

## COST AND TIME CONTROL DURING PLANNING AND CONSTRUCTION STAGES IN CONSTRUCTION PROJECTS

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### **ABSTRACT**

This research aims to develop time scheduling model including time cost trade off analysis, resource leveling and cash flow management during planning stage and project control during construction stage. To achieve research objectives, available options to improve project financing and current controlling techniques have been studied. The proposed model has been formulated using Excel program to combine CPM computations, time-cost trade off analysis, resource leveling, cash flow analysis and project control. The project management software (MS-Project) has been adopted to perform resource allocation and resource leveling to facilitate achieving the optimum solution in which the project can be performed with minimum cost, supposed deadline and within limited resources. The proposed model utilizes Solver built in Excel program to optimize interest charges or overdraft amount. This research reached the conclusion that it is possible obtain optimum solution performing time cost trade off analysis and resource leveling using Evolver program and then take the results of optimization process to perform cash flow optimization. The proposed model can measure deviations of actual progress from the baseline and monitor project progress to decide on proper corrective actions. Research results have been applied to a hypothetical case study and the application results come identical with research objective. Conclusions have been reached, recommendations regarding adopting and using the research results in construction planning and project management has been suggested.

**KEYWORDS:** Cashflow, Control, Time, Cost, Construction Stage.

MSProject

## Solver

## Evolver

**INTRODUCTION**

Planning for a project can be a difficult task, and, constructing the project is even a greater challenge. Various resource management strategies have been developed such as Time Cost Trade off analysis (TCT), Resource Allocation (RA), Resource Smoothing (RS) and cash flow management. These techniques are applied in succession to a project rather than concurrently, and as such optimum schedule considering all these techniques simultaneously are difficult to obtain.

Wealth of techniques and models has been developed for cash flow management. The most popular models can be divided into two: mathematical models and cost-and-time integration models (Navon, 1996). The attempt to include the optimization of the financing cost or the overdraft amount in the planning process secures achieving to the desired profitability level of the project.

Project monitoring and control are necessary to measure the deviation of actual from planned progress so that corrective actions can be made to meet project budget and deadline. Monitoring project progress can bring the project to a successful completion. This research extends the capabilities of a spreadsheet model originally designed for project scheduling to include project monitoring, tracking and reporting during construction stage.

**REVIEW OF PREVIOUS RESEARCHES**

While several efforts in the literature attempted to solve the individual sub-problems (e.g. TCT analysis, RA, RS and cash flow management), little effort has been done to achieve the overall schedule optimization. This is as a result of the complex nature of projects, the difficulty of modeling all aspects combined, and the inability of traditional optimization tools to solve large-scale problems (Hegazy and Petzold, 2003).

Among the limited efforts that focused on overall schedule optimization using integer – linear programming are (Karshanas and Haber, 1990) and (Li, 1996). Karshanas and Haber present an integer linear programming model for times schedule planning that minimizes the total project cost, considering resource constraints, and monthly cash flow limit. Resources are defined in the model with no limitation. Therefore, resource constraints are achieved by assigning a high cost to resources that are used beyond their available limit. The incremental cost of each resource relative to the other resources determines the most economical level used for that resource.

In 1996, Li developed a mathematical programming model that performs overall schedule optimization that considers investment allocations, resource supply, and weather impact on productivity.

The challenge involves generating a time schedule of an optimized combination of start time for each activity. The total objective attempts to balance the aspects considered in a least costly manner. This requires reducing the sum of financing interest, the cost incurred as a result of uneven resource supply and weather impact on productivity in order to facilitate overall cost minimization (Li, 1996).

The researcher reports that the model is suitable only for small size projects because of complexity of the model formulation.

Ersahin, T. in 2001 presented a practical approach for the modeling and optimization of construction schedule considering time, cost and resources. To facilitate this large size optimization, a non traditional optimization technique, genetic algorithms is used to locate the globally optimal solution (**Tolga, and Tarek**). Resources are defined in the model with no limitation; therefore, resource constraints are achieved by assigning a high cost to resources that are used beyond their available limit.

**Hegazy, T. and Petzold, K. in 2003** presented a comprehensive model for cost optimization and dynamic project control. The model incorporates an integrated formulation for estimating, scheduling, resource management, and cash flow analysis. An effort is made to combine the benefits of traditional project control techniques with critical chain project management (CCPM), to provide a general framework for project control that incorporates the proposed model (**Hegazy, and Petzold 2003**).

Mohammed, I. in 2006 developed an optimal model in a spreadsheet application that considers TCT analysis, resource allocation, and resource smoothing simultaneously. The model employed GAs to optimize the schedule at the planning stage. This work is extended in this research to include cash flow management during planning stage and project tracking and progress reporting during construction stage (**Alhamidi, 2006**).

## RESEARCH OBJECTIVES

Regarding to the planning stage, the objective of this research work is to develop an optimal scheduling model for combining time-cost trade off, resource leveling and cash-flow management.

With regard to construction stage, the objective is to extend the capabilities of above scheduling model to include project tracking and progress reporting.

## PROJECT CASH FLOW

A project's cash flow is basically the difference between the projects expense and its income (shaded area in **Figure1**). The shaded area represents the amount that needs to be financed (overdraft amount) (**Hegazy, 2003**).

For a project of  $n$  activities, the cumulative progress at time point  $t$ ,  $P_t$  is defined as

$$P_t = \sum_{i=1}^n W_i * P_{ti} \quad (1)$$

Where  $W_i$  = percent weight of activity  $i$  in the project;  $P_{ti}$  = percent complete of activity  $i$  at  $t$  (**Chung, and Fa 2009**).

The cost S-curve can be calculated from various points at the end of the time periods. For each point, the contractor accumulates the total costs of the planned work during that period and then draws a cumulative S-curve. The cumulative costs calculations are repeated day by day, bi-daily, weekly, or monthly along the project duration, depending on the time period of the project. Although this calculation is time consuming, it is necessary as the basis for cash flow analysis (**Hegazy, 2003**). During the construction stage, an S-curve agreed in the contract is used as the target against which the actual progress of the project at any point can be evaluated to establish whether it is overall behind schedule and to assess the amount of delay (**Chung, and Fa 2009**).

## PROJECT FINANCING

Various options are available to improve project financing, that is the expense and income curves closer together. Among these options is Front- end loading (Bid Unbalancing). In this strategy the contractor inflates the bid prices of the items that are early in the schedule and deflates

the bid prices of later items, so that the total bid remains unchanged. As such, the early invoices will be of higher value, thus attaining a larger income that can facilitate the financing of the remaining stages in the project. **Figure 2** illustrates the effect of bid unbalancing on cash flow curves, leading to some improvement as depicted in a lower monthly value to be financed (overdraft amount) and less interest charges. To perform bid unbalancing, contractors distribute the indirect cost plus mark up unevenly among the contract items. Contractors need to exercise care when doing the bid unbalancing because owners can detect unrealistic bids and can discredit them (**Chung and Fa, 2009**). It is possible to formulate the bid unbalancing situation as an optimization problem to determine the optimum unit prices that minimize the overdraft amount or reduce the interest charge.

### OVERDRAFT AMOUNT AND INTEREST CHARGES

The variables need to be considered in overdraft calculations and interest charges can be summarized as follows (**Hegazy, 2003**):

The project bar chart, which is developed considering project constraints.

Activities` direct and indirect cost (function of the construction methods).

Contractor`s markup.

Method of distributing indirect cost plus markup among activities.

Retainage amount.

Retainage payback time.

Time of payment delay by owner.

Owner mobilization payment.

Interest rate on overdraft amount.

### CONSTRUCTION PROGRESS CONTROL

Objective of the contractor during construction is to make sure that the project is executed as smoothly as possible, so that the planned level of profit can be attained.

Control is the calculating variances between actual measured cost and progress on one hand, and target budgets and schedules on the other hand, to determine if operations are being performed as intended (**Robert, and carr 1993**).

The various techniques used for cost and schedule control are described in the following subsections.

#### S-Curve Method

The planned S-curve can be plotted as an envelope bounded by the early-start S-curve and the late-start S-curve. The shape and the width of the project`s time-cost envelope depend upon the relative amount of float each activity in the network has. Figure 3 can be used to compare actual expenditures to the planned costs (direct indirect), and it is possible to draw an S-curve that is the average of the early-start and the late-start S-curves and then use these curves for decision making (**Hegazy, 2003**).

One of the drawbacks of this method is that it does not tell us if these extra expenses are caused by a fast execution of more work items than planned or simply because of higher unit rates paid to execute less work than planned.

#### The Earned Value Technique

The Earned Value technique involves a combination of three measures that are needed for the analysis. The Earned Value system defines these measures as follows (**Hegazy, 2003**):

Budgeted Cost of work scheduled (BCWS): measures what is planned in terms of budget cost of the work that should take place.

Budgeted Cost of Work Performed (BCWP) - Earned Value: measures what is done in terms of the budget cost of work that has actually been accomplished to date?

$$= \sum_{i=1}^n \text{actualPercentComplete}_i * \text{budget}_i \quad (2)$$

Actual Cost of Work Performed (ACWP): measures what is paid in terms of the actual cost of work that has actually been accomplished to date.

The schedule and cost performance of the project can be indicated by using these three indicators at its different reporting period as follows:

$$\text{Schedule Performance Index (SPI)} = \frac{BCWP}{BCWS} \quad (3)$$

SPI > 1.0 indicates schedule advantage

$$\text{Cost Performance Index (CPI)} = \frac{BCWP}{ACWP} \quad (4)$$

CPI > 1.0 indicates cost saving

CPI versus SPI can be plotted to facilitate the follow-up on project performance from one reporting period to the other as illustrated in **Figure 4**.

One of the simple approaches for forecasting the Estimate at Completion (EAC) is by adjusting the scheduled budget (BCWS) according to the difference between the actual cost (ACWP) and budget cost (BCWP),

$$\text{EAC} = \text{BCWS at completion} + (\text{ACWP} - \text{BCWP}) \text{ at present} \quad (5)$$

In order to ensure the successful completion of the project, the current predictions of project duration and cost at completion should be updated (**Cheol, and Reinschmidt, 2009**).

### SCHEDULE UPDATING

Because changes during construction are imminent, soon the plan becomes unrealistic and needs to be updated in order to reflect the new circumstances. It is advisable to frequently update the plan at reasonable intervals. Among the reasons for schedule updating, Changes in actual activity durations and network logic, Procurement delays, sudden changes regarding the availability of craftsmen, and Changes in owner requirements or design.

Schedule updating procedure:

All completed activities become fixed in the revised plan.

A new estimate of the amount of work remaining to be done should be made for each activity at the time of updating.

The probable output of various resources should be assessed to revise the durations of future and proceeding activities.

If the project behind schedule, future activities may be crashed or new methods of construction introduced.

Network analysis should be performed with an attempt to reschedule the work to obtain the cheapest overall solution to project constraints.

Variation means changes in the volume and duration of work to be performed from that envisaged at the start of the contract. Work omissions means less cost, but not necessarily less time and may result in wasting resources (**Robert, and Carr 1993**).

### OVERALL SCHEDULE OPTIMIZATION AND CONTROL MODEL

The proposed model comprises two main sections: "Time Schedule" sheet, and "progress" sheet. **Figure 3**-illustrates process chart diagram of the proposed model.

### Time Schedule Sheet

To effectively support construction process management, an integrated cost, schedule planning and control system is needed to collect quality data in a timely fashion and to provide quality historical databases for future planning of new projects (Rasdorf and Abudayyeh 1992). The main reason for scheduling a project is to predict if it is possible to meet an important project completion date and when various activities must be completed in order to ensure that the imposed deadline can be met. The proposed model includes the "Time Schedule" sheet which its use is required both in the planning and tracking stages of a project, integrating Time-Cost Trade-off (TCT) analysis, resource allocation, resource smoothing, and cash-flow management.

### Cash Flow Management Screen

Cash is a resource that is as important as labor, equipment, and material. Since different schedules lead to different investment allocations, different financing costs will result and need to be considered in calculating the total project cost. The objective of cash flow management is to minimize the cost of financing, which is the sum of interest paid on overdraft balance. Cash flow computations have been incorporated in the proposed model to serve the overall schedule optimization process.

This part comprises of two sections, the "Cost Calculations" sub-section and the "Cash Flow Computations" sub-section as illustrated in **Figure 6**.

The "Cost Calculations" sub-section incorporates an optimization model powered by Solver, an Excel add-in, to adjust the balanced indirect cost of a project. The "Adjust. (%)" field accommodates user entry, accepting values between -5.0 and +5.0 for each activity that must sum up to zero in order to unbalance the activities indirect cost without modifying the total cost. Solver, an Excel add-in, employs Simplex method to determine the values of the "Adjust. (%)" field, which are the variables for this optimization procedure with the "Max. The Overdraft Money (MID)" or "Total Interest Charges (MID)" cell will be considered as the target cell to be minimized. These two cells will be included within the optimization parameters screen in the following sub-section. The "adjust. (MID)" field determines the adjustable values of the indirect cost based on the adjustable weights entered in the "Adjust. (%)" field. The adjustable values consisting of positive and negative fractions of the project indirect cost are added to the respective cells of the "Balanced Indirect" field, the balanced indirect costs of each activity. The balanced indirect cost for each activity is determined as a fraction of the total indirect cost due to weight of the each activity direct cost divided by the project total direct cost. The "Total indirect" field consists of the unbalanced indirect cost of each activity calculated by the sum of the "Balanced indirect" and the "Adjust. (MID)" fields. The final field of this sub-section, "Total Budget" field calculates the budget of each activity with the summation of the project total budget displayed at the bottom. This field adds the direct and the unbalanced indirect costs of each activity and multiplies the sum by the markup percentage of the project from the "Markup (%)" field to determine the budget of each activity of the project.

The process of unbalancing the indirect cost of the activities to minimize financing cost is relevant to the planning and scheduling stage of a project, therefore, it is not applicable during the progress tracking and project control.

The other sub-section of the Cash Flow management screen, the "Cash Flow Computations" is compiled in a table format below the bar charts in "Time Schedule" sheet representing daily and cumulative expenditures, owner payments, and cash flow balance. The cash flow table is subdivided into periods equivalent to progress intervals (30 days as illustrated in **Figure 6**), extending the length of the project duration in addition to an extra progress period after project completion. The table displays daily and cumulative cash flow of early, late, and average direct and indirect expenses, budget, and BCWS among other expenditures in accordance with the early and late bar chart schedules. The owner's payment scheme, mobilization payment, markup percentage, and overdraft balance interest have been considered within cash flow computations. The cash flow table assists with cost control during both the planning and tracking stages of a project, by outlining the cost associated with the varying configuration and duration of the project schedule.

## PROGRESS SHEET

The “Progress” Sheet comprises of four parts: the “Actual Bar Chart”, the “Actual Progress”, the “Project Performance and Forecasting”, and the “Payment Schedule”. These parts are described in the following sub-sections.

### Actual Bar Chart

The bar chart allows for daily representation of the project in terms of time, cost, and resources; it is simple to construct and read; and currently has remained as the best tool for communicating to team members what is required to be done in a given time frame (**Hegazy and Petzold 2003**). The actual bar chart requires the most user interaction of the “Progress” sheet. Each cell within the chart represents a day in the project. The system user is required to enter the daily percent of work completed in each cell. **Figure 7** illustrates the actual bar chart.

### Actual Progress

Actual progress section consists of five fields of which four are calculation fields that are updated when data is entered in the actual bar chart. **Figure 8** illustrates the “actual Progress” section. The “Percent Complete” field provides the summation of the actual percentage of total work completed at the time actual bar chart is updated. The “Actual duration” field calculates the number of days that work was accounted for in the actual bar chart. The “Actual Start” field discloses the number of the day that an activity was actually started based on the first entry of the reported percentage of completed work in the actual bar chart. The “Current Finish” field displays the number of the day on which the last entry of percent completed work was entered for each activity. The “Actual Cost To date” field represents user input of actual cost spent for each activity at the time the actual bar chart is updated.

### Project Performance and Forecasting

This part calculates various performance parameters and indices based on the current status of the actual bar chart, using Earned Value (EV) analysis. The Earned Value technique is used during project control to evaluate the cost and schedule performance in a project. This method involves a combination of three measures that are required for the analysis: Budgeted Cost of Work Schedule (BCWS), Budget Cost of Work Performed (BCWP), and Actual Cost of work Performed (ACWP). The BCWP and ACWP can be derived from actual progress information, since they are based on the work performed. The “Project Performance and Forecasting” section generates these two measures on a daily basis in accordance with the actual bar chart. **Figure 9** illustrates project performance and forecasting section.

Along with progress measurement and performance evaluation, an important aspect of project control is to forecast the project completion cost at incremental stages of the project’s execution. Forecasting calculation is carried out to determine the Estimate at Completion (EAC) of the project by adjusting the BCWS as a result of the difference between the ACWP and the BCWP. This is done by using equation 5. The daily adjusted BCWS calculations including the EAC at the end are incorporated in the “Project Performance and Forecasting” section below the ACWP calculations, as shown in **Figure 9**. This section also contains the relationship of the Earned Value measurements in the form of the Schedule Performance Index (SPI) and the Cost Performance Index (CPI). These indicators provide measures of whether or not work is being accomplished as planned and over time, whether project performance is improving or deteriorating (**Hegazy, 2003**).

### Payment Schedule

This section summarizes the cash equivalent of the work completed to date, previous to the reporting period, and amount payable for the current reporting period. **Figure 10** illustrates “Payment Schedule” section.

The monetary value of the work completed to date is provided in the “Owing to End of Day” field. The next field, “total Paid before Day”, illustrates the amount of money that has been paid to the

contractor previous to the current reporting period. The third field, "Payable" displays monetary value payable to the contractor based on the work completed during the current reporting period. This section also provides the baseline budget of the project at the activity level, which can be used in comparison with the payment schedule to determine the cost performance of the project. Adjacent to the "Budget" column are two fields that reveal the percentage of the planned progress, "Planned% Progress", and actual progress, "Actual% Progress" of each activity that serves as an indicator of the project performance. The calculation fields illustrated in the payment schedule are calculated in accordance with the period displayed in the "For the Period" control (Cell D2 and D3). The reporting period can be determined by entering the "From Day No" (Cell D2) and "To Day No" (Cell D3) values in the "For the Period" control provided.

### OPTIMIZATION PROCESS

The proposed model uses software program based on genetic algorithms to perform the optimization process of TCT, RS, and RA. This program is called Evolver (Professional Version 4.08) which works as add-in program to the Excel environment. Solver program are used to perform cash flow optimization. **Figure 11** illustrates process chart of optimization process.

### MODEL APPLICATION CASE STUDY DESCRIPTION

**Figures 12** show a hypothetical case study of 12 activities in the form of activity on node (AON) network and a bar chart representation respectively. The project duration with longest method of construction is 102 days.

A summary of the case study data is demonstrated in **Table 1**

Performing Resource Allocation in Microsoft Project

Resource allocation is performed by using Microsoft Project according to the limited resources (L1, E1, and, L2) which are restricted to 6, 2, and 1 unit per day respectively. Time with longest method of construction of each activity is entered manually is MS Project to perform resource allocation.

The project duration will be extended to 120 days. Activities F and G are delayed by 3 and 18 days respectively.

### Optimizing Time Schedule Considering TCT&RL

This application demonstrates the proposed model ability to optimize time schedule considering time cost trade-off analysis, resource smoothing (fluctuation and utilization moments) and resource allocation. The user inputs of the project deadline is 115 days, indirect cost is 2MID per day and project start date. Initial delay values are the best ones obtained from Microsoft Project and initial values for the method variable are set as the shortest method of construction (method 3), Evolver then minimizes total cost.

The optimization parameters associated are as follows:

Objective function: minimizes "Total Cost" cell

Change: "Method Variables" field and "Delay" values in the "Delay" field.

Constraints:

Duration  $\leq$  Deadline (115 days) (soft constraint).

Construction methods are integers

Resources used  $\leq$  available limits (hard constraint)

Delays are integer values

Sum of delays = Min (soft constraint).

Total moment = Min (Soft constraint)

**Figure 13** illustrates the results of overall schedule. This application depicts the capability of the proposed model to decrease project duration to be less than the deadline, cost and resource moments while retaining the daily quantity of the required resource within its limits.



## Cash Flow Calculations

The result of applying TCT analysis and RL analyses is taken to perform overdraft calculations. The network has been crashed seven days by selecting appropriate methods of construction for the activities.

### Overdraft Calculations and Interest Charges (Manual Solution)

In this section the detailed overdraft calculations are demonstrated considering the cash flow variables. Bid unbalancing strategy is adopted to improve project financing. The effect of bid unbalancing on cash flow calculations is to reduce monthly value to be financed and less interest charges. Case study variables are as follows:

Indirect cost is 226 MID (2 MID per day).

Contractor's optimum mark-up is 8%.

Time period= 30 days.

Retainage amount is 10%.

All withheld retainage money will be paid back with last payment.

Owner's payment delay of any invoice is one period.

A 10% mobilization payment is given to the contractor at the beginning of the project and will be deducted from the first two payments.

The interest rate applied to any overdraft money is 1% per period.

Bid is unbalanced; the concept is to assign high positive adjustment percentages to the activities that are early in the schedule and high negative percentage to the ones that are late in the schedule, total bid does not change. **Table 2** illustrates the calculations of direct, unbalanced indirect costs and the budget value calculations. Shaded activities are crashed to reduce project duration.

Table 3 illustrates cash flow calculations in which, direct expenses is the calculation of the direct costs in every period based on the bar chart. The budget value of the work planned to be performed in each period can be calculated also from the planned bar chart but considering the bid price of activities shown in **Table 2**.

The sum of interest charges (17.15) is determined from row (11), representing the cost to the contractor due to project financing. The project's total direct plus indirect costs are 1003.3MID. With markup being 8%, a profit of 80.2MID is expected. If the interest charges are subtracted, the net profit becomes 63.1MID, as illustrated in the last row 12 of **Table 3**. The maximum finance amount (cash needed) is 530.77MID and is needed in the second period as shown in row 12 of **Table 3**.

### Performing Overdraft Calculations and Interest Charges

This application is performed to compare the proposed model results with manual solution of the case study. The user inputs are set as follows:

Time period is 30 days, markup 8%, retainage 10%, interest 1%, and mobilization 10%

**Figure 14** illustrates the proposed model results. This section is identical to the case study manual solution where the maximum overdraft money is 530.77MID needed in the second period and total interest charges is 17.15MID.

### Cash Flow Optimization

This application demonstrates the proposed model ability to optimize cash flow analysis. The time schedule is optimized by improving the project cash flow through a bid unbalancing process. The result of performing TCT analysis and resource leveling have taken and accordingly the activities' delay values and methods of construction are set to meet the project deadline and resource limits. Solver is used to optimize bid unbalancing. The optimization parameters associated are as follows:

Objective function: minimizes "Total Interest Charges" cell

Change: Activities' adjustment field, which leads to an increase or a decrease in the unit cost of the activities. Constraints:

Variables are integers (-5 to 5). To keep the unit price of the activities within the practical range acceptable to owners, a constraint on the maximum adjustment percentage is assigned.

Sum of the adjustment values = 0 (total bid unchanged).

The results of performing cash flow optimization are illustrated in **Figure 15** which indicates reduction in the total interest charges from 17.15 MID to 16.29 MID.

When a comparison between two cases, after and before performing bid unbalancing calculations to the optimized schedule (TCT&RL), it is concluded that reduction in the total interest charges from 17.42 to 17.15. Further reduction is concluded after performing TCT, RL and cash flow analysis from 17.15 to 16.29. **Table 4** illustrates a summary of final results.

## PROGRESS CONTROL

This application demonstrates the proposed model ability to monitor project progress, the finalized plan (**Figure 15**) is considered as a baseline for comparing actual performance. The project progress is tracked during the first 30 days of construction, the actual cost and the percent complete on the actual bar chart is entered in the white cells as illustrated in **Figure 16**. This figure also shows the progress payment. Between days 1 and 30, the project is 33.6% complete as opposed to the planned 43.6%.

**Figure 17** shows the S-curve envelope of early and late costs as well as actual progress until day 30 in which the actual cost point is above the average S-curve, it depicts additional project expenses.

**Figure 18** illustrates Earned Value Control, the project at 30 days exhibits a schedule delay and a cost saving. To forecast the estimate at completion (EAC), Equation 5 is applied using the calculations illustrated in Figure 19. The EAC is 1025.08 which is identical to the graphically representation **Figure 18**.

Cost table and the Gant view in MS Project is activated as illustrated in **Figure 18** showing the actual performance bars within the activity bars, the cost table shows a comparison of actual costs and baseline costs. All data in Figure 20 are consistent with the calculations in the model.

To facilitate the follow-up on project performance from one reporting period to the other, the plot of the CPI versus SPI is drawn as shown in **Figure 21**, it depicts the schedule delay and cost saving at the beginning of first period, then schedule advantage and cost saving but the trend shows that schedule delay is increasing.

Based on the results on the hypothetical case study, the scheduling model has the capability to obtain optimum solution performing time cost trade off analysis and resource leveling using Evolver program and then take the results of optimization process to perform cash flow optimization.

The proposed model can measure deviations of actual progress from the baseline and monitor project progress to decide on proper corrective actions.

It is worth mentioning that the model developed can operate and achieve solutions for small to medium sized projects.

## CONCLUSIONS

After developing the time scheduling model during planning and construction stages and validating its capabilities, the researcher has reached the following conclusions:

A – The scheduling model has the capability to obtain optimum solution during planning stage for performing time-cost trade off analysis, resource leveling and cash flow management, presenting a solution identical to manual solution.

B- The proposed model can perform cash flow analysis, while Microsoft Project Program on the contrary can only be the basis for cash flow analysis.

C – The model can measure deviations of actual progress during construction stage from the baseline and monitor project progress to decide on proper corrective actions. The calculations in the model are consistent with the data in MS project.

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**RECOMMENDATIONS**

Based on the work presented, these suggestions are put forward:

A – Through performing time cost trade off analysis and resource leveling using Evolver program, sometimes, stagnation occurs in the results of the program. To prevent such a case, it is necessary to rerun the program.

B – It is suggested to adopt the research findings in the application field throughout using the model in the planning and construction phases and managing of construction projects in Iraqi construction industry.

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**Table 1** Case Study Data

		3 Methods of Construction - Normal to Crash (No. 1 is cheapest and No. 3 is most expensive)						Resource Requirements		
ID	Name	Cost1 (MID)	Time1	Cost2 (MID)	Time2	Cost3 (MID)	Time3	L1	E1	L2
1	A	32	10	33	9			3.00		
2	B	75.1	17			78	14	1.00		
3	C	60	15	61	14	62	13	2.00		
4	D	90	20			95	15	2.00	2.00	
5	E	40	20	42	19			2.00		1.00
6	F	90	30			95	25	1.00		
7	G	85	23	86.1	22			2.00		1.00
8	H	40	25			44	21	2.00		
9	I	65	33	66	32	68	30	1.00		
10	J	55	40			60	35	2.00		
11	K	95	20			97	18	2.00		
12	L	25.1	12					3.00		

**Table 2** Calculation of direct, unbalanced cost and budget value

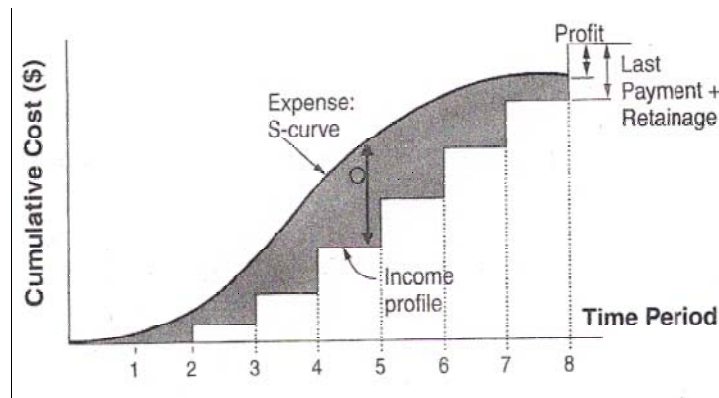
Activity	Duration	Direct Cost	Indirect Cost (unbalanced bid) Balanced*	Adjust. %	Total**	Total Cost	Markup(8%)	Bid Price
A	9	33	9.6	2.7	15.7	48.7	3.9	52.6
B	17	75.1	21.8	1.4	25.0	100.1	8.0	108.1
C	13	62	18.0	2.4	23.5	85.5	6.8	92.3
D	15	95	27.6	1.4	30.8	125.8	10.1	135.8
E	19	42	12.2	-1.6	8.6	50.6	4.0	54.6
F	30	90	26.2	1.0	28.4	118.4	9.5	127.9
G	22	86.1	25.0		25.0	111.1	8.9	120.0
H	21	44	12.8	-2.2	7.8	51.8	4.1	56.0
I	30	68	19.8	-1.4	16.6	84.6	6.8	91.4
J	35	60	17.4	-2.3	12.2	72.2	5.8	78.0
K	18	97	28.2	-1.4	25.0	122.0	9.8	131.8
L	12	25.1	7.3		7.3	32.4	2.6	35.0
<b>Total</b>		<b>777.3</b>	<b>226.0</b>		<b>226.0</b>	<b>1003.30</b>		<b>1083.5</b>

**Table 3** Cash Flow Calculations (Manual Solution).

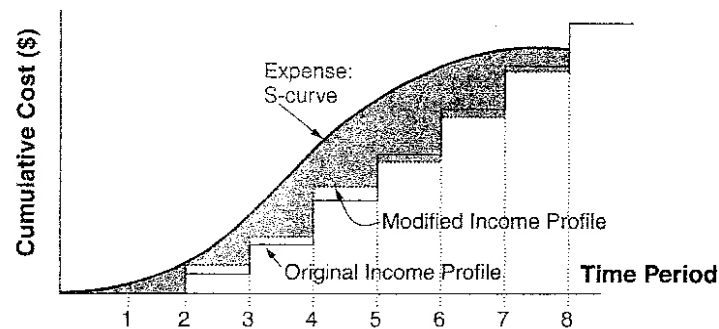
	Time Period					5th Retainage Payback
	1st	2nd	3rd	4th(Last)	5th(End)	
(1) Direct Expenses MID	298.36	213.02	221.97	43.96	0	
(2) Indirect Expenses 2MID/d	60	60	60	46		
(3) Total Expenses MID	358.36	273.02	281.97	89.96		
<b>(4) Cumulative Expenses = Cumulative of Row3 MID</b>	<b>358.36</b>	<b>631.38</b>	<b>913.34</b>	<b>1003.3</b>	<b>1003.3</b>	
(5) Budget Value of Work MID	432.1	292.91	299.05	59.5	0	=Sum of (6)
(6) Retainage(5)×10% MID	43.21	29.29	29.9	5.95	0	
(7) Amount Payable=(5)-(6) MID	388.89	263.62	269.15	53.55	0	
(8) Payment Received MID	108.36 (Mobil.)	334.7 Half mobil. deducted	209.44 Half mobil. deducted	269.15	53.55	
<b>(9) Cumulative Owner Payment = Cum. Of (8) MID</b>	<b>108.36</b>	<b>443.06</b>	<b>652.5</b>	<b>921.65</b>	<b>975.2</b>	
(10) Overdraft Balance at End of Period MID	-250	-525.52	-478.03	-363.33	-97.82	-98.798 +53.55 +108.35 = 63.1 MID
(11) Interest on Overdraft Balance=(10)×1% MID	-2.5	-5.255	-4.78	-3.633	-0.9782	
<b>(12) Total Overdraft Balance = (10)+(11) MID</b>	<b>-252.5</b>	<b>-530.77</b>	<b>-482.81</b>	<b>-366.96</b>	<b>-98.798</b>	

**Table 4** A summary of Final Result.

	Projects Duration	Direct Cost	Total Cost	Budget Value	Max. Overdraft	Interest Charge
Project Executed with longest Method of Construction	120	752.2	992	1072	502.55	16.73
Project Executed with shortest Method of Construction	110	785.2	1005	1086	612.41	17.12
After performing TCT & RL without Bid Unbalancing calculations Deadline=115	113	777.3	1003.3	1083.5	530.77	17.42
After performing TCT & RL with Bid Unbalancing	113	777.3	1003.3	1083.5	530.77	17.15
Time Schedule optimization (TCT, RL & Cash Flow Analysis)	113	777.3	1003.3	1083.5	530.77	16.29



**Figure 1** Project Cash Flow Curves.



**Figure 2** Effect of Bid Unbalancing

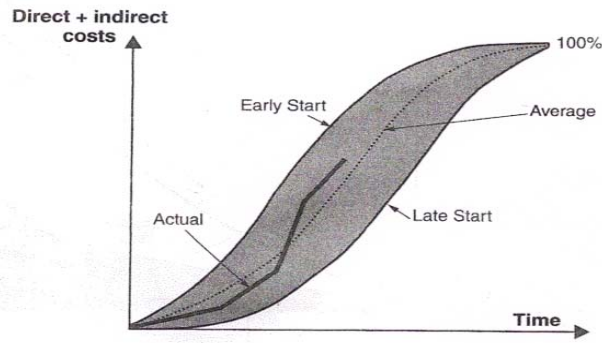


Figure 3 A Project Time-Cost Envelop.

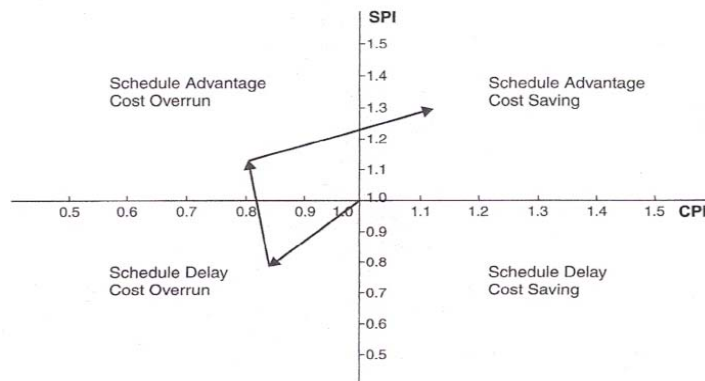


Figure 4 Project Performance Indices

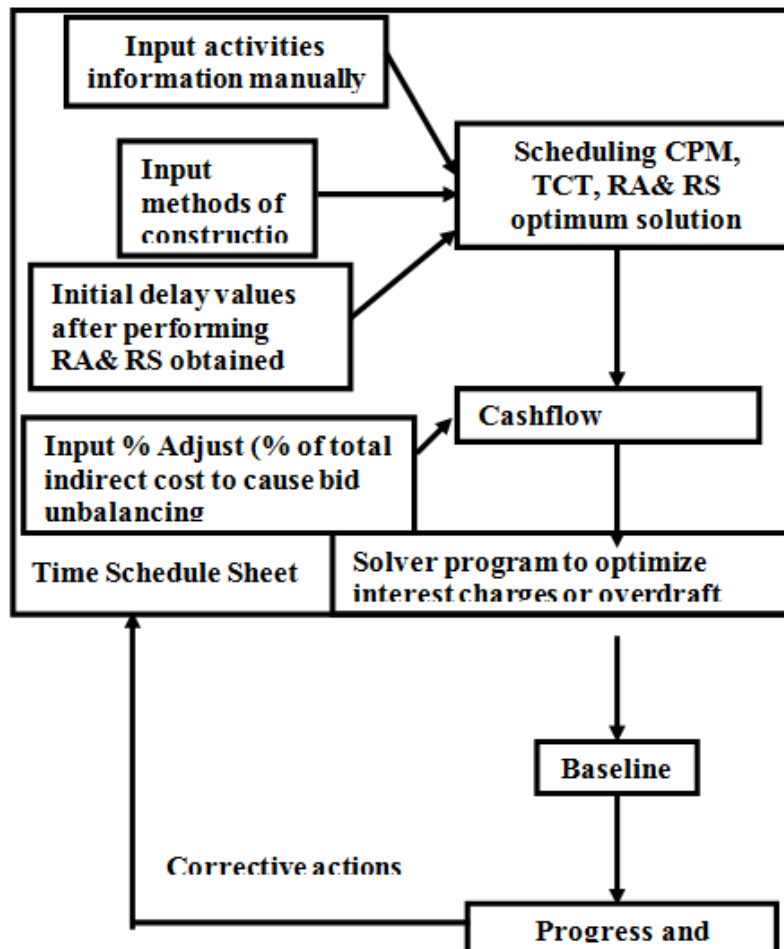


Figure 5 Process chart diagram of the proposed model

	AR	AS	AT	AU	AV	AW	AX	BY	BT	BU	BV	BW
6			1	2	3	4	26	27	28	29	30	
25	Daily direct expenses		3.67	3.67	3.67	3.67	8.72	4.31	4.31	4.31	7.31	
26	Direct Expense/Period										298.36	
27											298.36	
28	Daily Indirect Expense		2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	
29	Indirect expenses/Period										60.00	
30	Total Expenses / Period										358.36	
31	Cumulative Expenses - Early		11.95	23.89	35.84	47.79	210.57	222.52	234.47	246.41	258.36	
32	Direct+Indirect Budget / day		5.41	5.41	5.41	5.41	11.02	5.13	5.13	5.13	9.08	
33	Direct+Indirect Budget / Period										400.09	
34	Markup										32.01	
35	Contract Value / Period										432.10	
36	Retainage, sum n	100									43.21	
37	Amount Received / Period											
38	Cumulative Received	100	108.36	108.36	108.36	108.36	108.36	108.36	108.36	108.36	108.36	
39	Overdraft, before interest										-250.00	
40	Interest, sum n	-17									-2.50	
41	Total Overdraft	100	108.36								-252.50	
42												
43												
44												
45	BCWS (Early)		9.94	19.88	29.82	39.76	171.90	181.84	191.78	201.72	211.66	

Figure 6 Cash Flow Management Screen

Percent Complete on Actual Bar Chart:													
Description	1	2	3	4	5	6	7	8	9	10	11	12	13
A	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%			
B											5%	5%	5%

Figure 7 An actual Bar Chart.

Cost Control - ACTUAL PROGRESS DATA					
Reported Actual Progress Reached Day: 0					
Description	Percent Complete	Actual Duration	Actual Start	Actual Cost Todate	Current Finish
A					

Figure 8 Actual Progress

Actual Start	Actual Cost Todate	Current Finish	1	2	24	25	26	27	28	29	30	31
23			4.50	4.50	9.00	14.00	19.00	24.00	29.00	34.00	39.00	44.00
24	ACWP		4.50	9.00	24.00	27.00	29.00	29.00	39.00	39.00	39.00	44.00
25	ACWP-Forecast After Day No:	30	4.50	9.00	24.00	27.00	29.00	29.00	39.00	39.00	39.00	44.00
26												
27	Earned Value	BCWP										
28	calculations		4.50	9.00	24.00	25.00	26.00	27.00	28.00	29.00	30.00	31.00
29			5.20	10.40	16.00	16.40	16.80	17.20	17.60	18.00	18.40	18.80
30	BCWP		4.26	8.52	21.26	22.52	23.78	25.04	26.30	27.56	28.82	30.08
31												
32												
33												
34												
35			4.50	9.00	24.00	25.00	26.00	27.00	28.00	29.00	30.00	31.00
36	CPi		1.00	1.17	1.17	1.10	1.10	1.10	1.10	1.10	1.10	1.10
37	SPi		1.00	0.90	0.90	1.07	1.06	1.05	1.04	1.04	1.03	1.03
38												
39												
40	Vertical Line		30	30								
41	Progress Date											

Figure 9 Project Performances and Forecasting

For the period:							
From Day No.:		Enter values from 1 to Project duration.					
To Day No.:							
Activity	Description	Budget	Planned % Progress (Day to)	Actual % Progress (Day to)	Owing To End of Day	Total Paid Before Day	Payable
6							
7							

Figure 10 Payment Schedule

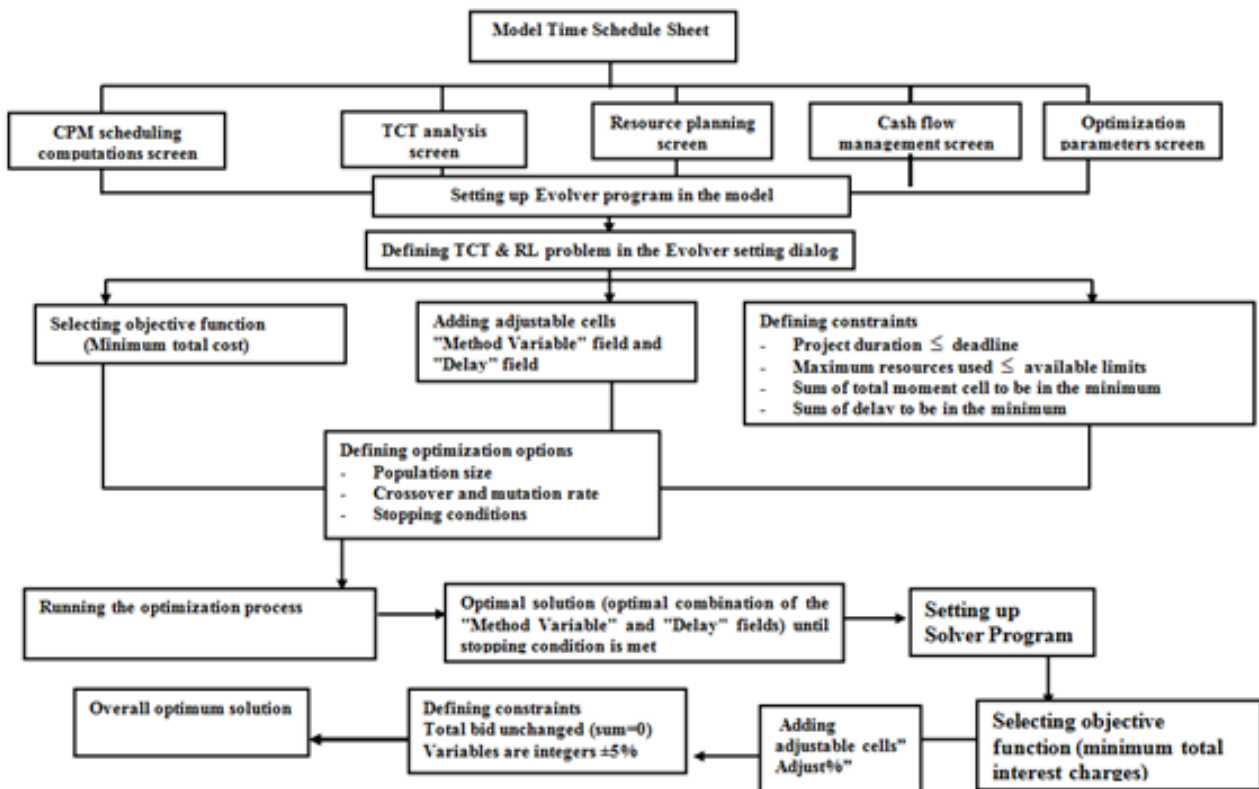


Figure 11 Process Chart of Optimization Process

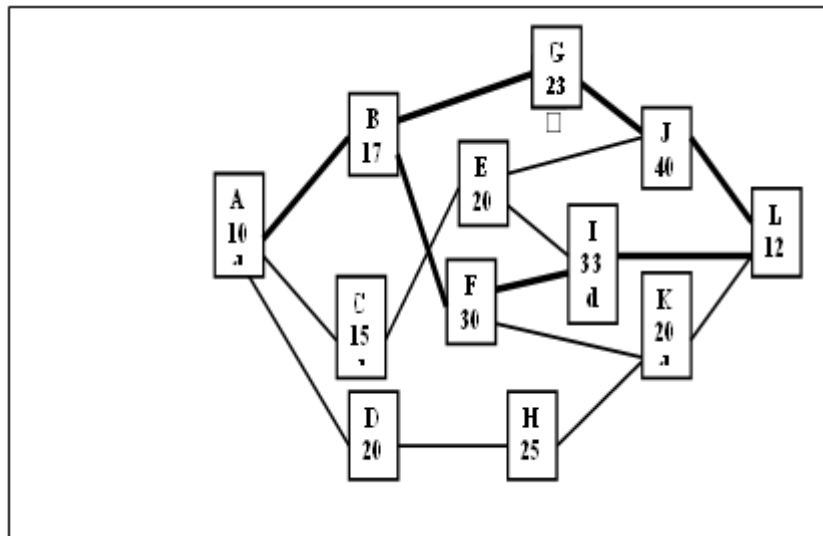


Figure 12 AON Network of 12 Activity Project (Case Study)

Activity	Name	Duration	Cost (MRD)	Delay	Mod Vari	Mod Meth	Costs (MRD)	Time 1	Cost2 (MRD)	Time 2	Cost3 (MRD)	Time 3
7	A	10	33		2	2	32	10	33	9		
8	B	17	78.1		1	1	78.1	17		78	14	
9	C	15	62		3	3	60	18	61	14	62	13
10	D	20	95		3	3	90	20		95	16	
11	E	20	49		2	2	40	20	42	19	48	16
12	F	30	90		3	1	90	30				
13	G	23	86.1		1.8	2	85	23	86.1	22	86	20
14	H	25	44		3	3	40	25		44	21	
15	I	33	68		3	3	65	33	66	32	68	30
16	J	40	60		3	3	55	40		60	35	
17	K	20	97		3	3	95	20		97	18	
18	L	12	28.1		1	1	26.1	12				

Activity	LS	ES	LS	ES	LS	ES
7	0	0	0	0	0	0
8	10	10	10	10	10	10
9	10	10	10	10	10	10
10	10	10	10	10	10	10
11	10	10	10	10	10	10
12	10	10	10	10	10	10
13	10	10	10	10	10	10
14	10	10	10	10	10	10
15	10	10	10	10	10	10
16	10	10	10	10	10	10
17	10	10	10	10	10	10
18	10	10	10	10	10	10

Parameter	Value
Penalty (MRD)	
Incentive (MRD)	2.00
Interest (MRD)	
Start Date/Day	3/11/2009
Duration (Days)	113
Total Penalty	
Total Incentive	
Total Interest	221.20

Figure 13 Results of TCT and RL



	AR	AS	AT	CX	CY	CZ	DA	DB	DC	AC	AD	AE	AF	AG
6			1	57	58	59	60	61	62	33				
25	Daily direct expenses		3.67	0.91	0.91	0.91	11.57	11.57	11.57	34				
26	Direct Expense/Period						213.02			35				
27							213.02			36				
28	Daily Indirect Expense		2.00	2.00	2.00	2.00	2.00	2.00	2.00					
29	Indirect expenses/Period						60.00							
30	Total Expenses / Period						273.02							
31	Cumulative Expenses - Early		11.95	604.07	613.17	622.27	631.37	640.77	650.17					
32	Direct+Indirect Budget / day		5.41	9.00	9.00	9.00	14.65	14.65	14.65					
33	Direct+Indirect Budget / Period						271.21							
34	Markup						21.70							
35	Contract Value / Period						292.91							
36	Retainage, sum =		108				29.29							
37	Amount Received / Period						334.71							
38	Cumulative Received		108	108.36	108.36	108.36	108.36	443.06	443.06					
39	Overdraft, before interest								-525.52					
40	Interest, sum =		-17.15						-5.26					
41	Total Overdraft		108	108.36					-530.77					

Figure 14 Performing Overdraft Calculations and Interest Charges

Name	Activity	Duration	Cost MID	Delay	Method Variable	Adjust. (%)	balanced Indirect	Adjust. (MID)	Total Indirect
A		9	33		2	5.0	9.59	11.30	20.89
B		17	75.1		1	5.0	21.84	11.30	33.14
C		13	62		3	5.0	18.03	11.30	29.33
D		15	95		3	5.0	27.62	11.30	38.92
E		19	42		2	5.0	12.21	11.30	23.51
F		30	90	3	1	-5.0	26.17	-11.30	14.87
G		22	86.1	18	2	-5.0	25.03	-11.30	13.73
H		21	44		3	5.0	12.79	11.30	24.09
I		30	68		3	-5.0	19.77	-11.30	8.47
J		35	60		3	-5.0	17.45	-11.30	6.15
K		18	97		3	-5.0	28.20	-11.30	16.90
L		12	25.1		1	-5.0	7.30	-11.30	-4.00

Figure 15 Performing Cash Flow Optimization

Description	Budget	Planned % Progress (Day 1 to 30)	Actual % Progress (Day 1 to 30)	Overrun % Cost of Day	Total Paid	Payable
JA	58.21	100.0%	100.0%	58.21	58.21	58.21
JB	116.69	100.0%	100.0%	116.69	116.69	116.69
JC	368.63	100.0%	100.0%	368.63	368.63	368.63
JD	144.83	100.0%	100.0%	144.83	144.83	144.83
JE	218.25	82.1%	23.9%	17.69	27.32	17.69
JF	113.20	3.2%				
JG	197.82					
JH	73.54	28.6%				
JI	82.98					
JJ	71.84					
JK	123.91					
JL	22.79					

Figure 16 Actual Progress Data and Progress Payment

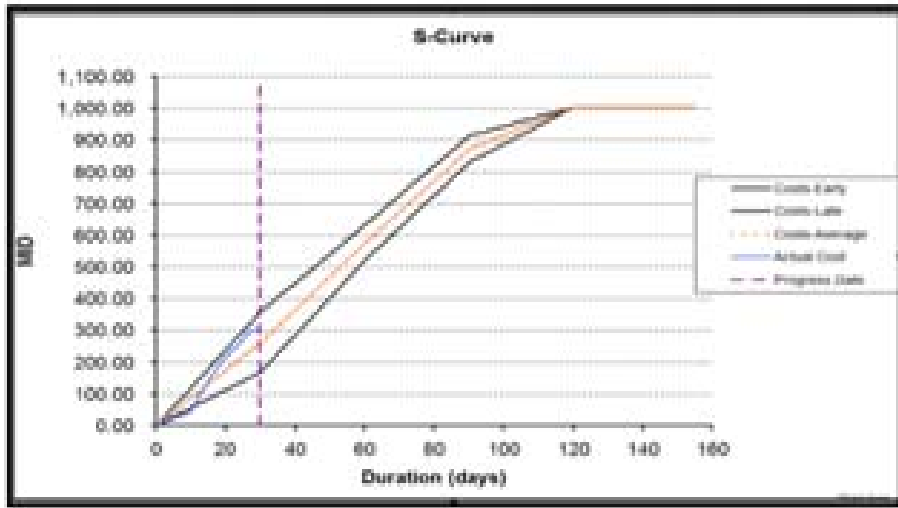


Figure 17 S- Curve Control

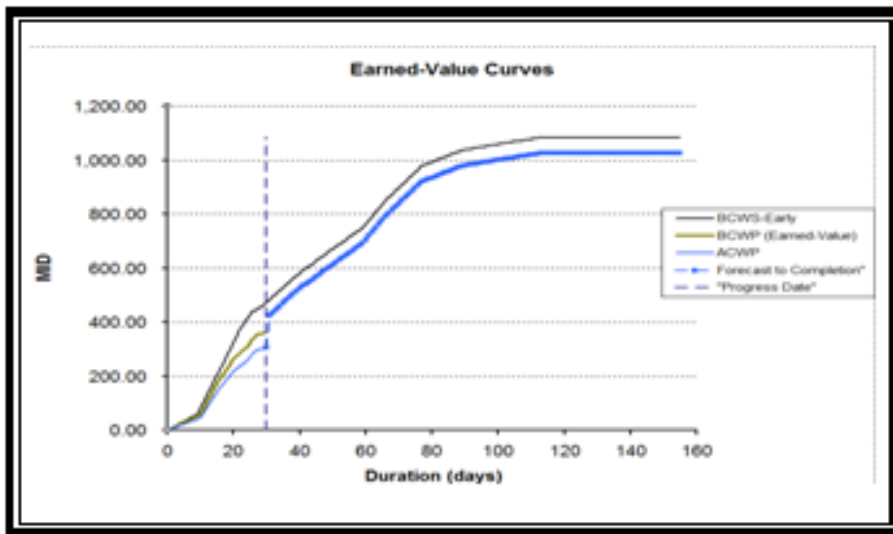


Figure 18 Earned Value Control.

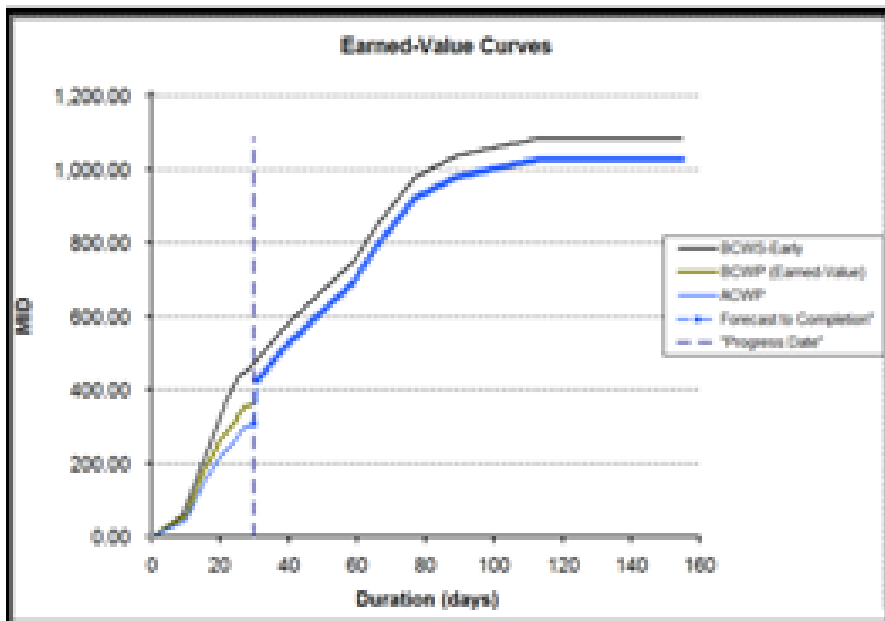


Figure 19 Earned Value Calculations

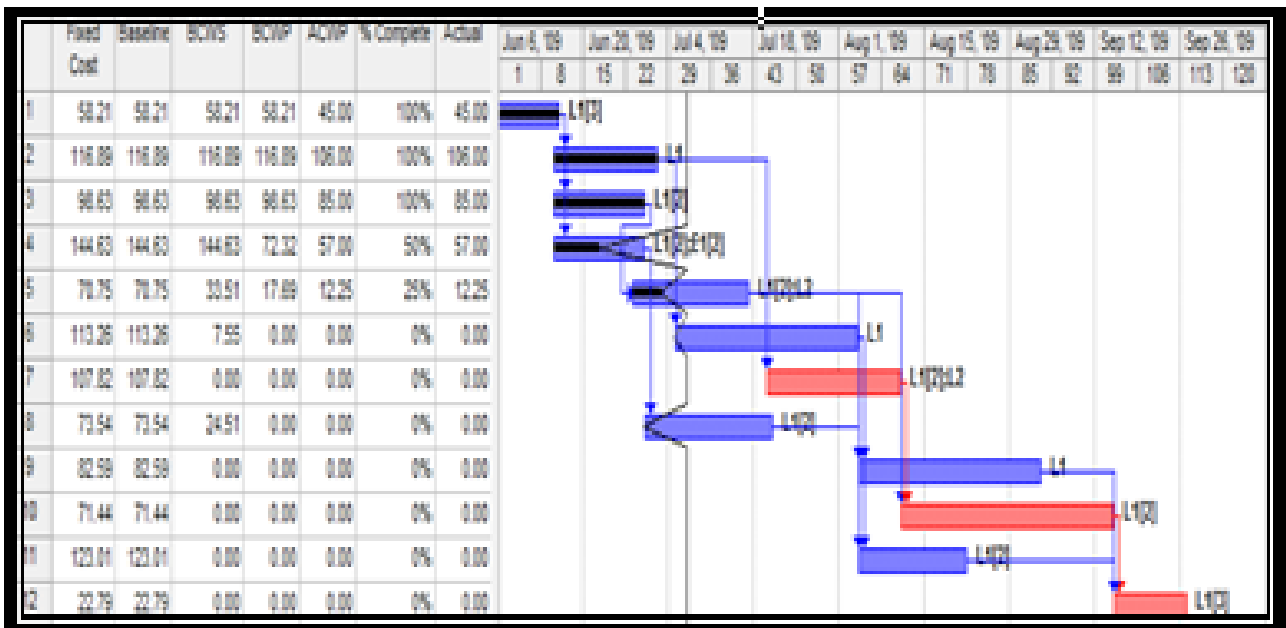


Figure 20 Cost Table and Gant view

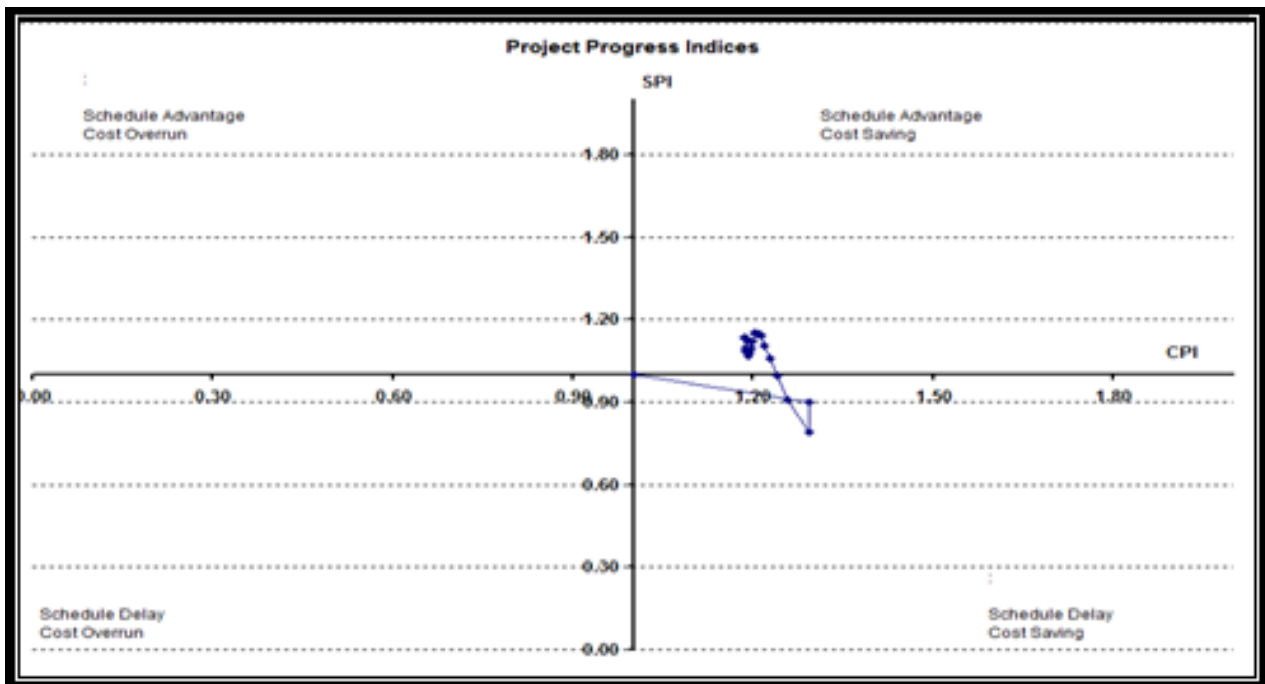


Figure 21 Progress Indices