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OPTIMIZATION OF MULTI-PROJECT ENVIRONMENT (OPMPE)

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ABSTRACT

Construction business is project oriented and that is why every construction organization is dependent on projects. Typically they undertake multiple projects with limited multiple resources and information. Most importantly they need to take continuous and quick decisions to keep it going. The reason behind this is lack of tools and structured approach that can efficiently deal with multi-project environment (PME). Resulting is problem of wrong project selection, project slippage and under/over utilization of scares resources. This paper presents a simulation model (OPMPE) for optimizing MPE. The model is capable of analyzing and predicting future problems, assessing the cumulative impact and generates valuable statistics and information for quick decision-making. It will work together with the available scheduling tools and will help strengthening the overall planning and execution system for MPE. The application and of the model is demonstrated using a collection of real project data for building construction.

1 INTRODUCTION

Traditionally, the vast majority of practical and theoretical developments on project management have been related to single projects considered in isolation (Evaristo & Fenema, 1999). The current demand for higher quality of living and greater technological development has meant that large construction projects are increasing in number and complexity year by year. Many complexities have been highlighted in managing multi-projects.

In a multi-project environment (MPE), management of engineering and construction companies are interested in (1) taking care of all the projects in different phases (e.g. a number of projects are under construction, some of them are waiting for start, while others are in bidding stage and a quite a lot of projects are in conceptual stage); (2) a structured approach for taking “go/no go” during project selection; (3) an optimum (the better solution within the feasible zone) program schedule that incorporates major decision variables of the company, project delivery system, individual project objectives, driven factor and priority; (4) dealing with uncertainties; and (5) regular checklist and reports related to site and management issues for improvement. They want simultaneous solution of the problems e.g. timely completion of all the projects on one hand and effective utilization of available resources on the other hand.

Main concentration in this situation is efficient and effective use of resources, which is a difficult process (Dumond & Dumond, 1993). Senior management often faces issues of resource misuse and shortage, resource conflicts, schedule overlapping, project slippage and other interdependencies of projects. Problems are accumulated as soon as projects are started, since uncertainties come into play (which were not considered in risk analysis) and multiply through shared resources. Hence, project is affected not only by its own uncertainties but also from the uncertainties of the other projects. However, management must decide, in these vulnerable situations, how to manage scares resources across multiple projects that have competing needs and goals. Existing planning tools and techniques are suitable for single project management but none of them are capable enough to effectively deal with MPE and failed to fulfill some central needs of management. Notable shortcomings include incapability: (a) to account project dynamics; (b) to handle uncertainties effectively; (c) to predict potential and critical future problems in advance; and (d) to manage project interfaces between planning and execution phases.

This paper discusses a preliminary of model to optimize the multi-project multiple resources planning and scheduling problem, which is critical for project success in a multi-project environment. The objective of the research study is to investigate multi-project environment with a target to optimize the overall system. This is achieved by an innovative idea of developing a multi-level and integrated computer simulation model. The model is capable to overcome the above-mentioned drawbacks and fill the gap in the area of concern. Simulation is a proven advanced technique for analyzing complex system behaviors without actual execution of the system (Pritsker & O'Reilly, 1999).

2 THE PROBLEM

Usually, the multi-project problem involves determine how to allocate resources to, and set a completion time for, a new project that added to an existing set of ongoing projects. This requires the development of an efficient and dynamic multi-project scheduling system. Typically, a general contractor undertakes several construction projects of different sizes and types at different sites. The contractor's organization is responsible for performing of all the projects simultaneously; these projects can start at different times at different locations - but at certain times some projects will require the use of the same limited resources with variable quantities. It is obvious that to complete an activity or work package of a project, one needs to allocate resources (like manpower, equipment, material, budget, etc) to the job.

This allocation of resources depends on many factors like requirement of the task or, phase of the project, availability of resources, sharing of resources among the projects, "wants & needs" priorities, schedule conflicts, etc. Thus, a huge complexity faced by the contractors is to optimize schedules and resources utilization while competing with other projects executed by other contractors. Resources discrepancies occur when the timing of the tasks is not well matched with the available resources. It is common in any construction project (like high-rise building) that about five to ten subcontractors are engaged for various trades by the general contractor. Involvement of these subcontractors makes the situation even more complex because it is difficult to consider unknown subcontractors' resource availabilities at the time the master schedule (or, baseline schedule) of a project is being drawn up by the general contractor. In addition, it is also very difficult to fix finite start and end date of multiple projects. The reason is nobody can predict exactly when the construction will start due to various inherent uncertainties and other complex issues.

In turn, this kind of complexity passes to the project site office to develop their own short-term construction schedules (like monthly schedule and weekly/two-week look-ahead schedule) considering risks, uncertainties, available resources and other constraints. In fact in all cases, these resources are limited or scares and they are being shared among the projects. It is also revealed that projects are not independent to each other i.e. resources may not be available at anytime they want or are not assigned exclusively to a particular project for unlimited time. There will also be some other risks and uncertainties e.g. materials shortage, poor soil condition, labor crisis, etc. So it is a big challenge for the project manager to deal with this kind of complexity and support the multi-project environment to achieve desired performance.

3 RESEARCH OBJECTIVES

The overall objective of the research was to develop the best practices and tools for construction industry managers to improve productivity by optimizing schedule and resources. The following are the specific objectives or intermediate milestones:

1. To investigate the current practices in construction industry for optimizing resources and schedules.
2. To identify key decisions variables that influence the overall quality and value of decisions
3. To identify the constraints that need to be addressed in optimizing schedules and resource planning in a multi-project environment (MPE)
4. To determine strengths and weaknesses in the scheduling optimization process
5. To identify key management and site issues in MPE, and;
6. To finalize and recommend a computer simulation model that integrate with available scheduling tools

The study sets the hypothesis "an integrated simulation-based scheduling and resource planning method provide better assurance of project success than existing and traditional scheduling tools in a multi-project environment".

The following assumptions are made to develop the model outlined above:

- Projects are interdependent through shared resources.
- Each project is broken down into a number of work packages (WP) and there are logical precedence relationships among them.
- The simulation model will use "level 2" schedule with a few high-level work packages.
- The general contractor will directly perform some work and other being performed by the trade contractors or sub-contractors.
- AON (activity on node) network for each project and overall program is available.
- The manpower resources allocation is known.
- The common resource pool can be used as soon as possible, if available.

- Projects in different phases (e.g. running, waiting for start, etc) will be considered.
- Project delivery system, driven factor and priority are pre-defined and known for each project.

4 THEORITICAL FRAMEWORKS

4.1 Concept of Multi-Project Environment (MPE)

When dealing with a single project, the basic unit of work is the individual activity or task which has the usual characteristics of duration, start date, resource requirements, etc. A multi-project program may contain ten, a hundred or a thousand projects. The basic unit of the program is no longer the activity or task but each self-contained project. Where necessary, the project may be subdivided into activities, but for most purposes each single project is treated as a component part of the overall program. The concept, then, of running a multi-project program is to effectively plan and control each project within certain specific guidelines. In a multi-project environment, construction or operations manager of a contractor does not want to have too few resources, because the work will not get done on time and the clients will go elsewhere. Likewise, a manager generally cannot afford to have "too much" of resources, because the cost of idle time cuts directly into profit.

Figure 1 shows the influence diagram for MPE. The main components are multi-project program schedule, management issues, business strategies, decision variables that influence the quality of decision, project objectives, constraints and uncertainties. Program schedule is persuaded directly or indirectly by all other components. So from the business point of view, to optimize multi-project environment it is essential to address and manage properly all of the above-mentioned factors.

4.2 Conceptual Framework

Figure 2 illustrates the conceptual framework behind developing the model called optimization of multi-project environment (OPMPE). It has four parts – input data (multi-project program, company strategy), simulator, theoretical basis, model development (phase 1) and model validation (phase 2). The simulation model is developed using the Simphony.NET (Mohamed and AbouRizk, 2005) environment, an object-oriented programming language, suitable for discrete event simulation.

Expert's opinion are tallied and incorporated during phase 1 of model development. The model then simulate the progress of multiple projects of different stages e.g. some of them are running, some are waiting and other may be in bidding stage. The user will use input data i.e. program schedule (including start and end date of the project, duration and resources required for each work packages), company capacity, resource pool available, project delivery system, project priority, project driven factor, etc and generate results. It will have the capability to analyze the MPE system using the logic setup (theoretical basis) into it and can predict accurately any kind of conflicts and calculate the impacts that may occur in future, alerts the managers in advance in case of resource crisis or other problems. Heuristics rules are used for prioritizing the projects for allocating resources while asking by the multiple projects at the same time. These results then be integrated with the project schedules for continuous refinement and adjustment and finally ensure optimum solution for scheduling and resource planning. It is expected to consider several techniques to optimize the system - Decision theory (Taha, 1997), Dynamic Programming (Rao, 1984), Stochastic Decision Trees (Moussa et al, 2006), and Markov Process (Jacob, 2005) where applicable.

4.3 Optimization Theory

Optimization theory is a mathematical technique for determining the most suitable or least disadvantageous choice out of a set of alternatives. Typically the set of alternatives is restricted by several constraints. Optimization theory is the more modern term for operation research.

4.3.1 Decision Theory

"Decision theory" is one of the stochastic operation research tools that can be used to assist management in making decisions under certainty, risk or uncertainty (Taha, 1997).

Suppose, a_i = represents action i; s_j = represents state of nature j ; $v(a_i, s_j)$ = payoff or outcome associated with action a_i and states s_j, then the best alternative is,

$$\max_{a_i} \{\min_{s_j} v(a_i, s_j)\} \text{ , if } v(a_i, s_j) \text{ is gain}$$

$$\text{Or, } \min_{a_i} \{\text{mix}_{s_j} v(a_i, s_j)\} \text{ , if } v(a_i, s_j) \text{ is loss}$$

4.3.2 Dynamic Programming

"Dynamic programming" determines the optimum solution to an n-variable problem by decomposing it into n stages with each stage comprising a single variable subproblem (Rao, 1984).

Let $f_i(x_i)$ be the shortest distance to node x_i at stage I, and define $d(x_{i-1},x_i)$ as the distance from node x_{i-1} to node x_i, then f_i is computed from f_{i-1} using the following recursive equation:

$$f_i(x_i) = \min. \{ d(x_{i-1},x_i) + f_{i-1}(x_{i-1})\}, I = 1, 2, 3$$

all feasible, (x_{i-1}, x_i) routes

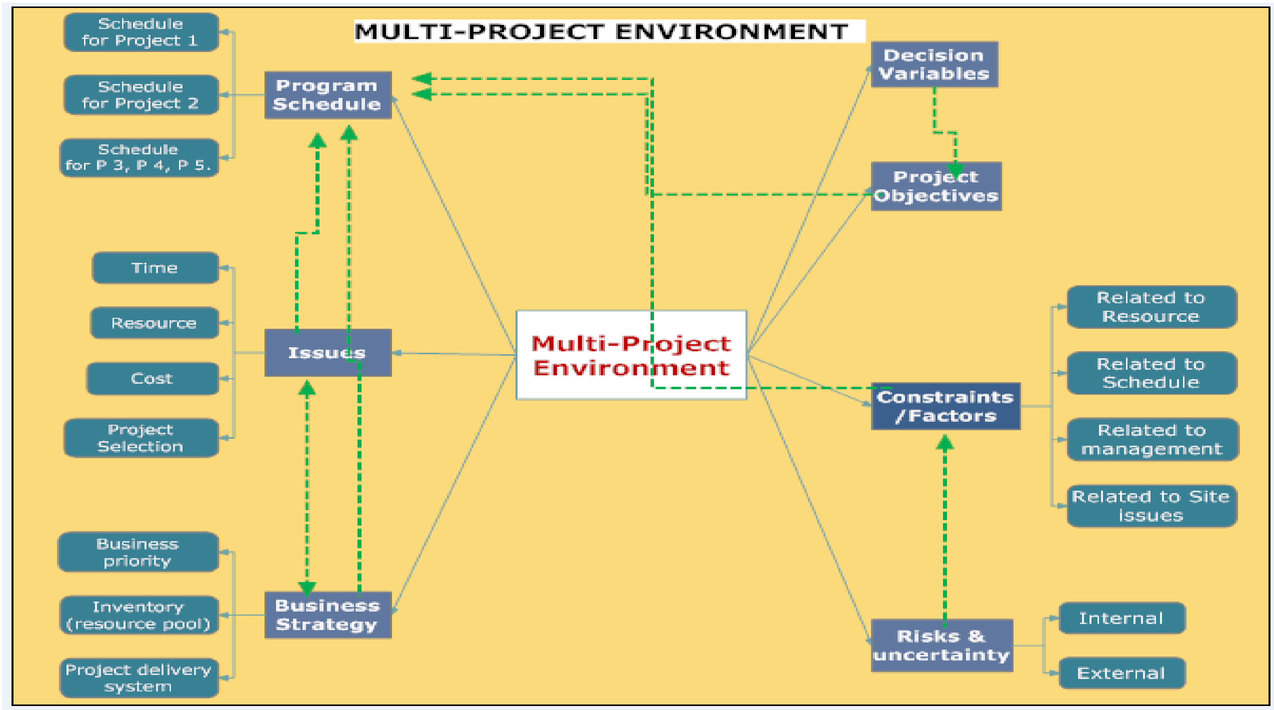

Figure 1: Multi-project environment

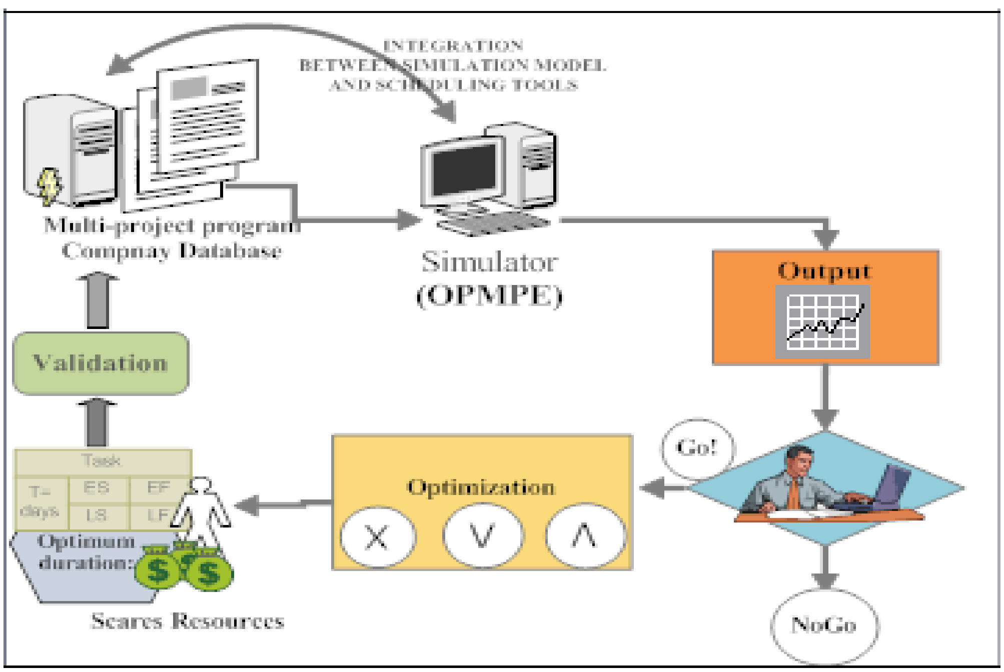

Figure 2: Conceptual framework for developing OPMPE

4.3.3 Markov Process

The occurrence of a future state in a Markov process depends on the immediately preceding state and only on it. If $t_0 < t_1 < \ldots. T_n$ (n = 0, 1, 2, ….) represents points in time, the family of random variables $\{€_{tn}\}$ is a Markov process if it possesses the following Markovian property (Jacob, 2005):

$$P\{€_{tn} = x_n \mid \{€_{tn-1} = x_{n-1}, \ldots. €_{t0} = x_0\} = P\{€_{tn} = x_n \mid \{€_{tn-1} = x_{n-1}\}$$

for all possible values of $€_{t0}, €_{t1}, \ldots\ldots, €_{tn}$

The probability $P_{xn-1,\, xn} = P\{€_{tn} = x_n \mid \{€_{tn-1} = x_{n-1}\}$ is called transition probability. It represents the conditional probability of the system behind in x_n at t_n, given it was in x_{n-1} at t_{n-1}. The probability also referred to as the one-step transition because it describes the system between t_{n-1} and t_n. An m-step transition probability is thus defined by

$$P_{x,\, xn+m} = P\{€_{tn+m} = x_{n+m} \mid €_{tn} = x_n\}$$

4.4 Heuristics Rules and Usage of Resources

When more than one project will demand for a particular scares resource at the same time, then the resource would be allocated to them sequentially according to the following combination of priority rules to break ties:

1. Minimum slack first
2. Most resources first – the assumption behind this assumption is that more important project usually place a higher demand on scares resources.
3. Shortest work package first
4. Most critical followers first

Figure 3 displays the sources and uses of resources in a multi-project environment. The stock of resources or availability of resources is calculated as,

$$R_{av} = R_i + R_c$$

Where, R_{av} = available resource
R_i = inventory, and
R_c = released by the contributor

5 RESEARCH METHODOLOGY

Overall research methodology can be divided into two phases. There are three steps in phase 1 that are followed during this research. These are: (1) literature review in the areas of scheduling, resource planning, concept of multi-project management, productivity and simulation. Main focus was to notice the findings of the previous researchers in the relevant field; (2) monitored multi-storied building construction sites for six months to study work schedule, resource allocation and registered risks and uncertainties at construction sites. During this time a pilot questionnaire survey is performed with both site superintendent and office management people to validate the survey tools and quality of data and (3) developed an initial conceptual framework and then coded and programmed the simulation model.

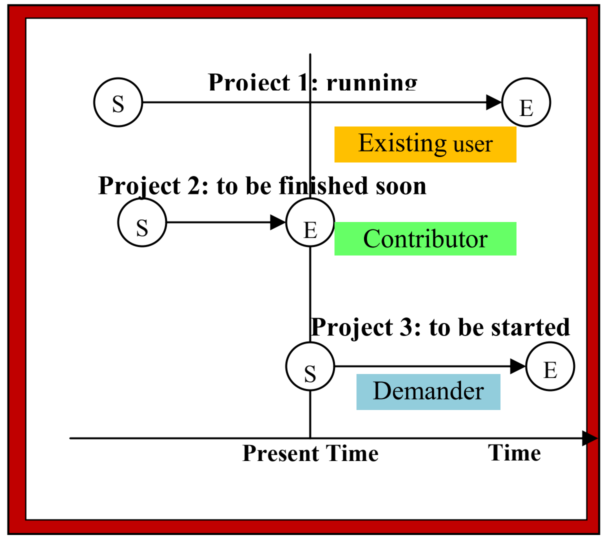

Figure 3: Sources and uses of resources

In phase 2, there are five steps that followed the above-mentioned steps. Those are: (1) to investigate current practice in construction industry by document analysis (case studies, reports from completed projects) and a series of meeting with expert personnel both in site office and head office; (2) data (that are collected using questionnaire from site superintendents to management people in the area of questions) were analyzed using statistical analysis tool "SPSS" ver. 13.0 (Statistical Package for the Social Science) and based on the findings the multi-level and integrated simulation model were developed; (3) For the validation purpose of the model, the simulation results were compared with the actual project data. Sensitivity analyses were performed using "Premier Solver" to identify most significant factors or constraints of the system; (4) the model then applied in real projects to see how it works. Results were analyzed and checked if further experiments are required; and finally (5) documented the conceptual model, description of the computer program and the study results and its interpretation.

6 STRUCTURE OF THE SIMULATION MODEL

The planning and execution simulation model presented in this paper is a special-purpose simulation (SPS) tool that is used to optimize a multi-project environment focusing on company resources, program schedules, uncertainties and business strategies. The simulation model is developed using Simphony.NET and integrated with Microsoft Access (database) and Primavera (scheduling tools). It has total 10 modeling elements in three different levels. These are global/root element, Data base, Program, Output, and Project start, Work package, Link, Project finish, Constraints, uncertainty. Figure 4 illustrates the layout of the model and the hierarchical structure of modeling elements. It operates with Windows XP with Microsoft.NET framework 2.0 or above. The model allows user to import/export data from/to MS Excel, Primavera,.

The global element is to guide the entity among the modeling elements as and when required and also collect statistics and output from any modeling element at any stage during simulation run. Table 1 describes the Output, input and statistics of global element whereas Table 2, 3 and 4 display for the modeling element of Data base, Program and Output respectively. The input/output for other modeling elements are illustrated in Table 5, 6, 7, 8, 9 & 10.

The users can change or modify the input parameters for any modeling element specific to the company and project. The output parameters and the statistics are the valuable information generated by the simulation model. The users can retrieve different type of output and statistics value from different modeling element.

Table 1: Output, input and statistics for global element

MPSM_Root(2) Properties

Outputs	
Program_Duration	0
Parameters	
BType	Construction Management
CoName	ABC Construction Services
NumProjects	10
Res_total_CM	4
Res_total_EMC	10
Res_total_FEN	20
Res_total_FM	15
Res_total_MAN	***Compnay Resource Pool**
Res_total_PC	15
Res_total_PM	13
Res_total_S	15
Res_total_SPM	5
Res_total_SS	6
Statistics	
Program_Duration	**Statistic**
Res_Res_CM_QueueLength	**Statistic**
Res_Res_CM_Utilization	**Statistic**
Res_Res_CM_WaitingTime	**Statistic**

Res_total_MAN
*****COMPANY OWNED RESOURCE POOL*****

Table 2: Input parameters for database element

Data_Base(65) Properties

Parameters	
Stgy1_MPE_Prob	Resource management
Stgy2_Decision_Var	Overall company profit
Stgy3_Prj_Obj	minimizing uncertainty
Stgy4_Prj_Selec	Selec. of right project in right time
Stgy5_Site_Issue	Flexibility in Schedule

Stgy1_MPE_Prob
Highest priority MPE problem

Table 3: Output, input and statistics for Program

Program(40) Properties

Outputs	
ProComplete	0
Parameters	
NoPrjPlanning	10
ScheduleImported	Primavera
ScheduleType	Level 2
Statistics	
ProComplete	**Statistic**

ScheduleType
Type of Sceduled considered

Table 4: Output for "Output" element

Out_Put(39) Properties

Outputs	
FinalPrgDuration	1215
NoNEWProjects	3
NoPrjDeferred	1
NumberConflicts	5
OrgPrgDuration	1120
OverallPrgDelay	95
ResAvaiNow	6
SlippedPrjID	P003

SlippedPrjID
Id of project that has slipped

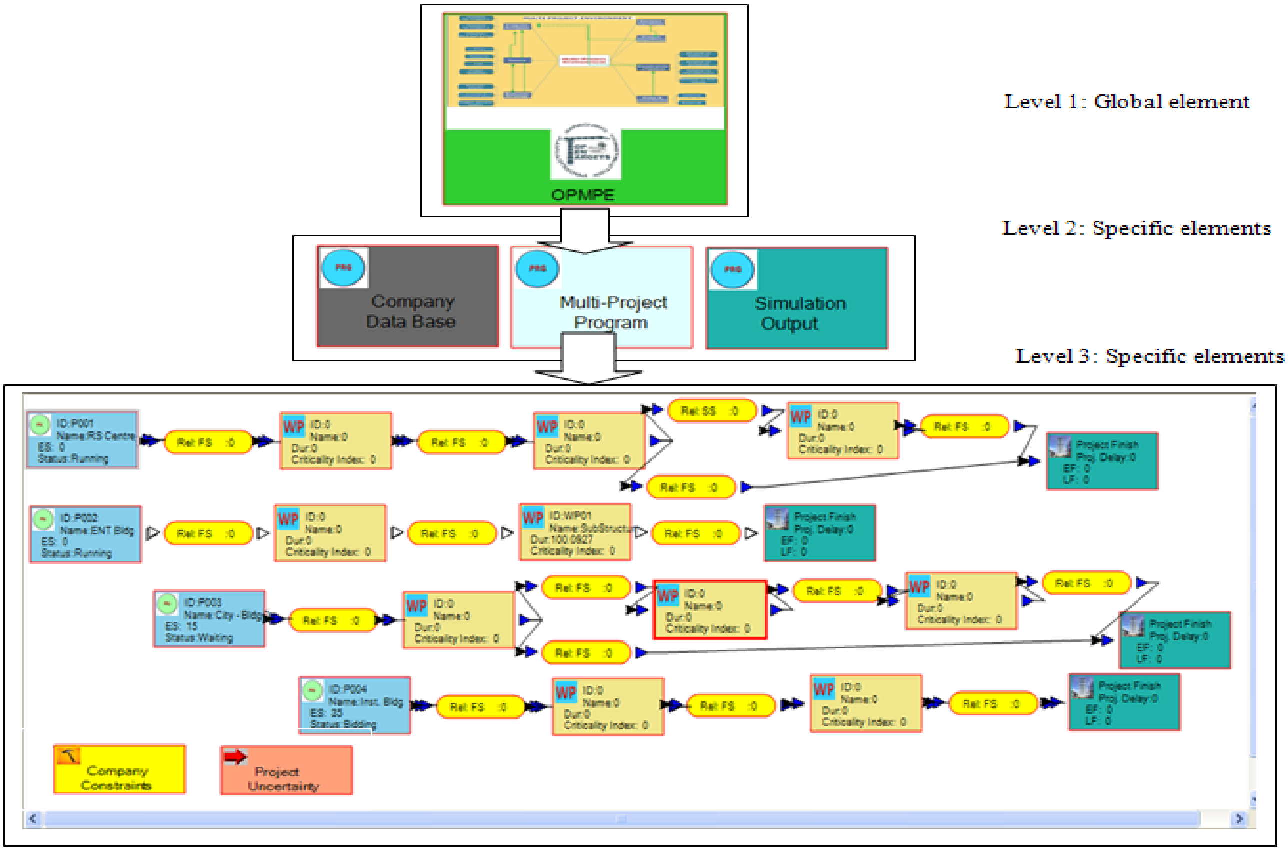

Figure 4: Model layout with hierarchical structure

Table 5: Input parameters for project Start element

Project_Start(44) Properties

Parameters	
1ES	15
PrjDeliverySystem	Design Build
PrjDrivenFactor	Performance
PrjID	P001
PrjLocation	Calgary
PrjName	City Bldg
PrjPhase	Waiting
PrjPriority	High
PrjSize	Very Large

PrjDrivenFactor
Driven factor of the project

Table 6: input parameters for link element

Link(55) Properties

Parameters	
LeadLag	**Triangular(5, 6, 8)**
(DistType)	**Triangular**
1:Low	5
2:Mode	6
3:High	8
RelType	SS

RelType
Relation Type

Table 7: Output, input & statistics for WP element

WorkPackage(65) Properties	
⊞ **Outputs**	
⊟ **Parameters**	
⊟ Dur	**Uniform(90, 105)**
(DistType)	**Uniform**
1:Low	90
2:High	105
Output_MAN	In Number?
Res_WP_MAN	In Number?
RR_WP_CM	1
RR_WP_EMC	1
RR_WP_FEN	2
RR_WP_FM	1
RR_WP_PC	2
RR_WP_PM	1
RR_WP_S	2
RR_WP_SPM	1
RR_WP_SS	1
WPName	**SubStructure**
WPNum	**WP01**
⊟ **Statistics**	
⊞ 1ES	**Statistic**
⊞ 2EF	**Statistic**
⊞ 3LS	**Statistic**
⊞ 4LF	**Statistic**

Res_WP_MAN
*****INPUT for MANPOWER Requirement*****

Table 8: Output & statistics for project Finish element

Project_Finish(38) Properties	
4LF	487.5
Delay	37.5
⊟ **Statistics**	
⊞ 4LF	**Statistic**

Delay
Project Delay
Numeric [-1.79769313486232E+308, 1.79769...

Table 9: Input parameters for constraint element

Constraint(42) Properties	
⊟ **Parameters**	
Const1_Impact	0
Const1_Name	Sharing of resources
Const2_Impact	50
Const2_Name	Inventory limit
Const3_Impact	2
Const3_Name	Limit. of Partial allocation
Const4_Impact	7
Const4_Name	Change Order
Const5_Impact	3
Const5_Name	Technical constraint

Const4_Name
Description of Constraint 4

Table 10: Input parameters for uncertainty element

Uncertainty(43) Properties	
⊟ **Parameters**	
Uncert1_Impact	0.3
Uncert1_Name	Unknown soil
Uncert2_Impact	0.6
Uncert2_Name	Labour absentism
Uncert3_Impact	0.2
Uncert3_Name	Change of Driven factor
Uncert4_Impact	0.5
Uncert4_Name	Shortage of resources
Uncert5_Impact	0.1
Uncert5_Name	Emergency issue arrise

Uncert3_Name
Description of Uncertainty3

7 ANALYSIS OF SIMULATION OUTPUT

The simulation model has been tested using "level-2" Primavera schedule (as shown in Figure 5) from real project data for a series of building projects undertaken by a large construction company in Alberta. There are ten projects, out of which one project just completed, four are running, two projects are waiting to start and the remaining two are in bidding stage.

These scheduling data are used as one of the input value for running the simulation. The other input parameters are company resource pool, logical relationships of work packages within the project, interdependencies of multiple projects and various project properties. Types of project properties are (i) Project delivery system, (ii) Project driven factor, (iii) Location, (iv) Project phase, (v) Project priority, and (vi) Project size

The main intention is to analyze multi-project environment based on above-mentioned input data and generate simulation output.

7.1 Application of the Model

During simulation run, the following important alerts and messages about conflicts are generated (Figure 6) that reflects the actual situation of the multi-project program.

The first and second messages (Figure 6) are indicating that construction manager (CM) and project coordinator (PC) are not available at this moment for the project ID # P003 and subsequent recommendation (third message in Figure 6) is "NOT to start the project now" to avoid project slippage. The last message in figure 5 is showing that the expected project delay is about 90 (LF = 738 days and EF = 648 days) days if this project is started according to the planning date (showing in Figure 5)

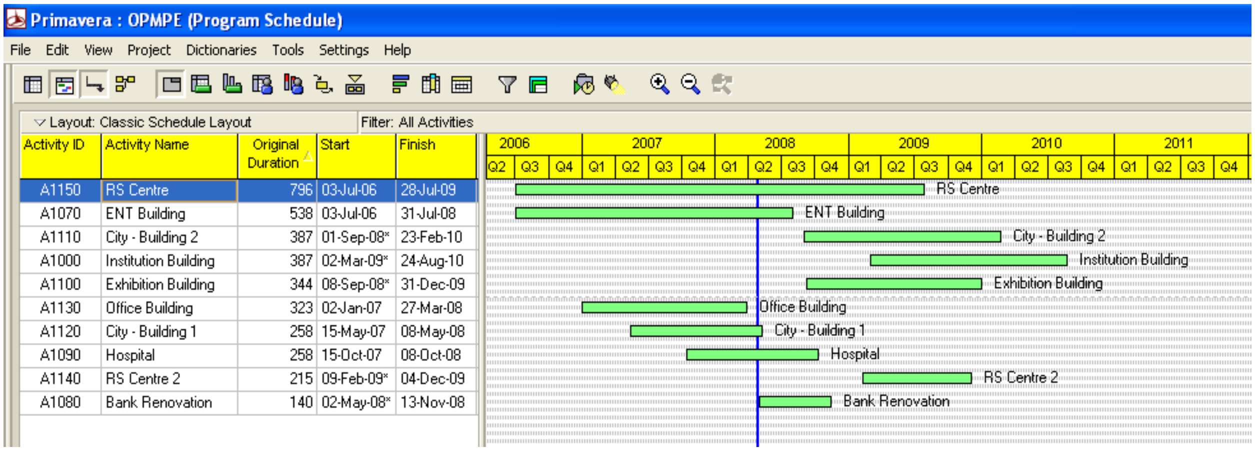

Figure 5: Multi-project program schedule using Primavera

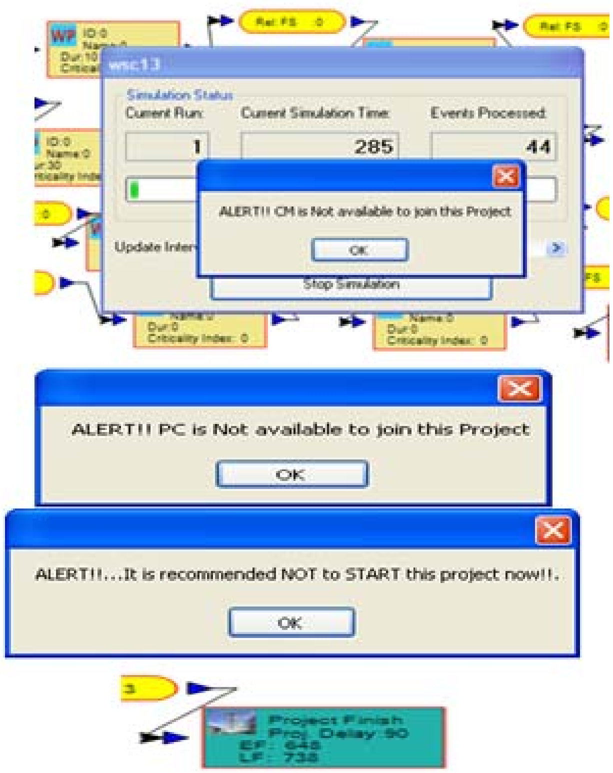

Figure 6: Message alerts about conflicts

The model also generates various kinds of important statistics that will help the decision maker to make quick and right decisions. Figures 7 and 8 illustrate two different statistics collected from three different modeling elements. Figure 7 is showing the overall program completion time in days. Likewise Figure 8 displays the resource utilization graph for one of the resources, collected from a work package element.

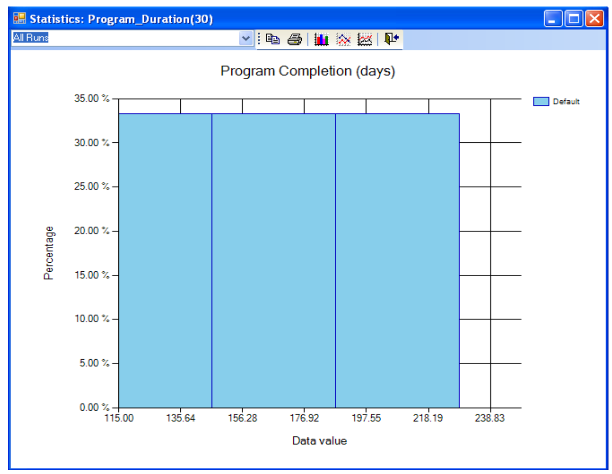

Figure 7: Statistics about program completion time

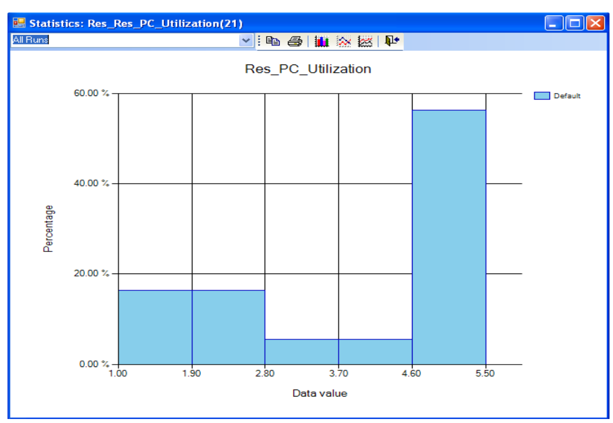

Figure 8: Statistics about resource utilization

8 CONCLUSION AND FUTURE WORK

This paper introduces and describes a framework and SPS tool for optimizing multi-project environment for a construction company. The model is composed of a number of modeling elements, each of which is designed and programmed to analyze some specific area/key issue of MPE. These issues are scarce resources, program schedule, business strategy, constraints and uncertainties. It is capable of fulfilling the key objectives of the study such as identifying resource and schedule conflicts, overall program completion time considering conflicts and delays, calculating the quantity of resource deficiency, estimating the expected delay time, points of conflict, percentage of resources utilization and finally suggestions for senior management when to start a new project to avoid project slippage. Ultimately this tool will provide a means of reducing the waste of idle time of resources, minimizing the uncertainty and help to prepare an optimization plan during planning phase. It can also be used during construction phase to monitor the project status and help in quick decision-making. The model can be used for any number of projects occurring simultaneously regardless of project size, nature and type of resources, project delivery system and other business strategies and constraints. Recommendations for future that are under development include:

- Further enhancement of the simulation model by integrating VB.NET interface
- Full integration and embedding of simulation model with three independent software – MS Access, Primavera P6 and Genetic Algorithm based optimization tool

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