 The cost of the project for time optimization for different allowable credits of the 15 activities project.

TIME OPTIMIZATION	
CREDIT	COST
$ 1,650,000.00	$ 18,743,096.27
$ 1,700,000.00	$ 22,845,060.75
$ 1,750,000.00	$ 20,501,560.61
$ 1,800,000.00	$ 23,011,657.43
$ 1,850,000.00	$ 27,471,712.03
$ 1,900,000.00	$ 19,939,737.59
$ 1,950,000.00	$ 25,930,073.86

Table 4-8 The cost of the project for time optimization for different allowable credits of the 50 activities project.

TIME OPTIMIZATION	
CREDIT	COST
$ 2,520,000	$ 40,509,223.00
$ 2,570,000	$ 35,791,566.00
$ 2,620,000	$ 38,503,676.00
$ 2,670,000	$ 35,681,686.00
$ 2,720,000	$ 36,419,758.00
$ 2,770,000	$ 40,580,566.00
$ 2,820,000	$ 40,220,268.00

4.1.3 Multi-objective Sensitivity Analysis

After finding the optimal values of the profit and duration of the project for different allowable credits, final optimization is done both for profit and time simultaneously to get the near optimal solution of the profit and time applying the goal programing. The multi-objective optimization for different credits is exactly the same as in chapter 3 multi-objective optimization. The setting and constrains of the model remain the same as for the individual optimizations of profit and time. A sample of screen shoot of the multi-objective optimization can be shown as in the figure 3-26 and 27.

PROFIT AND TIME OPTIMIZATION		
Initial values	PROFIT	TIME
	$ 2,514,504	135
INDIVIDUAL NEAR OPTIMIZED VALUE		
	PROFIT	TIME
	$ 2,432,470	65
DEVIATION FROM OPTIMUM		
	PROFIT	TIME
	0.033724568	1.07692
WEIGTHS OF INDIVIDUAL FOR OPTIMIZATION		
	PROFIT	TIME
	0.6	0.4
WEIGTHED DEVATION		
	PROFIT	TIME
	0.020234741	0.43077
MULTI OBJECTIVE OPTIMIZATION		
	0.451003972	

Figure 4-5 Result of the optimized profit and time by minimizing the deviation for the fifteen activities project.

PROFIT AND TIME OPTIMIZATION		
	PROFIT	TIME
	3471024	176
INDIVIDUAL NEAR OPTIMIZED VALUE		
	PROFIT	TIME
	$ 3,471,856	162
DEVIATION FROM OPTIMUM		
	PROFIT	TIME
	0.000239641	0.08642
WEIGTHS OF INDIVIDUAL FOR OPTIMIZATION		
	PROFIT	TIME
	0.6	0.4
WEIGTHED DEVATION		
	PROFIT	TIME
	0.000143785	0.03457
MULTI OBJECTIVE OPTIMIZATION		
	0.034711686	

Figure 4-6 Result of the optimized profit and time by minimizing the deviation for the fifty activities project.

After optimization of the multi-objective of profit and time, for different credits, the relationship between the profit and credit allowable shows about a linear relationship whereas the time doesn't show any correlation with the allowable credits. The near optimal time and profit of the result for different credit scenarios can be shown in table 4-8.

Table 4-9 Results of near optimal profit and time for different allowable credits of the project with 15 activities.

ALLOWABLE CREDITS	NEAR OPTIMUM PROFIT	NEAR OPTIMUM TIME
$ 1,650,000	$ 2,127,771	81
$ 1,700,000	$ 2,147,171	106
$ 1,750,000	$ 2,211,762	74
$ 1,800,000	$ 2,418,168	125
$ 1,850,000	$ 2,559,206	104
$ 1,900,000	$ 2,595,429	120
$ 1,950,000	$ 2,791,936	113

The near optimal profit after the multi-objective optimization is plotted against the allowable credits and maintains a linear relationship with the credit allowable as shown in figure 4-3.

Table 4-10 Near optimum profit for different allowable credit of the project with 15 activities.

ALLOWABLE CREDITS	NEAR OPTIMUM PROFIT
$ 1,650,000	$ 2,127,771
$ 1,700,000	$ 2,147,171
$ 1,750,000	$ 2,211,762
$ 1,800,000	$ 2,418,168
$ 1,850,000	$ 2,559,206
$ 1,900,000	$ 2,595,429
$ 1,950,000	$ 2,791,936

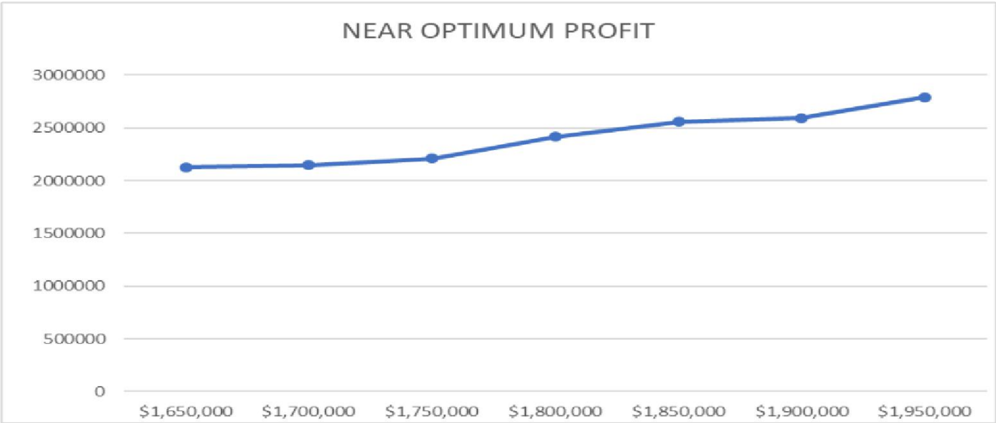

Figure 4-7 Near optimum profit for different allowable credits of the project with 15 activities.

Table 4-11 Near optimum profit for different allowable credit of the project with 50 activities.

ALLOWABLE CREDITS	NEAR OPTIMUM PROFIT
$ 2,520,000	$ 3,275,149
$ 2,570,000	$ 3,307,656
$ 2,620,000	$ 3,345,960
$ 2,670,000	$ 3,471,024
$ 2,720,000	$ 3,502,642
$ 2,770,000	$ 3,557,336
$ 2,820,000	$ 3,600,748

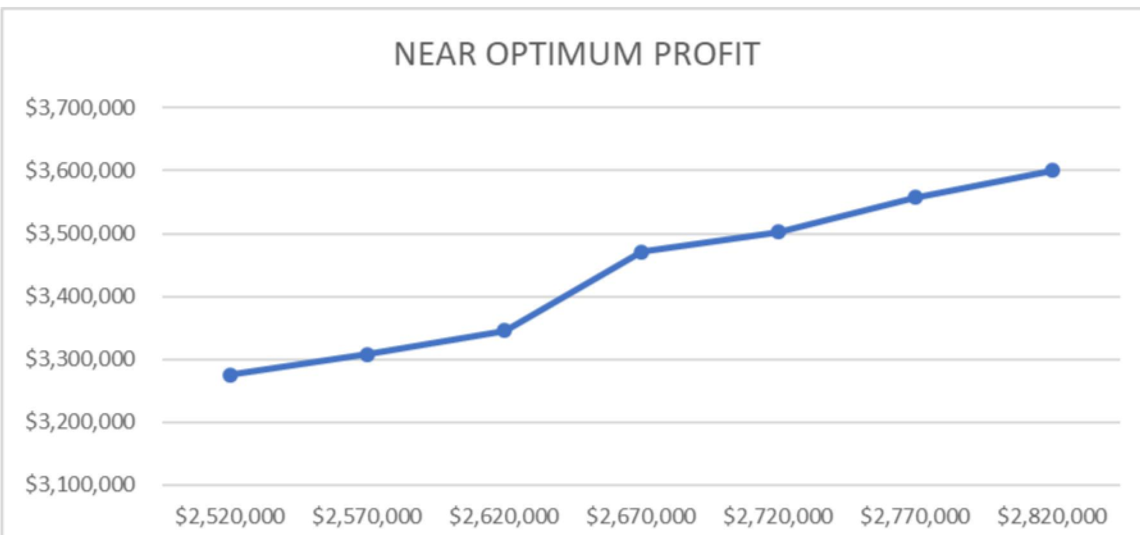

Figure 4-8 Near optimum profit for different allowable credits of the project with 50 activities.

The cost of the projects after it is optimized for both profit and time was tabulated. It shows a linear correlation with the increase in allowable credits.

Table 4-12 Cost of the project for the time-cost optimization for different allowable credits of the project with 15 activities.

MULTI-OBJ OPTIMIZATION	
CREDIT	COST
$ 1,650,000.00	$ 25,398,556.00
$ 1,700,000.00	$ 26,101,306.00
$ 1,750,000.00	$ 26,684,778.00
$ 1,800,000.00	$ 29,355,126.00
$ 1,850,000.00	$ 30,510,705.00
$ 1,900,000.00	$ 31,753,970.00
$ 1,950,000.00	$ 33,030,409.00

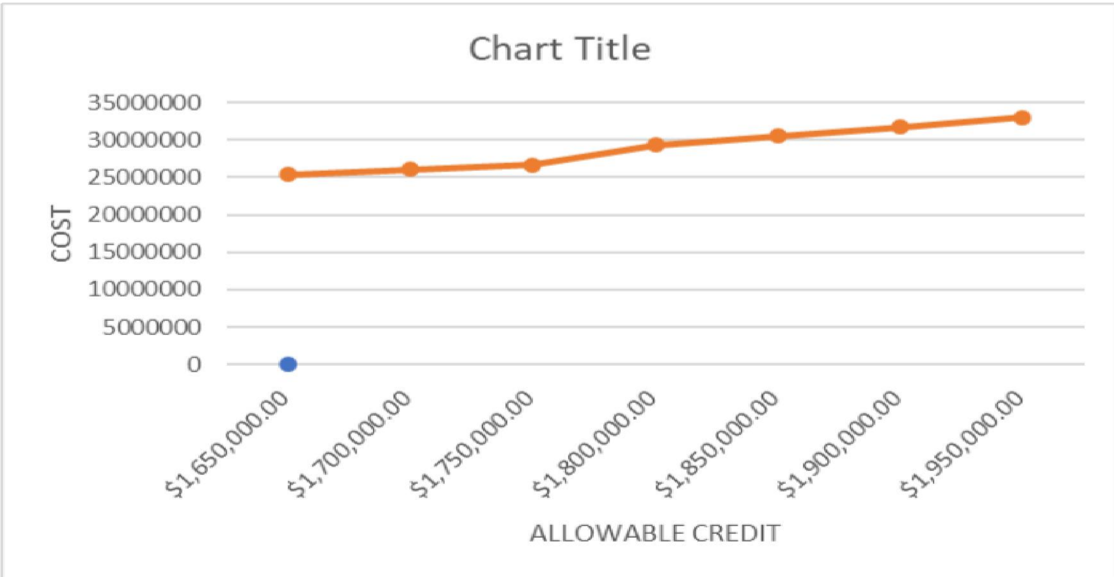

Figure 4-9 Graph of cost of the project for the time-cost optimization for different allowable credits of the project with 15 activities.

Table 4-13 Cost of the project for the time-cost optimization for different allowable credits of the project with 50 activities.

MULTI-OBJ OPTIMIZATION	
CREDIT	COST
$ 2,520,000	$ 40,328,352.00
$ 2,570,000	$ 40,679,917.00
$ 2,620,000	$ 41,150,798.00
$ 2,670,000	$ 42,734,871.00
$ 2,720,000	$ 43,151,069.00
$ 2,770,000	$ 44,030,074.41

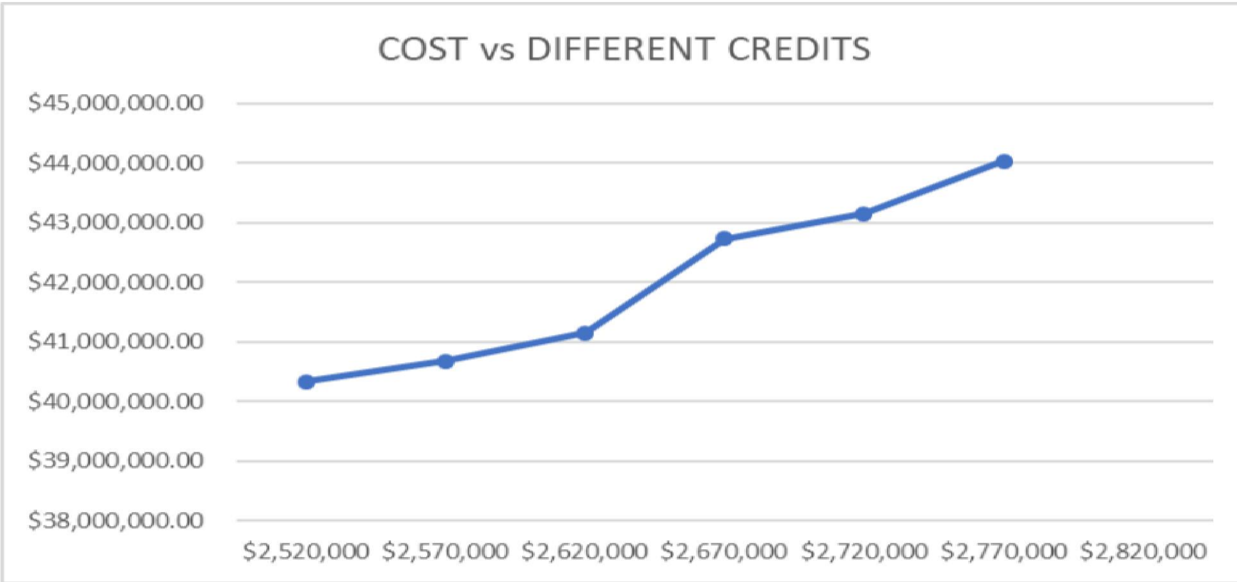

Figure 4-10 Graph of cost of the project for the time-cost optimization for different allowable credits of the project with 50 activities.

CHAPTER 5 VALIDATION OF THE DEVELOPED MODEL (Case study)

5.1 Background

For the validation of the developed model and demonstrate its efficiency, it was applied to case study from the literature, which have been used by (Elbeltagi et al. 2017), for Scheduling and Cost Optimization of Repetitive Projects Using Genetic Algorithms.

The Example used was the construction of a three-lane-highway for stretch of 15 Km and consist of five activities on each of one unit. The project is divided into 15 repetitive units each of length 1 Km. Each of the five activities is repeated at each of the 15 segments or units of the project. The precedence relationships among these sequential activities are finish to start with no lag time. The first and second activities don’t have the same amount of work for all the segments. However, for simplicity and for assumption of the model that every unit have the same quantity of work, the average of all the segments is taken. Indirect cost of $2000 was considered. The data of alternative construction methods and quantities for each activity is shown in the Table 5-1 below.

Table 5-1 Activities with their different method of construction and duration.

	METHOD ONE					METHOD TWO					METHOD THREE				
ACTIVITY DESCRIPTION	RATE	COST	QUANTITY	DURATION	CREW	RATE	COST	QUANTITY	DURATION	CREW	RATE	COST	QUANTITY	DURATION	CREW
CUT AND CHIP TREES	3000	2000	18800	6.3	4	2500	1250	18800	7.5	4	3500	1500	18800	5.4	4
GRAB AND REMOVE STUMPS	4000	2000	18800	4.7	2	3000	1500	18800	6.3	2	3500	1750	18800	5.4	2
EARTH MOVING	1000	1700	6340	6.3	2	1000	2500	6340	6.3	3	900	1600	6340	7	2
BASE	3200	3000	32000	10	4	3200	3000	32000	10	3	3000	3800	32000	10.7	3
PAVING	4000	3000	32000	8	3	4000	3000	32000	8	2	4000	3500	32000	8	3

The rate parameter in the table 5-1 indicates that production of quantity of the work per day. Then the duration is calculated by dividing the total quantity to the rate of production. The activities name is input as A, B, C….These data are input to the developed model with all the options of construction, respective cost and duration and with their predecessors' relationships. Data which are not available in the literature for developed model in this research are added by the user. Interest rate, duration of a project, incentives and liquidate damage, allowable credits are among the these missed data to be added.

5.2 Input data

The data of the project was put to the input data of the model. The names of the activities are input in English alphabet so that it would be easy to be applied in the model. The input data are shown in the figure 5-2.

	Construction Methods								
Activity	1			2			3		
	Cost1	Duration1	Crews1	Cost2	Duration2	Crews2	Cost3	Duration3	Crews3
A	$ 2,000	6.3	4	$ 1,250	7.5	4	$ 1,500	5.4	4
B	$ 2,000	4.7	2	$ 1,500	6.3	2	$ 1,750	5.4	2
C	$ 1,700	6.3	2	$ 2,500	6.3	3	$ 1,600	7	2
D	$ 3,000	10	4	$ 3,000	10	3	$ 3,800	10.7	3
E	$ 3,000	8	3	$ 3,000	8	2	$ 3,500	8	3

Figure 5-1 construction method input

PRED 1	LAG1	PRED 2	LAG2
A			
B			
C			
D			

Figure 5-2 predecessors' input

Description	Value	Description	Value
Number Of Units	15	Markup	10%
Deadline of The Project (Days)	90	Retention	12%
Working days per week	6	Advance Payment	10%
Early Completion Bonus/day	$ 2,000	Number Of Construction	5
Liquidated Damages/day	$ 1,500	Intrest Rate/Year	20%
Indirect Cost/day	$ 2,000	Number of activities	5
Interruption Penalty	$ 1,750	Cost Weight	0.6
Additional Cost/Crew	$ 2,000	Time Weight	0.4
days allowed for incentive	15		

Figure 5-3 parameters input table of the project.

After the user input all the required data, optimizations were run to get the output using the same procedures used in chapter 3 for profit, time and multi-objective of time and profit. First individual runs were made to maximize the profit and minimize the time. The first optimization is to maximize the profit subjected to allowable credit, and limited number of crews, the duration of the project being greater than the duration of one unit. After that time minimization takes place with the same constraints as the profit. Then multi-objection optimization takes place in minimizing the deviation between the optimum values of individuals and the initialized values.

Sensitivity analysis have been carried out for the maximization of profit, minimization of time as well as multi-objective optimization of the time and profit simultaneously for different allowable credits. It was optimized for five different allowable credits. The results of the optimization of the profit with different allowable credit are given in the table 5-2 below.

Table 5-2 maximum profits for different allowable credits.

ALLOWABLE CREDITS	MAXIMUM PROFIT
$ 86,000	$ 127,893
$ 87,500	$ 128,085
$ 90,000	$ 133,285
$ 91,500	$ 133,520
$ 93,000	$ 133,520

The profit gets increased with the increase in allowable credit until at some point where it gets stabilized or increasing the credit will not make any effect on the profit.

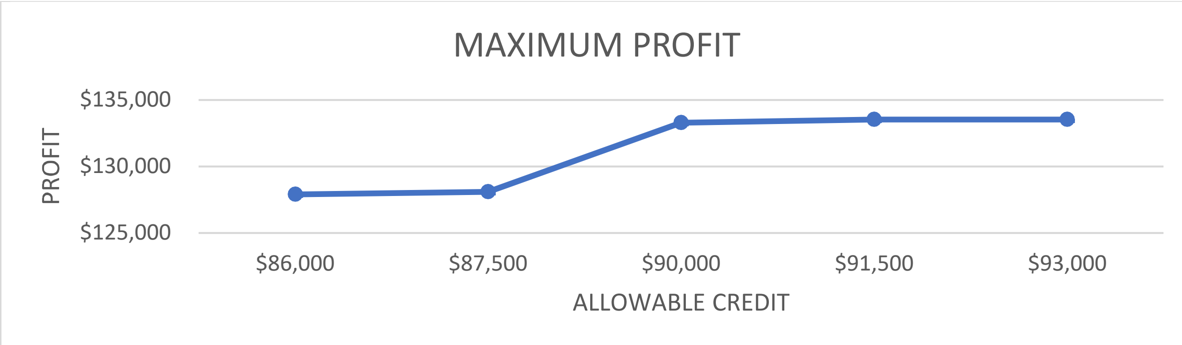

Figure 5-4 optimized profit with different allowable credits.

When it was analyzed for the time minimization with different allowable credits, it was found that it doesn't have any correlation with increase in the allowable credits. It gives almost equal duration of the first three different credits. The remaining two credits in a similar way to the first one has equal duration.

Table 5-3 optimized time for different allowable credit

ALLOWABLE CREDITS	MINIMUM TIME FOR EACH CREDIT
$ 86,000	81.0667
$ 87,500	81.0667
$ 90,000	81.0667
$ 91,500	80.833
$ 93,000	80.833

In the sensitivity analysis for the multi-objective optimization of both the profit and time, the profit shows an almost linear relationships with the allowable credits. However, the duration becomes the same for all scenarios of the allowable credits. The table shows the result of the multi-objective optimization of the profit and time for the five different allowable credits.

Table 5-4 near optimal result of profit and time for different allowable credits

ALLOWABLE CREDITS	NEAR OPTIMUM PROFIT	NEAR OPTIMUM TIME
$ 86,000	127893	81.0667
$ 87,500	127893	81.0667
$ 90,000	130610	81.966
$ 91,500	133134	81.0667
$ 93,000	133134	81.0667

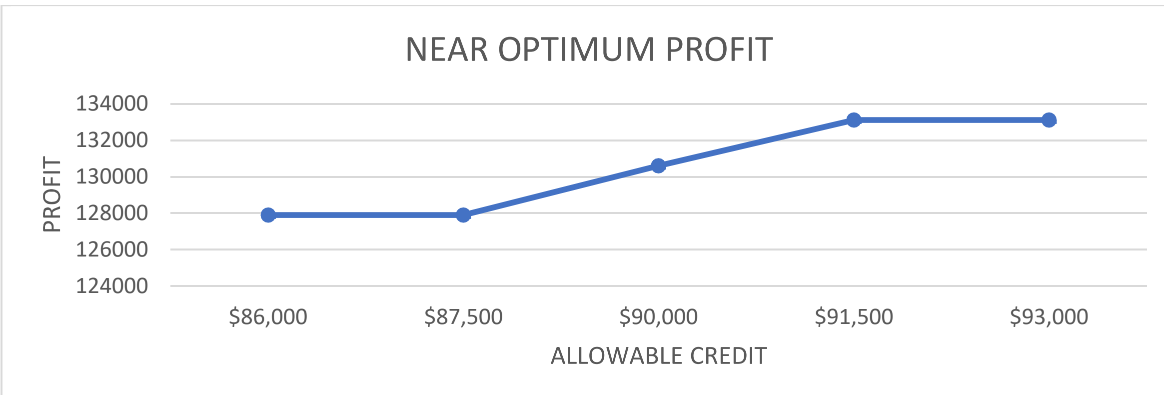

Figure 5-5 graphical representation of increase in profit with increase in allowable credits.

5.3 Comparison of the results of the developed model and the literature.

The model developed for this study doesn't include work interruption. It schedules the activities without interruption and assumes a smooth progress once an activity is started. So, any activity's start is adjusted in such a way there will be no interruption depending on its predecessor's progress and rate of production.

The outcome of the literature without interruption was given in the figure 5-6 with all its direct cost, indirect cost, total project cost and minimum duration.

Optimization Output Details

Project duration (Days)	Project direct cost (LE)	Project indirect cost (LE)	Project total cost (LE)	Total interruption (Days)
86	1,262,100	172,000	1,434,100	0

Figure 5-6 output of the literature cost and time without interruption in the progress of rate.

The method of execution for each activity are given as 2,3,1,2 and 1 respectively from A-E in the literature.

For the developed model since the purpose of the model is different from the literature it is inevitable to get some change. However, it can be summarized as the table given for the near optimal optimization of the multi-objectives.

Table 5-5 summery of all execution method, direct and indirect costs and duration of the multi-objective optimization with different credits.

ALLOWABLE CREDITS	Execution Method					DIRECT COST	INDIRECT COST	TOTAL COST	DURATION
	A	B	C	D	E				
$ 86,000	3	1	1	1	1	$ 1,266,579	$162,133	$ 1,428,712	81.0667
$ 87,500	3	1	1	1	1	$ 1,266,579	$162,133	$ 1,428,712	81.0667
$ 90,000	1	1	1	2	1	$ 1,334,340	$163,933	$ 1,498,273	81.9667
$ 91,500	3	1	2	2	1	$ 1,343,299	$162,133	$ 1,505,432	81.0667
$ 93,000	3	1	2	1	1	$ 1,343,299	$162,133	$ 1,505,432	81.0667

It can be clearly seen that from the table 5-5, the time in all scenario of the developed model is lower than the result of the literature. The duration in the developed model has been reduced by 4.65% from the result of the literature. On this aspect the developed model shows its efficiency and strength. Since the duration is lower than the duration in the literature, the indirect cost is also lower than that of the literature by 5.7%, even though future value of the costs was taken into consideration by incorporating the inflation rate.

However, the direct cost shows a little bit increase from the literature which is about 4400 dollars (0.35%) for the first case of the allowable credit. With the increase in the allowable credit the percentage of increase in the direct cost from the literature get increased. The reasons for this occasion are double. First the cost takes into the consideration the impact of inflation and always consider the future value. Second, the purpose of the optimization is different. This model finds near optimal profit and time whereas the literature finds minimal cost only. But the total cost of the project is lower than that of the literature. The total cost of the project in the literature is $1,434,100 whereas the lowest cost of this model's result is $1,428,712 where it shows an improvement of 0.38% from the literature.

Generally, when the allowable credit is increased the profit is also increased so does the direct cost, until at some point increasing the credit will not bring a change to the profit and cost. However, if it is needed to look the least direct cost, the model shows its efficiency on optimization to find the minimal cost which is less than the result of the literature with minimal credits. So, the developed model produces acceptable results which can be applied to any project. Sample of the schedule of one of the scenarios and cash-flows are shown in the figures 5-7 and 8 below.

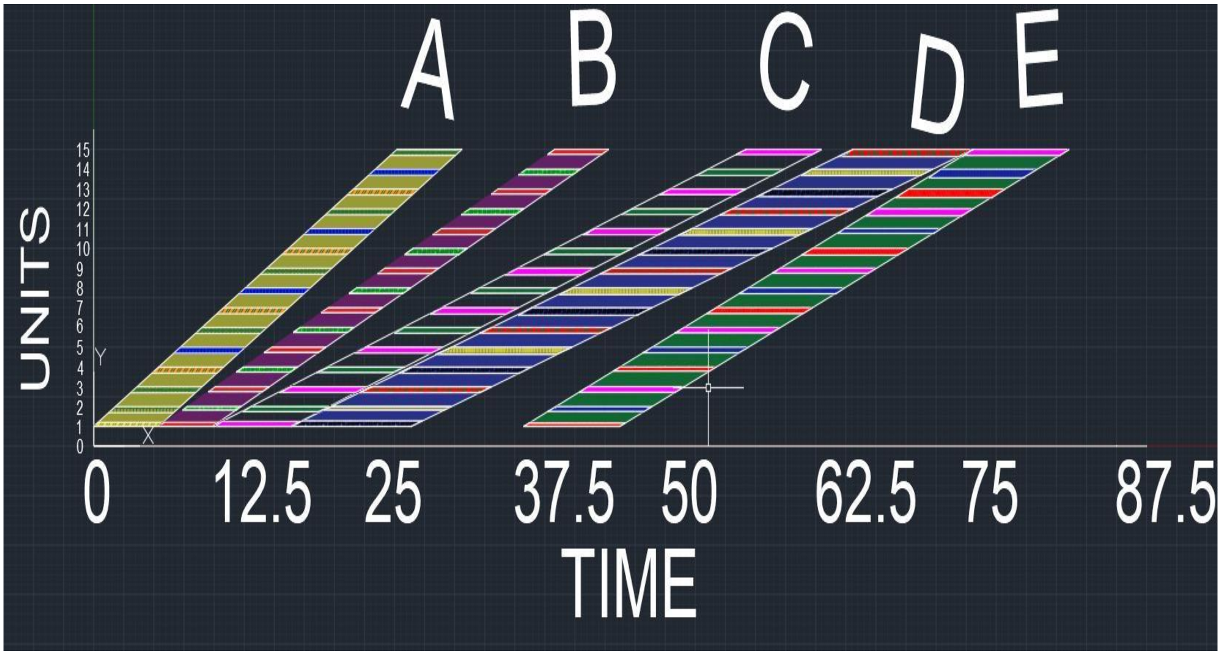

Figure 5-7 schedule of line of balance of a sample from the different scenarios of the optimization of the project

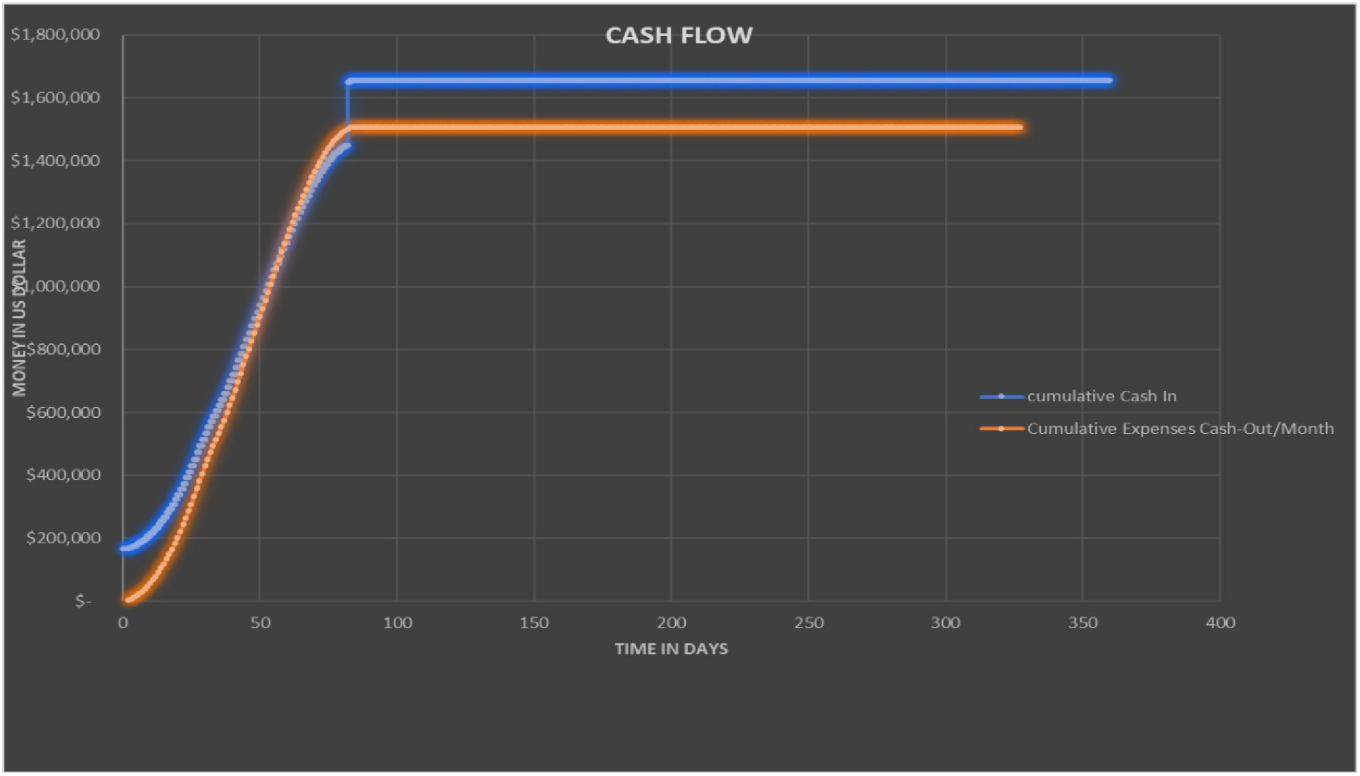

Figure 5-8 Sample of cash flow analysis of one of the scenarios of the project.

CHAPTER 6 Conclusion and Recommendations

The main objective of project management is to manage the ongoing projects in such a way that they will be finished within the estimated budget, according to a pre-specified level of quality, within the estimated duration and with some profit from it. Therefore, the total duration, cost, and quality of construction projects are of great importance for contractors and project managers. To achieve a balance among these contradicting parameters, Time-cost optimization or TCT is considered one of the most important features of projects' planning and controlling. That means time-cost trade-off is done to strike a balance between the decreased indirect costs and the increased direct costs associated with accelerating projects.

The research on hand is aimed on optimizing highway construction of time and profit. This model is typically designed for optimization of repetitive projects like highway. Since multi-objective optimization TCT or TCQT doesn't give any clue about how the financing of the project is going to be handled, this research aimed to take into considerations of the cashflow analysis in to the optimization. It is also a different direction of optimization of cost and time of repetitive projects in terms of profits with different allowable credits.

6.1 Conclusions

The traditional time-cost trade-off was enhanced with the three-dimensional time-cost- quality optimization in the last two decades. The optimization is aimed to minimize the time and cost as much as possible while increasing the quality of the infrastructure to be built. However, achieving a balance among these contradicting attributes doesn't guarantee a project from failing. The issue of financing in developing countries has been a bottle neck of success in constructing infrastructure like highway. It was studied that the main causes of delay and budget overrun in Ethiopia and

Egypt are due to the failure of providing enough financing. So, this study has a double fold contribution in the construction of infrastructure in general and highways in particular. It doesn't only look for multi-objective optimization approach but also accommodates the cash flow analysis for the same purpose. In this way it gives a clear vision that how the cashflow will look like and the likelihood of the profit of the project. This research gives another angle of optimization which will produce a multi-objective optimization which deals with cash-flows analysis for the whole project duration. It is concluded that the developed model can optimize the cost and time of big projects in terms of profit and time which is different from the direct time-cost approach to optimization.

6.2 Research Findings and Contributions

This research will improve controlling and planning of construction projects in general and highway construction in particular. It used the goal programing method of multi-objective optimization. It will help and facilitate the decision makers to select the most appropriate execution options to complete projects' activities which will give near optimal time and profit. The main contributions of this research can be summarized as follows:

- Investigating recent MOO techniques and the most effective one is utilized by the developed models.
- The utilization of the Evolver add in as a powerful optimization tool is outlined. It was found out that, it is among the good optimizing tools available.
- The optimization model and scheduling model are synchronized in a such a way that optimized results of the optimization model are scheduled in the scheduling model.
- The models being implemented in Excel software which is easily accessible by any project manager or practitioners.

- The developed models integrated both the critical path method and line balance to schedule for the repetitive project of the highways.
- The model incorporates the detailed cash- flow analysis of the project.
- The approach from the searching of the optimal time, and cost, in the construction project is changed in to an approach where it can be optimized to suit the limit of credits allowed and maximize the profit.
- From the models developed it can be seen that the profit of a project can increase with increase in allowable credit.
- This optimization model has many benefits than the ordinary optimization of time and cost, as this research provides more information in the cash-in and cash-out, so that it can help the decision makers on allocating and adjustment of budgets.
- It was validated for a study case project from the literatures and the developed model showed about 4.65% time improvement and 0.38% cost improvement.

6.3 Limitation of the Research

Even though the study has fulfilled its intended purpose on optimizing profit and time on the construction of highway, it has also so many assumptions and limitations. These limitations and assumptions can be explained as:

- The quantity of work in each unit is assumed to be equal, however, in reality it is difficult to get the same amount of work scenario.
- The interdependence predecessors of the activities are finish to start with lags.
- The model only allows for maximum five predecessors.
- No correlation is shown between the duration of the project and the allowable credit.

- Work interruption was not allowed.
- The allowable credit is assumed the total money borrowed and its interest to be paid.

6.4 Future Research and Recommendations

Taking the simplicity and robustness of the developed models and full-filling the intended purpose as good merits, still there is a huge room of recommendation for various other enhancements and improvements for further extensions of the current research. Among these recommendation for future researches are:

- Develop a script of programing of optimization which can optimize for different amount of work in each unit.
- Incorporating a third objective, which is the quality of the highway.
- Include Impact of the delay of the construction on society in the multi-objective optimization.
- The interdependence predecessor relationships to be any type of relations other than finish to start.

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