# 2006-1847: MODELING AND SIMULATION: A NEW FRONTIER FOR PROJECT CONTROLS EDUCATION

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Stephen has spent the past nine years creating, developing, and implementing new concepts, systems, and solutions for complex problems facing the construction industry and its constituent companies. Working in both academic and commercial settings, he has successfully formulated and managed numerous initiatives to improve the financial and operational performance of several companies through the projects and programs which they execute. In particular, Stephen has developed a number of new techniques and management practices for repetitive building programs. He has specific program management experience in numerous arenas, from retail store rollout and low-income housing to large industrial and infrastructure projects.

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# Modeling and Simulation: A New Frontier for Project Controls Education

The successful management of construction and engineering projects depends upon effective monitoring and control. As a result, project controls continues to be a primary means used to achieve a wide range of project goals and objectives. Due to its importance, many construction engineering and management (CEM) programs around the world maintain several project controls courses such as time control, cost control, and quality control. Given this background, this paper presents a new frontier for project controls education through the use of modeling and simulation software.

The drawbacks of contemporary project controls education are twofold. First, project controls-based decision-making is premised on static quantities and estimates completed in the past. This requires that new baselines be periodically reestablished as a reforecast. Second, elements of cost control (e.g., chart of accounts), time control (e.g., critical path method schedules), and quality control (e.g., statistical process control) commonly function as disparate entities. This situation exists largely because integration depends on resource continuity; something that the critical path method cannot ensure.

Recently, project modeling and simulation has been used by the author to demonstrate prospective, integrated project control. Assisted by software originally developed at the Center for Integrated Facility Engineering (CIFE) at Stanford University and commercialized as ePM's SimVision®, specific projects were modeled concurrent with the resources necessary for their execution. Given this form of resource continuity, real-time forecasts of time, cost, and quality parameters were quantified based on several "what if" scenarios, thereby presenting modeling and simulation as a compelling platform for project control.

Through several case studies, this paper validates the use of modeling and simulation as an integrated medium for project controls education. It also demonstrates the advantage that an intuitive interface can provide to an engineering student; one which graphically and prospectively depicts the integration between resources, time, cost, and quality. In such an environment, students are able to comprehend project controls information and develop a feel for the impact which certain decisions have on project goals and objectives, thus creating knowledge. While additional research regarding the use of modeling and simulation in project controls is underway, the findings contained herein point towards a larger role for its use in future projects and engineering education.

## *Introduction*

Aspects of the project management function such as planning, control and monitoring require the integration of time, cost, and quantity of work with available resources. Since the early 1950's, the classical scheduling methods of the Critical Path Method (CPM) and the Project Evaluation and Review Technique (PERT) have been used not only for planning, but also for controlling and monitoring projects. Historically, if the duration of the activities in the network is known, or can be ascertained, CPM has provided the means of calculating the duration for the entire project. On the other hand, if the duration of each activity is probabilistic, the project evaluation and review technique PERT has normally been used to calculate the project's overall duration. Either way, "schedules produced by these conventional methods often turn out to be unsatisfactory and eventually little use to real-world project planners[1]." Undeniably, being task-based rather than resource based, "CPM and PERT preclude flexibility in resource allocations – generating schedules, which utilize resources in a less efficient way[1]." As Fendley[2] has pointed out, the classical scheduling methods are handicapped by the following assumptions:

- *Deterministic performance time*. Since the performance times of the activities are actually uncertain, the sequencing of the individual activities must be handled on a dynamic basis. When a conflict arises between two or more activities requiring the same resources, a resource allocation process must occur. A typical result is that one activity is allocated the resource in demand and the other activities must wait their turn for use of that resource[1].
- *Single project operations*. Despite the fact that scheduling problems arise from limited time and scarce resources that are normally shared with multiple projects, most of the past research has been conducted as if each project stood in isolation.
- *Splitting activities*. The objective of scheduling is not only meeting a single goal directly related to a particular activity, but also satisfying many goals that originate from decisions made regarding other activities.
- *Unconstrained resources*. The use of CPM and PERT is based upon the implicit assumption that unlimited resources are available for assignment to the project at hand. While the assumption may be justified in some cases, most project managers are faced with the problem of limited resources, causing the conventional analyses to be modified through various imperfect heuristics and algorithms.

Due to the deficiencies of the traditional scheduling approaches, many researchers began to examine methods of integrating organizational resources with project schedules in order to make the schedules more useful. Where similar projects were executed as part of a larger program, repetitive scheduling methods (RSM) such as line of balance (LOB)[3] and velocity diagrams[4] were proposed. These scheduling methods have been known to contribute to cost and time efficiencies, especially where standardization of design permits construction to proceed in a repetitive fashion. This is because activities that repeat from project to project create a need for a schedule that facilitates the uninterrupted flow of resources from one project to the next. However, the main reason for the use of repetitive scheduling methods is that the traditional methods such as CPM and PERT are ineffective for scheduling repetitive projects, mostly because they do not ensure resource continuity. By assuming that only the most significant resource will be used for like activities in successive repeating units, RSM is not able to account for varying production rates and resource discontinuities[5]. Nonetheless, project controls practice and education has continued to rely upon these imperfect scheduling methods by developing implementation schemes to cope with their inherent weaknesses.

***Implementing Project Controls***

In the classical project control and monitoring process, project objectives are assumed to be fixed and means for achieving those objectives to be variable only as needed to recover from failure to conform performance to the original plan[6]. Effectively, this means that project controls-based decision-making is premised on static quantities and estimates completed in the past. This requires that new baselines be periodically reestablished as a reforecast according to the process illustrated in Figure 1.

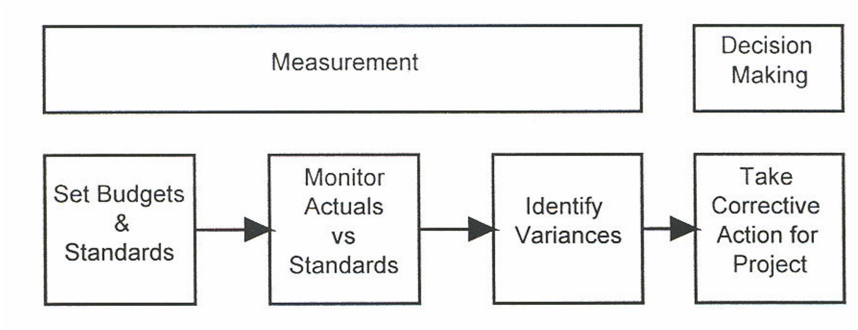


**Figure 1. Classical Control and Monitoring Process[6].**

The classical project controls model is often described in terms of the so-called "thermostat" model, in which the decision to take corrective action to bring performance into alignment with a pre-set standard is automatic[6]. This rarely occurs because the pre-set standard is generally established using accelerated productivity rates maintained within corporate databases. While these types of databases are common to many construction firms, most cannot delineate the effects of changes in technology, materials or regulations (i.e., safety) over time, nor guarantee that data were not intentionally misreported.

To prevent this possibility, the skill and experience of project controls personnel is often required to weigh the cost of adding resources with the benefit of reducing project duration. Doing so is an iterative process generally accomplished using by trial and error method using resource leveling functionality inherent in today's CPM software. However, if these changes are completed incorrectly, the process of identifying variances between actual and standard levels of achievement can lead to decisions which diminish performance even more. For these reasons, the classical project control and monitoring process is inadequate for controlling today's quick, uncertain and complex projects. Moreover, it is entirely too unwieldy to explain and instruct to students with little practical experience with project controls and related CPM or PERT software.

Recently, the development of modeling and simulation software has highlighted the need to gain an overall, holistic and systemic view of project controls. As a result, there has recently occurred a surge of interest in the project management community regarding continuous system simulation. This form of simulation presents a very useful mechanism for modeling, analyzing, and synthesizing operations with other aspects of the business. However, its use is a departure from the long-standing precedent of employing discrete-event simulation on projects which never really gained widespread use in the projects industry. Largely, this was because "existing implementations did not represent many of the relevant characteristics of project components or resources and because it is tedious to collect and assemble the required input data necessary for these simulation networks[7]." Plus, simulation for project control is really more about helping managers to see a little way into the future and make decisions that affect where the project is headed and less about automating decision-making. This makes the implementation of continuous system simulation for project control increasingly viable by enabling the evaluation of project performance to be made against process capability instead of against inaccurate historical benchmarks. Facilitating such an implementation depends upon intuitive and simple graphical interfaces, something the latest software possesses.

***Project Modeling and Simulation***

In the early 1970's, Galbraith[8] observed how project managers could become burdened by large numbers of 'exceptions' (i.e., non-routine situations in which workers lacked the information to proceed, thus requiring assistance from their managers). Since then, Galbraith's view of organizations has advanced theories of organizational design, becoming a prime motivator for the development of modeling and simulation technology for project control[9]. Based on his findings, subsequent research conducted at the Center for Integrated Facility Engineering (CIFE) at Stanford University confirmed the need to model organizations working on interacting projects so that aggregate performance predictions could be generated[9].

Today, this research has been commercialized by the Vité Corporation and ePM, LLC as the multi-faceted software known as SimVision®. This software is capable of taking a unique look at project execution by tying the allocation of resources to activities and then simulating the probability of outcomes. These outcomes include identifying schedule pressure, rework, decision-wait, work backlog, and quality risk, to name a few. A sample SimVision® model and related project control predictions can be seen in Figure 2.

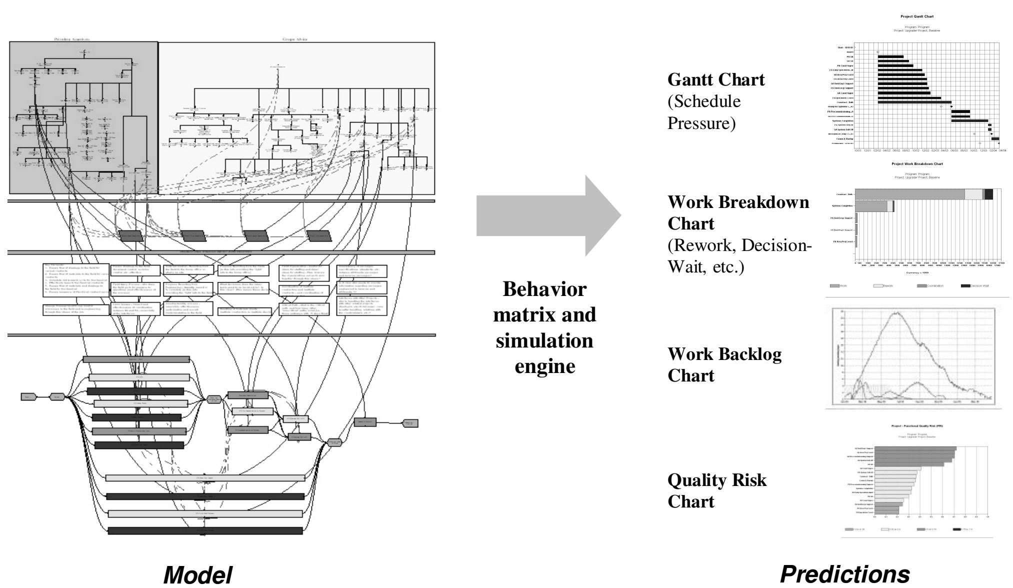


**Figure 2. SimVision® Modeling and Simulation[10].**

In late 2003, the author was engaged by a U.S.-based energy company to perform a schedule forecast and analysis for the engineering, procurement, and construction of a large scale petroleum project off the shore of China. This $3 Billion project was comprised primarily of several subprojects such as a floating production storage and offloading (FPSO) facility, numerous jacketed wellhead platforms (WP), a central processing complex (CPC), sub-sea pipelines, tanker moorings, and various transport activities. Of these subprojects, the FPSO facility was particularly complex given that its hull and topsides were to be designed and fabricated by separate companies on different continents. In addition, the U.S.-based energy company was partnered with an international petroleum firm and had recently hired a global engineering, procurement, and construction (EPC) contractor.

ePM's SimVision® software was used to create the model shown in Figure 3. The model ties individual managers to subprojects via lines of responsibility (i.e., shown in grey). Notably, all the organizations involved in the venture are shown (i.e., from left; owner, partner, contractor, and subcontractor organizations). Precedence relationships between the subprojects are shown as dark, solid lines. Paths for rework and coordination are displayed as dark, dashed lines in cases where exceptions might occur.

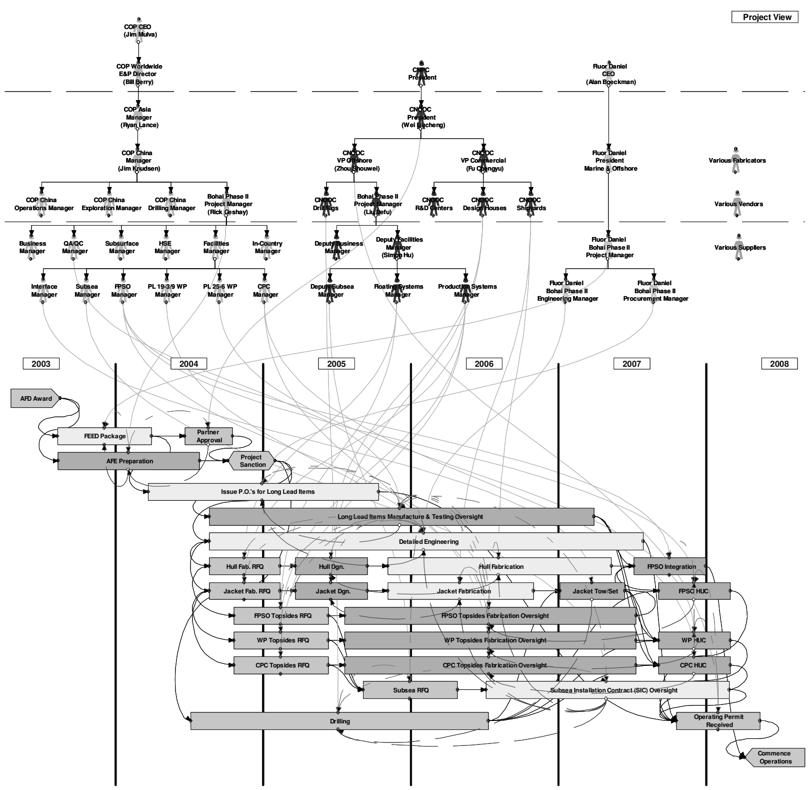


**Figure 3. Example Project SimVision® Model.**

The resulting simulation output is shown as a Gantt chart in Figure 4. The simulation forecasts which subprojects are likely to be critical based on their resource utilization, precedence, and likelihood for exception occurrence. In Figure 4, critical subprojects are shown in dark grey and represent 55% of all subprojects planned for execution. Here, the simulation output also identifies the revised completion date in comparison with the expected date generated separately using critical path method (CPM) software. In this case, a final project completion date 11 months past the planned completion date was anticipated.

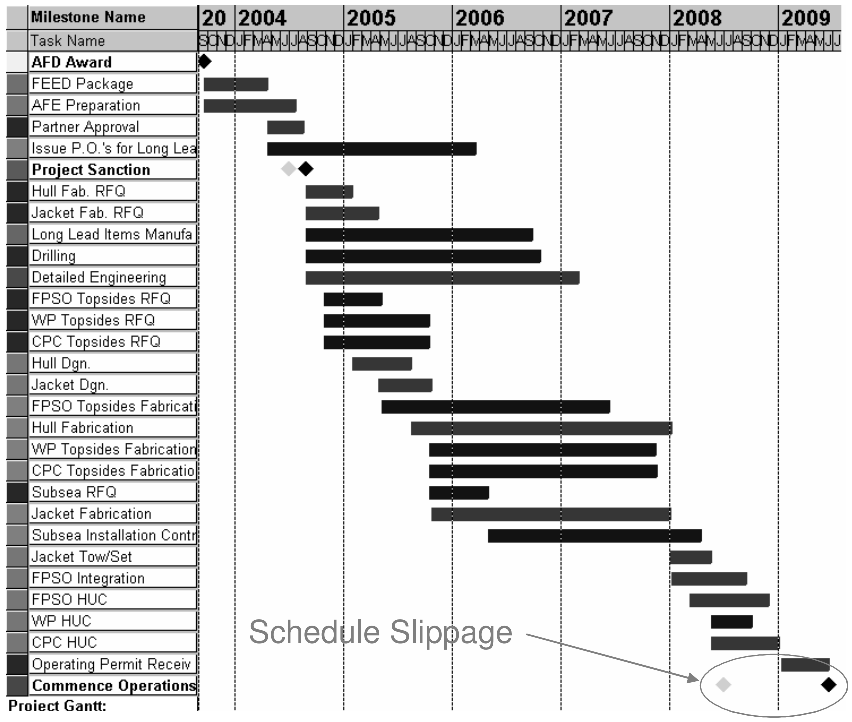


**Figure 4. Example Project SimVision® Simulation**

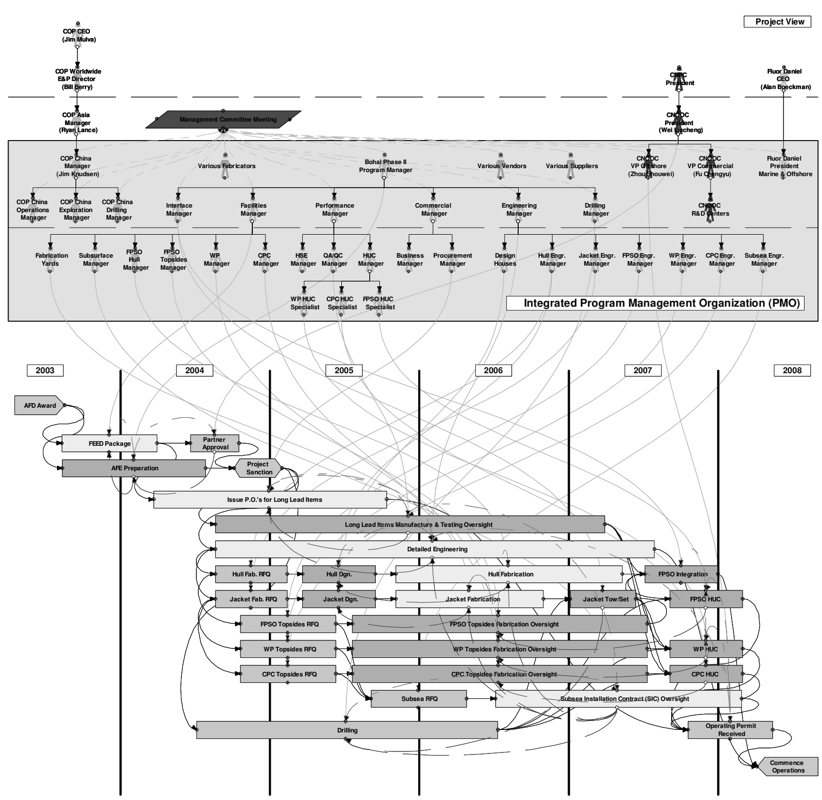


**Figure 5. Revised Example Project SimVision® Model.**

To bring the project back in alignment with planned milestones, the author developed several alternate execution scenarios. Some of these scenarios added resources, some aggregated subprojects, and others changed delivery methods. However, the preferred scenario consisted of a program management organization (PMO) taking responsibility for the entire project. The PMO is represented in Figure 5 by the light grey rectangle. The likelihood of exceptions was also reduced by changing the organizational structure within the PMO. Individual managers still retained links to their parent organization, yet their principal reporting lines transferred to new PMO managers. In addition, a monthly coordination meeting (i.e., shown as the grey parallelogram in the organization chart) was installed to keep senior management at the parent firms informed and involved in the program. So, although lines of responsibility changed, the precedence relationships between the projects remained.

The installation of the PMO had the intended effect. Principally, by reducing project overhead and facilitating decision-making, the program's performance improved as can be seen in Figure 6. In fact, the PMO was also forecast to mitigate risk by two primary means. First, the number of critical projects was projected to decrease from 55% to 37%. Second, the PMO changed the program's ability to accommodate systemic risk. As a result, project managers changed their focus from planning to actual deliverables such as the integration of the FPSO, its 'hook-up' and commissioning (HUC), as well as the sanctioning of the entire program. Notably, the overall program schedule was forecast to be compressed by two months, or 19.7%.

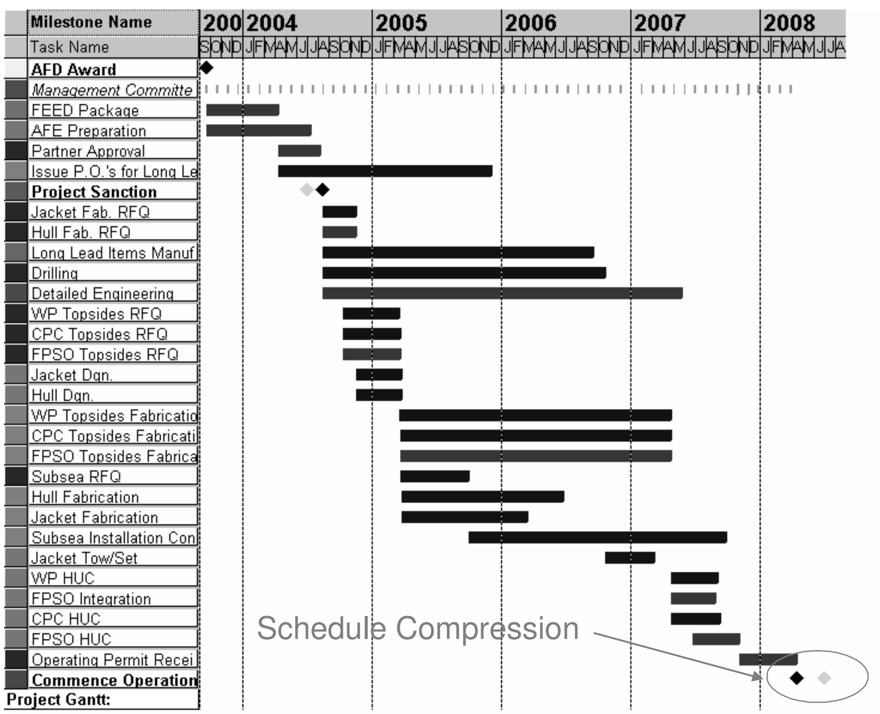


**Figure 6. Revised Example Project SimVision® Simulation.**

For an offshore development project such as the one considered here, the revenues generated from hydrocarbon production are of primary concern. These are depicted in Figure 7. Here, the changes made to the original project model shown in Figure 3 result in a much faster project schedule and realization of revenue. On the left side of Figure 7, this improvement is shown as a solid, increasing line. This line can be compared to its baseline target that is shown as a dashed, increasing line. In fact, the additional revenues from hydrocarbon production were calculated to be a 56.8% increase in the return on capital employed (ROCE) once baseline costs (i.e., the 'horizontal' solid and dashed lines, respectively) were taken into account. This significant result was also accompanied by a forecast of reduced quality, communication, and functional risks as depicted by the SimVision® simulation output shown on the right side of Figure 7.

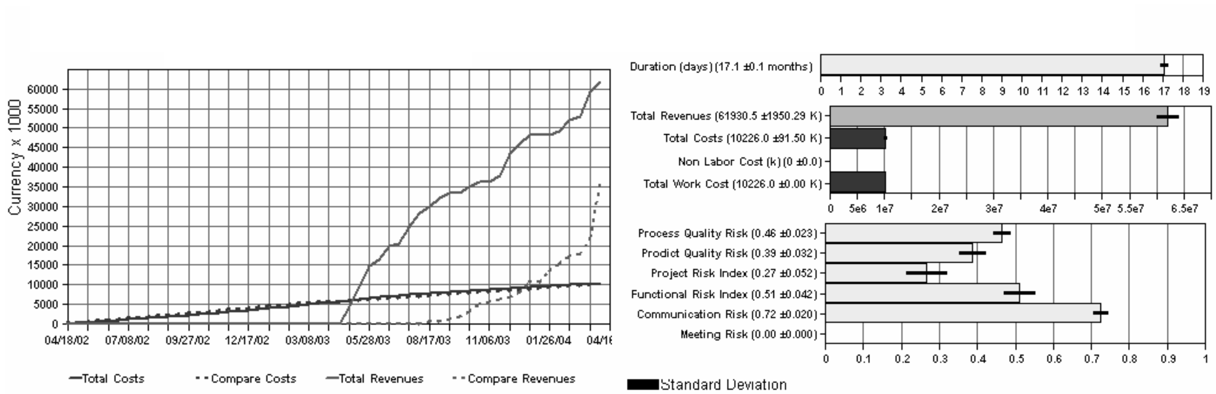


**Figure 7. Revised Example SimVision® Simulated Performance Gains.**

Unlike the implementation of classical project controls based on CPM/PERT, modeling and simulation as presented here integrate elements of cost control, time control, and quality control in a single, prospective application. This is significant because, until now, integration of this type was not possible as resource continuity could not be ensured by traditional methods of project control.

***Importance for Project Controls Education***

Recently, the author has used the SimVision® modeling and simulation software in an undergraduate course in construction project management and scheduling to illustrate the necessary integration of resources, time, and cost for project control. Due to the fact that this software directly depicts both the resources and the activities necessary for project execution, students develop an improved understanding of project control basics, especially where concepts of resource allocation and leveling are concerned.

Students have also planned projects using the SimVision® software by simultaneously designing both the activity precedence relationships and the organizational resources as a model. Typically, they report that the process is simple and intuitive. Certainly, the activity of modeling a project leads to excellent questions being asked by the students about project control and monitoring while in a laboratory setting. Plus, once their simulation is compiled, students receive immediate feedback regarding the potential time and cost impact of their design. This form of feedback allows each student to make adjustments to improve project planning in much the same way as the example used in this paper did. If their model represented an active project at the outset of the course, the students could track its progress as it developed to create revised models based on actual experience. Today, this form of classroom experience is currently taking place using the construction of a single custom residence as an active project.

Through the use of SimVision's® graphical interface, students learn that the evaluation of project performance should be made relative to the capacity of the project's resources. Further, by referencing this capacity to project goals as a model, students gain confidence that they have control of project outcomes instead of merely reporting progress against pre-set standards. This empowers the student to think about how the project could be improved in its implementation and control, rather than just developing a reforecast. Effectively, such a thought process is one of production control and is focused much more on constantly adjusting the activities, their precedence, and their resources to meet or exceed a performance standard. Moreover, such a shift toward production control lessens the "management through contract" phenomenon by making project objectives more achievable. Consequently, such a concept of project controls becomes less about administration and more about design in the student's mind. Indeed, the students typically 'compete' against each other to establish the best organizational and activity design using cost and time performance as benchmarks. To be sure, such 'competition' is necessary for leading-edge education and practice in the discipline of project control and monitoring.

***Conclusions***

The examples of modeling and simulation for project control presented here are analyses of a particular EPC project. As a result, they exist as stand-alone representations of performance and are not integrated within the day-to-day information systems used by project controls personnel. This dichotomy points toward a need to develop project information management systems (PIMS) to aid project controls education and practice. Yet, PIMS creation is an expensive undertaking, one that must be justified via benefit/cost analysis (BCA). One way to accomplish this analysis is through the use of a value tree. In such an application, each branch in the tree reflects the potential outcomes of decisions made as the project progresses. Consequently, one path through the value tree gives the greatest benefit. The trick to obtaining this benefit is to modify the probability of a desirable outcome at each stage in the project. Today, the best means of improving outcome probability is found in forecasts created via modeling and simulation technology. In fact, for the case study presented here, the amount of improvement is calculated to be $1.11 Billion for the project's execution.

Through an in-depth case study, this paper justifies the use of modeling and simulation as an integrated technology for project controls education. It also demonstrates the power of a graphical interface trained on the deployment of resources for a project. This way, project controls focuses more on the forecast of achievement than on its analysis, prospectively depicting the resulting impact on resources, time, cost, and quality. Given such advanced modeling and simulation technology, engineering students are able to develop a better understanding of the need for project controls and their relationship to the attainment of project goals and objectives. Finally, students are able to easily and intuitively evaluate trade-offs that exist on projects between time, cost, and quality. Certainly this type of understanding points towards an increasing role for modeling and simulation in project controls education in the future.

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