Profit Maximization and Strategic Management for Construction Projects

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ABSTRACT

Profit maximization is the first goal for any construction company whether it is stated directly or hidden in between the strategic management lines. At the same time construction projects are known for frequently being over budget and behind schedule. As it is known the resources are limited not only for the contractors, but also for the clients. In order to allow construction companies to make a profit on projects they need to practice intelligent approaches and find ways of minimize its costs. Traditional approaches no longer serve the industry and informed decision-making is important for any construction company to be profitable and stay in the market.

In the mission of helping the industry in the process of informed decision-making and strategic management a decision-support tool is developed called Strategic Management for Construction Projects (SMCP). The aim of the tool is to help in deciding on optimal resource allocation for any construction project with consideration of resource availability and the stakeholder guidance. The decision-support tool takes into consideration the technical aspects of projects as well its business perspectives for cash-flow and activity planning. The tool can be used for project contract management as well, since it provides the information necessary to consider for having a successful project.

Within its constraints the tool allows to analyze the sustainability compliance of projects if such imposed or pioneered. As such the decision-support tool can aid the construction management industry for optimal decision-making in strategic management.

INTRODUCTION

In capitalistic economy production for profit and accumulation is the driving force for continuous development. As stated by Joseph Schumpeter (1911) in his book titled *The Theory of Economic Development*, "Without development there is no profit, without profit no development,". From economic development perspective the profit maximization or cost minimization serves as the driving force for many businesses if not for all. Construction industry is no different from this perspective, yet has many specificities that make it a distinct industry by its nature (Koskela, 2000).

In construction industry compared to other manufacturing industries projects are unique, must be in place and can be completed by different assembly teams. Such setup in many cases may cause the anomalies related to the resource allocation and availability, which when seasoned with stakeholder needs may push projects to be delayed as well as be over budget. From Project Management Institute's Talent Triangle perspective this is where all the pieces of project management come together and try to overcome the obstacles (PMI, 2017). With talent triangle consideration it assumes a meeting of minds and skills for the potential best outcome for successful project delivery. With meeting of minds it seeks to utilize the available resources and by complying with actual limitations or considerations for project completion.

In the industry this process when directly linked to scheduling of a project is frequently known as a resource-constrained project scheduling problem (Koulinas and Anagnostopoulos, 2012). In resource-constrained scheduling the availability of limited resource is assumed at any time. The goal under such assumption is to minimize the duration of projects by efficiently rescheduling all project activities. As long as the solution is found the next phase of analysis assumes resource allocation. This in its turn is assumed to be helpful in cost minimization by reducing the need of temporary addition of required resources. Then it comes to the resource leveling to smoothen day to day resource needs which under CPM method still consider the unlimited availability (Demeulemeester and Herroelen 2002). With unlimited resource availability it seems to be much easier to allocate resources for project completion. When the limitation of resources is added to the picture the scheduling may become more challenging. When such setup is associated with the input from stakeholders the picture becomes more and more complicated.

In this paper the goal is to develop a decision-support tool that will aid management from multifaceted perspective such as lower costs, in time completion with resource constrained setup. The developed model is used on a hypothetical problem based on unlimited resource version adopted from Winston (2004). Results indicate that the impact of resources can be analyzed beforehand and may indicate the projects' resource infeasibility range or will tell how much investment is necessary in order to finish the project under enforced conditions.

Resource usage and limitations for resources in projects may be both continuous or in integer values. To allow more practical usage of material among projects it was decided to allow the model variables to be continuous which on the other side allows more efficient solution times for solving the problems more reliably without worrying of the solution being local or global . For analyzing the developed tool GAMS and LINDO software packages were utilized to solve the sample problem on a laptop computer that has Intel® Core™ i3-3110M CPU @ 2.40GHz with 64-bit operating system and 4.00GB RAM. Computational time of the problem was in terms of 00:00:00 as reported by the solver for the sample case study problem with 17 variables, which will be slightly different for a full scale problem analysis, but is not expected to cause any significant issues due to the linear and effective formulation of the tool and constraint formulation. Results are analyzed at the Results section of the paper.

PROPOSED METHODOLOGY

For any construction project there are many competing contractors that bid and expect to get the projects based on more accurate cost and duration estimates, as well as their reputation. From managerial perspective it can be seen that the resource availability would be the other dimension which when analyzed accurately can aid in such competition and goal of getting a project.

In this paper, an optimization-based methodology is developed and proposed for management to consider resource limitations that can be expressed in terms of quantity or budget and time. Such approach allows to proceed with the best potential strategy to evaluate and complete construction projects within considered limitations if such option is at all feasible.

Schematic representation of the proposed decision-support system is presented in Figure 1. The top-level in Figure 1 is the decision-making unit for strategic and business management that analysis and optimizes the resources along with schedule among construction sites. The lower-level represents construction sites from which an updated data on a continuous basis is supplied to the top level. The arrow in the third-level on Figure 1 indicates that the information exchange is not solely between the centralized decision-making system and the sites, but also among the construction sites managed by single company.

In Figure 1 the top-level unit is responsible for all decision-making and problem solution activities, while the lower levels are required to supply data and adopt the decisions provided from the top level.

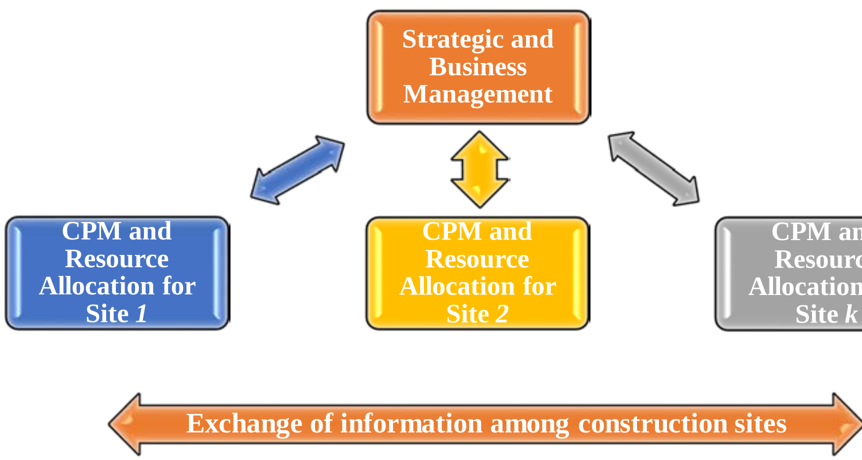

Figure1. Schematic representation of a Management System

The limited details of the system formulation as an optimization model is provided in the next section followed by preliminary results of a case study. The developed approach utilizes the strengths of CPM and PERT (Program Evaluation Review Technique) where the duration of activities or resources can be based on the optimistic, pessimistic and average values. For the sake of simplicity and space limitation only one site setup is partially presented.

MATHEMATICAL MODEL

In order to develop the mathematical model for the scheduling problem with constraint resources it is necessary first to formulate the problem with unlimited resources setup. To find the critical path of a project using Critical Path Method it is important to define the list of activities and the predecessor relationship along with the corresponding durations. Once this step is complete the network diagram can be built and the physical or logical connections can be presented. In general the mathematical formulation allows to set up the models for project crashing or shortening the duration of individual activities.

The model of CPM is presented in its general form with unconstrained resources followed by the model for crashing the project duration, which in its turn is followed by partial representation of a novel approach that considers the constrained nature of resources with stakeholder requirements presented in terms of limitations.

The Model

Notation employed in the mathematical formulation of the *SMCP's* objective function are defined next.

I	=	set of origin where activity starts
J	=	set of destination where activity finishes, J* is the last element in the set
TD	=	total duration right hand sight value where necessary
R_k	=	construction resource types right hand sight value where necessary (e.g. material, labor, budget, time, stakeholder needs, sustainability, etc.) $k \in K$
R_{ijk}	=	usage of resource type k for activity ij $i \in I, j \in J, k \in K$
CC_{ij}	=	cost of crashing activity ij $i \in I, j \in J$
L_{ij}	=	right hand side value as limitation on crashing activity ij $i \in I, j \in J$
La_{ij}	=	estimate of the activity's crashing duration under the most favorable conditions
Lb_{ij}	=	estimate of the activity's crashing duration under the least favorable conditions
Lm_{ij}	=	most likely value for the activity's crashing duration
ta_{ij}	=	estimate of the activity's duration under the most favorable conditions
tb_{ij}	=	estimate of the activity's duration under the least favorable conditions
tm_{ij}	=	most likely value for the activity's duration

Decision variables

x_i and x_j	=	start and finish times of activity ij, $i \in I$, $j \in J$
CT_{ij}	=	crashing duration of activity ij, $i \in I$, $j \in J$ where applied
Z	=	objective function value

Formulation of a traditional CPM as Linear Program:

Objective function:

$$\min Z = x_{J*} - x_1 \qquad (1)$$

Subject to:

$$x_j \geq x_i + t_{ij} \qquad \forall\, i \in I, j \in J \qquad (2)$$

$$x_i \text{ and } x_j \text{ URS} \qquad \forall\ i \in I, j \in J \qquad (3)$$

With the need for crashing the project the linear programing allows using a unique formulation that can minimize the crashing cost of the activities.

With such set up the formulation looks as the following:

Objective function:

$$\min Z = \sum_0^{J*} CC_{ij} * CT_{ij} \qquad (4)$$

Subject to:

$$CT_{ij} \leq L_{ij} \qquad \forall\ i \in I, j \in J \qquad (5)$$

$$x_j \geq x_i + t_{ij} - CT_{ij} \qquad \forall\ i \in I, j \in J \qquad (6)$$

$$x_{J*} - x_1 \leq TD \qquad \forall\ i \in I, j \in J \qquad (7)$$

$$CT_{ij} \geq 0 \qquad \forall\ i \in I, j \in J \qquad (8)$$

$$x_i \text{ and } x_j \text{ URS} \qquad \forall\ i \in I, j \in J \qquad (9)$$

In formulations (1)-(9) the time of each activity duration is set as deterministic value, while PERT allows consideration of estimated time values for each activity duration. When combining the PERT time estimate approach in CPM combined with project crashing formulation along with consideration that any crashing duration is also an estimate the linear program formulation can be structured as the following:

Objective function:

$$\min Z = x_{J*} + \sum_0^{J*} CC_{ij} * CT_{ij} - x_1 \qquad (10)$$

Subject to:

$$CT_{ij} \leq \frac{(La_{ij} + 4Lm_{ij} + Lb_{ij})}{6} \qquad \forall\ i \in I, j \in J \qquad (11)$$

$$x_j \geq x_i + \frac{(ta_{ij} + 4tm_{ij} + tb_{ij})}{6} - CT_{ij} \qquad \forall\ i \in I, j \in J \qquad (12)$$

$$x_{J*} - x_1 \leq TD \qquad \forall\ i \in I, j \in J \qquad (13)$$

$$CT_{ij} \geq 0 \qquad \forall\ i \in I, j \in J \qquad (14)$$

$$x_i \text{ and } x_j \text{ URS} \qquad \forall\ i \in I, j \in J \qquad (15)$$

The objective function (10) overall value would not be intuitive for the use. Since both CPM formulation and project crashing formulation are minimization objectives the combination of these functions for overall lowest value detection in a linear set up allows to solve the problem while identifying the shortest completion time of a project and applying the crashing strategies. The estimated time consideration is also applied in constraints (11)-(12) which allows decision-makers values to be considered in the optimization process. Such approach helps to overcome the difficulties that traditional PERT approach faces for justification of activity duration independencies and the issue of assuming that critical path found through CPM will be the critical path at all the times. This formulation allows to find the critical path and the crashing strategies while considering the estimated durations for activities. To report the actual project duration and the cost of crashing the project two additional equations can be added to the formulation. Those will be:

$$\text{TPD} = \left(x_{J*} - x_1\right) \quad (i)$$

$$TPCC = \sum_0^{J*} CC_{ij} * CT_{ij} \quad (ii)$$

Where TPD is total project duration and TPCC is total project crashing cost.

Proposed formulation can be seen as a goal programing problem where multiple objectives are considered, but with one difference that the preference value is not imposed on the functions. FOR SMCP as multi-objective optimization problem the resource availability is being added to the formulation (10)-(15) combined with (*i*) and (*ii*). The formulation for the stakeholder requirements and resource constrained formulation with an objective to reduce the resource usage is partially presented below:

Objective function of SMCP:

$$\min Z = x_{J*} + \sum_0^{J*} CC_{ij} * CT_{ij} + \sum_0^{J*} \dots\dots\dots - x_1 \quad (16)$$

Subject to:

$$CT_{ij} \le \frac{(La_{ij} + 4Lm_{ij} + Lb_{ij})}{6} \quad \forall\ i \in I, j \in J \quad (17)$$

$$x_j \ge x_i + \frac{(ta_{ij} + 4tm_{ij} + tb_{ij})}{6} - CT_{ij} \quad \forall\ i \in I, j \in J \quad (18)$$

$$x_{J*} - x_1 \le TD \quad \forall\ i \in I, j \in J \quad (19)$$

$$\dots\dots R_{ijk} \dots\dots \le \dots R_k \dots \quad \forall\ i \in I, j \in J \quad (20')$$

$$CT_{ij} \ge 0 \quad \forall\ i \in I, j \in J \quad (21)$$

$$\text{TPD} = \left(x_{J*} - x_1\right) \quad (22)$$

$$TPCC = \sum_0^{J*} CC_{ij} * CT_{ij} \quad (23)$$

$$x_i \text{ and } x_j \ URS \quad \forall\ i \in I, j \in J \quad (24)$$

Stakeholder requirements in terms of limitations are structured in constraints (20’), where “’” indicates that it is more than one constraint, which are not presented in full for this paper.

Next section presents project analysis using the models presented between (1) and (24).

SACE STUDY

Case study analyzed in this paper is considering the project specifics presented in Winston (2004) as discussed above. As such the project activities and corresponding durations are presented in Table 1 and the Activities on Arc (AOA) network diagram is presented in Figure 2. Using model presented between (1)-(3) we find that the project duration is 38 days with a critical path including critical activities B, D, E, F through Dummy arc.

Table 1. Duration of Activities and Predecessor Relationships for the Case Study Project

Activity	Predecessors	Duration in Days
A	None	6
B	None	9
C	A and B	8
D	A and B	7
E	D	10
F	C and E	12

The AOA network diagram would be:

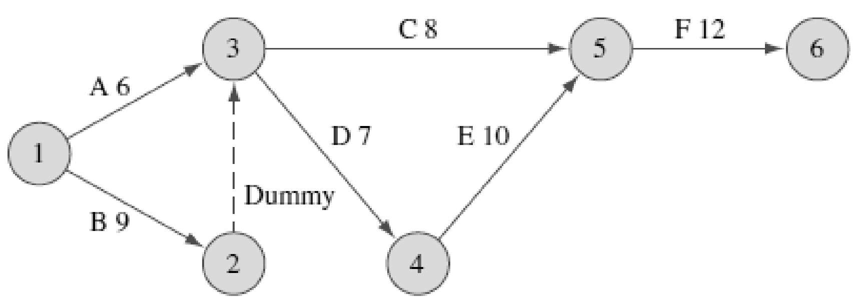

Figure 2: Activities on Arc Network Diagram for the Case Study (Winston, 2004).

When considering data for project crashing to complete it in 25 days based on crashing costs and maximum crashing days per activity from Winston (2004), which are presented in Table 2, we find that using the model between (4)-(9) the duration limitation of 25 days is achievable with a cost of $390.

Table 2. Crashing Cost of each activity and the crashing duration limit for the Case Study Project

Activity	Crashing Cost Per Day ($)	Limit on Crashing Duration (Days)
A	10	5
B	20	5
C	3	5
D	30	5
E	40	5
F	50	5

Solution of the problem suggest crashing activities A, B, D and E for 2, 5, 5 and 3 days accordingly. After adopting the model proposed solution the project is possible to complete in 25 days. The updated network with activity durations can be presented as in Figure 3.

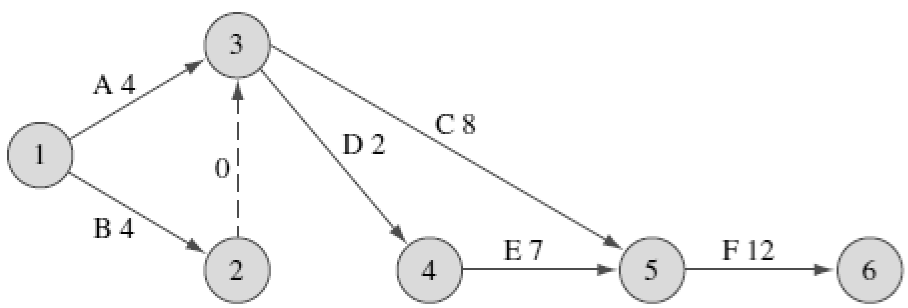

Figure 3: AOA Network Diagram for the crashed project Case Study (Winston, 2004).

With traditional approach the decision-maker should verify that the crashed activities are on a critical path and observe the presence of any changes in the diagram. In this particular case it is noticed that after crashing the project the critical path now becomes two, with both having the same duration of 25 days. The current critical paths go through activities A, D, E, F and as before B, D, E, F again through Dummy arc.

This problem can be analyzed using developed SMCP model given between (10)-(15) extended to (*i*) and (*ii*) or (16)-(24). After running the model it was noticed that the decision-maker can automatically track the critical path as with the case of CPM linear program (1)-(3). Moreover, the output of the model indicated two critical paths that were generated as a result of crashing the project as marked above. The sign of the Dual Price in front of each activity representing constraint is negative indicating that the activity is on a critical path and any increase of those values may negatively impact the completion time of the entire project. Table 3 presents the optimistic, pessimistic and most likely completion times for each activity used to run the model presented in (16)-(24).

Table 3. ta, tb, tm values for activities in the Case Study Project

Activity	Predecessors	Duration in Days		
		ta	tb	tm
A	None	5	13	9
B	None	2	10	6
C	A and B	3	13	8
D	A and B	1	13	7
E	D	8	12	10
F	C and E	9	15	12

For simplicity La, Lb, Lm values were all considered to be five in this example by allowing at most five days for crashing each activity. In other problems based on the decision-maker's analysis this value may change as necessary. For the rest of the resource allocation, sustainability and stakeholder input and resource leveling analysis the model is extended to the full formulation of (16)-(24), which is not presented in this work due to space limitations and for privacy.

RSULTS AND SUMMARY

Results indicated that the novel approach by combining and structuring accurate constraints any project can be analyzed without loss of generality of the model (16)-(24) indicating its flexibility for such analysis. The key component in the efficiency of the model is to keep it linear, but structure the model in a way that the output will be useful for practical implementation. The output of the model (16)-(24) after running it on LINDO is presented below in Table 4:

Table 4. LINDO output variable values from running SMCP for Case Study

LP OPTIMUM FOUNR AT STEP 11					
OBJECTIVE FUNCTION VALUE IS 415					
VARIABLE	VALUE	REDUCED COST	VARIABLE	VALUE	REDUCED COST
X6	25	0	F	0	10
X1	0	0	X3	4	0
A	2	0	X2	4	0
B	5	0	X5	13	0
C	0	3	X4	6	0
D	5	0	TPD	25	0
E	3	0	TPCC	390	0

Objective function value of SMCP as discussed above is not intuitive and therefore values for Total Project Duration (TPD) and Total Project Crashing Cost (TPCC) (shaded cells) are also reported as 25 days consistent with the constraint for duration limitation and $390 as crashing cost. The model is verified through the results obtained from models given between (10)-(15) extended to (*i*) and (*ii*). Shaded cells in the Table 4 correspond to constraint lines representing activities that are on a critical path as discussed above. The negative sign is present for any critical activity.

Table 4. LINDO output slacks and dual prices from running SMCP for Case Study

ROW	SLACK OR SURPLUS	DUAL PRICES	ROW	SLACK OR SURPLUS	DUAL PRICES
2)	3	0.00000	10)	6	0.00000
3)	0	10.00000	11)	0	-6.66667
4)	5	0.00000	12)	0	-6.66667
5)	0	10.00000	13)	0	-6.66667
6)	2	0.00000	14)	0	-30.00000
7)	5	0.00000	15)	0	39.00000
8)	0	-1.66667	16)	0	0.00000
9)	0	-5.00000	17)	0	0.00000

Slack or Surplus values indicate an excess amount of resources or value for other constraints and consequently represent non-critical activities with none zero values. Resource constraints in this Case Study were added with large right hand side values and did not impose any additional restrictions on the solution.

Multisite project management scenarios with profit maximization are not presented here due to space limitations as well. When the linkage and communication of data between multiple projects are imposed the solution output presents valuable and at the same time non-intuitive information for decision-makers and hence serves as useful and practical tool for strategic management of any project. Without loss of generality the model can be applied to any project management process where resource and other limitations are present. For any project where the resources are optimally utilized and costs are minimized the potential profit share is maximized.

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