Journal of Construction Education
Summer 2003, Vol. 8, No. 2, pp. 101 - 114

1522-8150/01/$5.00/Educational Research Manuscript

Three Success Factors for Simulation Based Construction Education

Moonseo Park, Ph.D., Swee Lean Chan, Ph.D. and Yashada Ingawale-Verma, MA
National University of Singapore
Singapore

Construction education needs to emphasize more on practical knowledge and efficient tools that will enhance the students' thinking, problem solving and interpersonal skills. Simulation has emerged as an important approach to meet this need. However, simulation based tools are greatly under-represented in construction curricula. As an effort to address this issue, three success factors for the implementation of simulation tools are proposed. Their application to construction education is demonstrated through two case studies. With dynamic simulation models developed based on system dynamics, we discuss the effectiveness of the proposed success factors in education for fast-tracking and resource management. The findings obtained from the case studies would provide useful guidelines to the development of simulation tools for construction education.

Key words: Construction education, Simulation, System Dynamics, Tradeoff, Feedback

Introduction

Traditionally, construction education has been carried out with clear demarcation between the education sector and the industry. Universities have provided students with discipline-based education and basic skills, while the industry has trained them into professionals (Gann, 2000). However, this distinction is recently becoming blurred under rapidly changing industry environment. As a result, universities try to provide more practical education (Gibbons et al., 1994), and focus on interdisciplinary research and collaboration with industry participants.

The enhanced mode of educational delivery includes internships, simulation of practice, gaming, case-based instruction, service integration, field trips, student follow-ups and application papers (Senior, 1998; Chinowsky, 1998). Among these, simulation has emerged as an important approach to provide practical construction knowledge. Simulation is the construction of an abstract model that represents systems in the real world (Davies and O'Keefe, 1989). By exposing the student to situations in the real world and allowing repeatable experimentations under controlled conditions, simulation helps to build up students' thinking, problem-solving, reasoning and interpersonal skills (Chinowsky, 1998; Banks et al., 2000; Burr, 2001). Particularly, in industrial education where the educational goal is for students to transfer and apply the knowledge to real-world problems, the use of simulation in class can be an effective learning strategy (Gokhle, 1996).

Despite the claimed benefits of simulation, there have existed some hindrances to using simulation in education. The educational effectiveness of simulation tools depends on how well they represent real world situations, while keeping their application simple and easy to access.

The complex structure of a simulation tool often makes it difficult for students to understand the concepts intended to deliver (Al-jibouri & Mawdesley, 2001) and the development of such a tool requires enormous efforts in terms of time and resources. Meanwhile, the high level of assumptions in simplified simulation tools can be detrimental to the understanding of the real construction process (Senior, 1998), which may misguide students, failing to achieve the target educational goals. Particularly, the exclusion of human factors that significantly influence the construction process can result in less realistic simulation and limited educational effect (Park, 2001). In addition, the development of simulation tools has not kept pace with the development of computer technologies. As a result, many simulation tools are still text-based, whilst most computer application programs have moved to a graphical user interface (Al-jibouri & Mawdesley, 2001). In the case of some state-of-art simulation tools, they run on a specific platform, which makes students' access to them limited.

As an effort to address these issues, we propose the following three success factors for the development of simulation based construction education tools:

- Considering human factors involved in the construction process and feedback effects triggered by them,
- Focusing on tradeoffs associated with managerial decisions and construction policies, and
- Developing an easy-to-use standalone tool that runs on any platform without other supporting programs.

The application of these success factors to construction education is demonstrated through two case studies presented in this paper. With dynamic simulation models that have been developed based on system dynamics, we discuss the effectiveness of the proposed success factors in education for fast-tracking and resource management. The findings obtained from the case studies would provide useful guidelines to the development of simulation tools for construction education. Following a brief introduction of previous simulation education tools and system dynamics, case studies are presented.

Simulation based Construction Education Tools

Many simulation based construction education tools have been developed targeting either university students or industry professionals. Some examples categorized by their application areas are listed below.

Estimating

Caldwell (1991) developed TAKEOFF, which is an interactive Quick BASIC program that can be used to educate calculation and estimation skills in quantity surveying. With this tool and given a random set of dimensions for building components, the student can practice taking-off and have a feel of what the estimator in a construction firm does. Computer Aided Drafting and Design (CADD) interactive systems also provide educational estimating software (Wallace, et al., 1990). One example is Estimator (DATACAD LLC., 1984-2003). By using this tool, students can perform quantity take-off and price the item out for a given sample of construction data.

Bidding

A simulation game developed by Nassar (2002) allows users to explore the bidding process. By providing a tool to analyze the bid prices of the competing teams, it improves the ability to develop a bidding strategy. A networked classroom computer system that can simulate the construction bid process was presented by Mead (1995). This system focuses on helping students to understand how construction teams work during the bidding process. By simulating the process of collecting bids from sub-contractors and suppliers, and analyzing them, students experience how work is delegated and managed by project team members during bid preparation.

Construction Process Management

Al-jibouri and Mawdesley (2001) developed a simulation game to teach the planning and control of a rock and clay fill dam construction project. Having equipped with a graphical user interface (GUI) and the Internet hookup, this game helps user to experience situations encountered during dam construction. Game participants act as different role players. The educator sets simulation conditions for the contractor’s office, and the student acts as the project manager whose actions are responsible for the project performance.

Equipment Management

Nassar (2002) developed a multi-player EQUIPEMNT REPLACEMENT simulation game. It aims to assist students in understanding the effect of equipment buy/sell strategies on the operation of contractor firms.

Evaluating

A simulation tool that can be used for educating the external review of a construction firm's financial condition was developed by Perreault (1989). With the provision of this tool, he suggested that financial audits should be included in construction management curricula.

System Dynamics

Since its development in the late 1950s, system dynamics has been applied to analyze industrial, economic, social and environmental systems (Richardson, 1985; Turek, 1995). The most powerful feature of system dynamics lies in its analytic capability (Kwak, 1995), which can provide an analytic solution for complex and non-linear systems. Owing to this special feature, a system dynamic modeling approach is well suited to deal with the dynamic complexity of construction projects, as demonstrated by some researchers (Ng et al., 1998; Peña-Mora and Park, 2001).

Education is also an important area of application for system dynamics. In helping to understand how complex systems change over time, system dynamics forces the learner to become actively involved in the education process (SDS, 2003). In particular, the wide range of applications for system dynamics makes it an excellent tool for integrating the material of many subjects in education (SDS, 2003). Models can be constructed from the micro worlds of academic disciplines, and the understanding of their structures and behavior transcends any particular discipline (deSantis, 1999).

Case Studies

The educational tools presented in this section are being used in construction management courses in the Department of Building at the National University of Singapore. These tools have helped students to acquire core educational concepts associated with fast tracking and resource management. To show the usefulness of the proposed success factors for simulation based education, we review their educational objectives and important issues in developing them, focusing on human factors and tradeoffs involved in the construction and decision process. We also demonstrate how they can be used as standalone tools, with which students can manipulate and test policy scenarios without the help of other supporting software and equipment.

Fast-tracking

The fast-tracking delivery method has been widely used for faster project delivery. However, fast tracking often results in unexpected costs and does not necessarily lead to a desired shorter project duration (Fazio et al., 1988). This is mainly attributed to the increased level of uncertainty (Russell et al., 1991) during the design and construction process. The simulation tool presented in this case study (the Dynamic Fast-tracking Simulator; DFTSim) exposes students to uncertain conditions and makes them appreciate the potential effects of feedback processes involved in fast tracking. As a result, with the opportunity to analyze and suggest strategies, students can acquire decision-making skills such as overlapping strategies, workforce control policies, and schedule adjustments that can minimize the negative impacts of fast-tracking.

Feedbacks in Fast-tracking

Fast-tracked construction involves many feedback processes including those depicted in Figure 1. Overlapping between the design and construction increases the possibility of design changes for several reasons, e.g., increased assumptions by the designer and frequent design changes by the owner (Tighe, 1991). Consequently, more construction changes can occur, which result in more work to be done. Construction schedule, however, cannot be simply extended due to time constraints. One possible control action to meet the schedule is to increase work hours, either by hiring more workers or putting them to work overtime. This control action can facilitate the delayed construction process. At the same time, it can result in unanticipated side effects due to vicious feedback processes. Workers newly involved in the construction team may affect the team’s average productivity and adopted overtime may lower productivity by increasing workers’ fatigue (Sterman, 2000). Lowered productivity, then, can further delay the process (R1 in Figure 1). Meanwhile, workers’ fatigue can also deteriorate work quality, which results in more construction changes and a rise in construction costs (R3 in Figure 1).

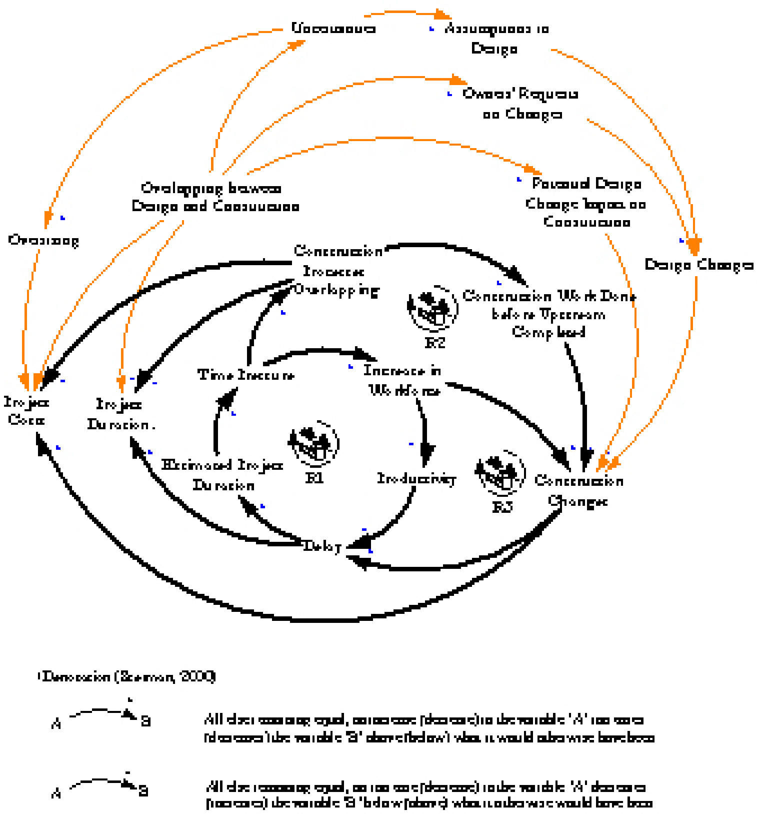

Figure 1: Feedbacks Involved in Fast-tracking Construction (Pena-Mora and Park, 2001)
Another possible way to meet the schedule is to run more project activities in parallel by overlapping the activities (R2 in Figure 1). As a result, the predecessor work does not have enough time to absorb the impact of changes made during successor work. This can lead to an increase in construction changes and further delays, which, in turn, requires more overlapping of the construction processes. Consequently, these feedback processes can produce more construction changes by self-reinforcing their vicious loop effects, which results in schedule delays and cost overruns.

Depending on the size, the complexity, and the project team, the feedback processes discussed thus far can have a significant impact on the project performance, especially when a project is fast-tracked in a heavily constrained environment. To effectively manage a fast-tracking project, these feedback processes should be identified before physical execution is undertaken and it should be carefully monitored throughout the project duration.

Work Productivity and Quality

In representing the construction process, DFTSim dynamically handles work productivity and quality throughout the construction duration, focusing on changes in workers' responses rather than simply applying a different productivity and quality level according to construction stages. As a result, DFTSim simulates work productivity and quality based on workers' experience on the project involved (learning effect), and the effect of schedule pressure and fatigue. Details are discussed below.

- Learning Effect: The productivity and quality of workers vary depending on the construction progress over time. For example, workers' productivity and quality are usually low in the beginning of construction due to the lack of knowledge of the work environment but productivity and quality tend to be enhanced, as construction progresses and when they become more familiar with the environment.

- Schedule Pressure and Fatigue: Lasting schedule pressure can lower work quality, since workers often attempt to achieve the target schedule by cutting corners. In addition, when overtime continues after a certain threshold, workers' fatigue would possibly lower work productivity and quality.

Cost-Benefit Tradeoff

The effectiveness of fast tracking cannot be measured solely based on economic principles because there can be many intangible benefits. However, except for cases when market conditions change rapidly and require owners to beat their market competitors with an earlier completion of their projects (Tighe, 1991), the cost-benefit tradeoff can be useful for comparing the effectiveness of different fast-tracking strategies. In Figure 2, the cash flow of a typical construction project during the project life cycle is conceptualized. The tradeoff of different fast-tracking strategies can be calculated by subtracting the increased cost to reduce the project duration (A-C in Figure 2) from the possible capital gain through the shortened project duration (B in Figure 2).

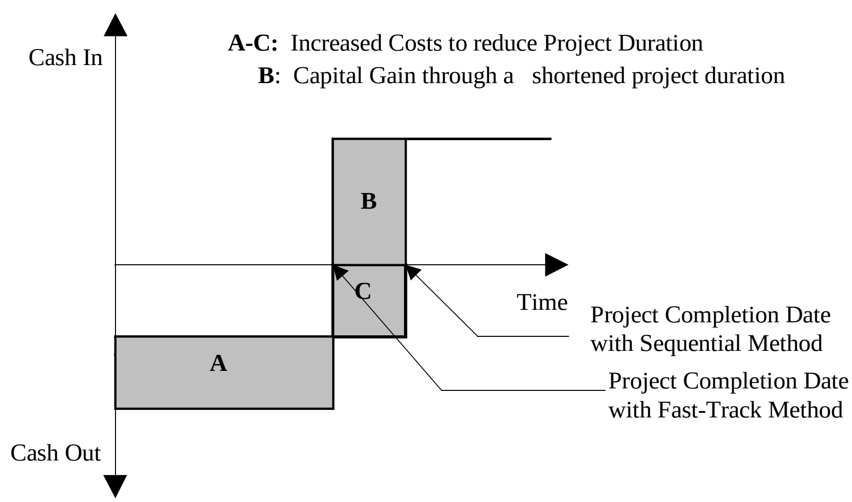

Figure 2: Cost-Benefit Tradeoff of Fast-tracking

Capital Gaming for Fast-tracked Construction

By incorporating the concepts discussed thus far into system dynamics model structures, DFTSim was built to simulate twelve design and construction processes of a building construction project, using Vensim (Ventana Systems Inc., 1996-2002) as an underlying engine. This tool provides students with an opportunity to simulate fast-tracking building construction projects with different scenarios and to find out ways to ensure their effective delivery without driving up costs (see Figure 3). While attempting to balance the increased cost due to fast tracking with the expected capital gain obtained through the earlier completion, students come to 1) appreciate the significance of human factors and their feedback effect during policy applications; 2) realize the potential benefits of fast tracking in the context of the cost-benefit tradeoff; 3) understand the importance of an appropriate construction policy such as labor control, design and construction overlapping; and 4) come up with policy implications such that:

- The planning and management of a fast-tracked project requires a systematic approach because of the diversified and dynamic feedback processes involved in fast-tracking construction process.

- The synergetic effect of feedback processes makes workers' productivity continuously vary throughout the construction process, which requires a flexible labor control.

- The decision-making process in design and construction should be shortened, since time delays can magnify the ripple effects of the feedback processes under time and resource constraints.

Resource Management

Construction progress can be considered as being constrained by either work availability or resource availability. Work availability at a certain time of the project is governed by the work dependency within the same activity (e.g., structural steel erection on the second floor can start only after completion of the first floor work) or between activities (e.g., a finish-to-start relationship between foundation and excavation). Work dependencies are normally beyond the project manager's control as they are determined by the nature of work. In contrast, resource availability is determined by resource plans and managerial decisions. This suggests that construction management is nothing but resource management.

The simulation tool presented in this case study (the Dynamic Resource Management Simulator; DRMSim) aims to build up students' decision-making ability in construction resource management. To do this, DRMSim provides a tool to examine the effectiveness of resource management policies during construction and focuses on feedbacks involved in resource management and the tradeoff of resource coverage and project performance. With this capability, university educators can equip students with decision-making ability and help them to gain indirect experience in classroom environment.

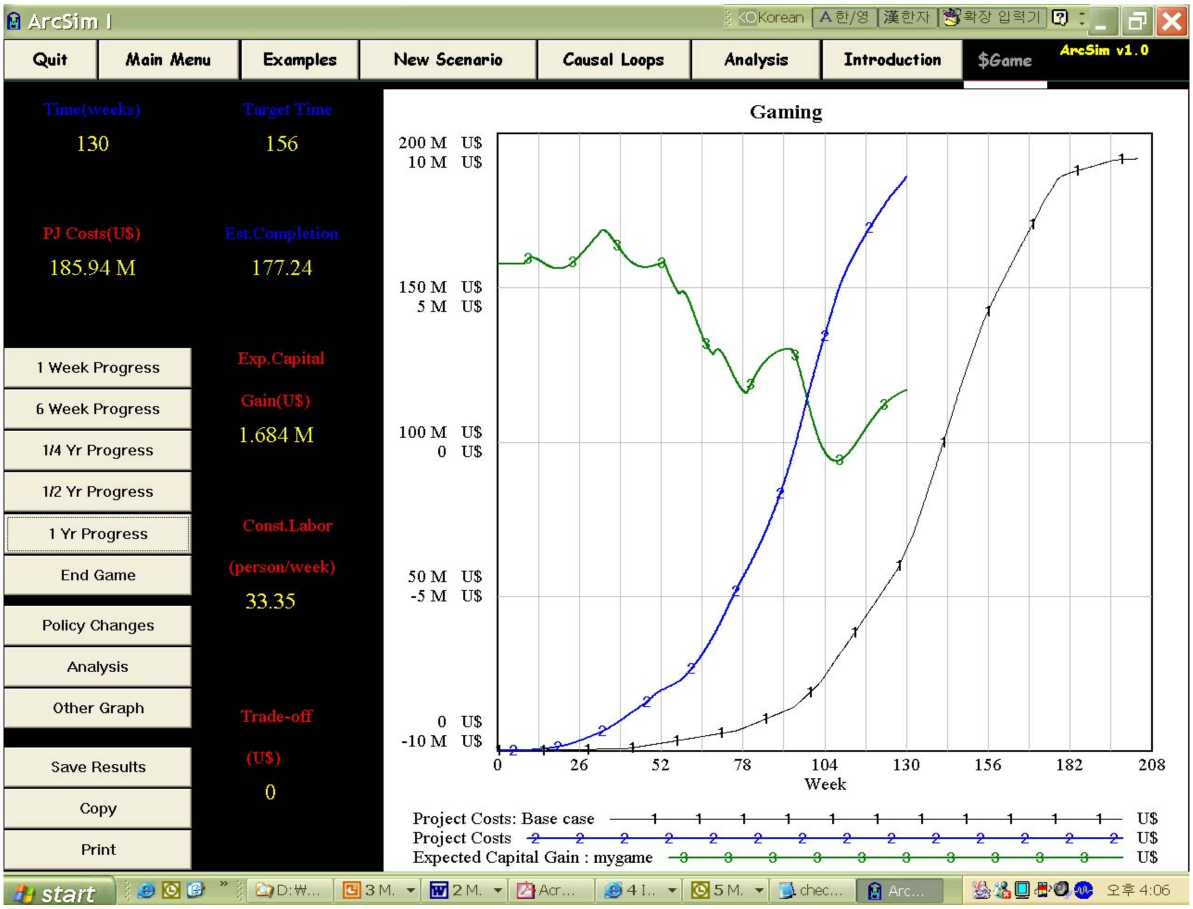

Figure 3: Fast Tracking Simulation Tool

Construction Progress Determinants

We discussed that construction progress is constrained by either work availability or resource availability. As shown in Figure 4, the available quantity of work at a certain time is determined by construction progress and work dependencies (internal and external, Ford and Sterman, 1997). Higher progress and lesser work dependency introduce more work. For example, only 20% of concrete skeleton work is available at the beginning of 5-storey building construction due to the work dependency caused by a physical constraint, and the remaining work becomes progressively available in proportion as construction progresses. In contrast, if the construction work pertains to a single-storey building where work dependency does not exist, then the total amount of work becomes available with the start of construction. Work availability determines the potential construction rate (‘work-based construction rate’), which in turn determines the actual construction rate, when it is less than ‘resource-based construction rate’.

Meanwhile, resource-based construction rate is mainly determined by resource availability and productivity. Resource availability is affected by resource management policies such as resource coverage and resource allocation. Productivity varies according to construction conditions (e.g., schedule pressure under sluggish progress) and management actions (e.g., fatigue resulting from overtime). When resource-based construction rate is less than work-based construction rate, it governs the actual construction rate and progress, triggering the feedback processes in Figure 4. As discussed thus far, the interrelationship between construction progress and its determinants, and the feedback effect caused by them make the construction process highly dynamic and unstable. Thus, it is difficult to allocate necessary resources in a timely and economic manner, which often results in resource overshooting and process interruptions.

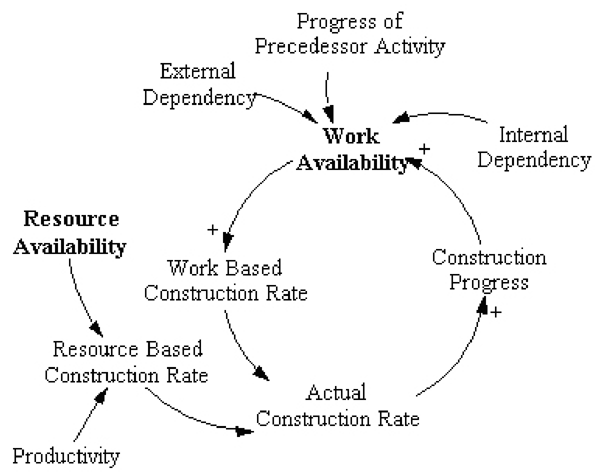

Figure 4: Construction Progress Determinants

Tradeoff in Resource Management

One important issue associated with resource management is how to set target resource coverage (e.g., the workforce level or the number of days of the expected material consumption that the project manager seeks to maintain). The tradeoff between resource coverage and project performance is depicted in Figure 5. When target resource coverage and, accordingly, the actual resource coverage have been increased to meet the schedule, resource availability is increased, which would reduce the chance of construction being interrupted by resource bottleneck. As a result, the project could avoid schedule overruns that have been anticipated. However, the increased resource availability would result in low resource utilization and more resource idling and waste. This tradeoff can also be observed in the opposite case, in which decreasing resource coverage could reduce cost overruns at the expense of construction schedule. Therefore, it is important to target the proper level of resource coverage that leads to achieving the planned project performance rather than attempting to minimize resource idling and waste.

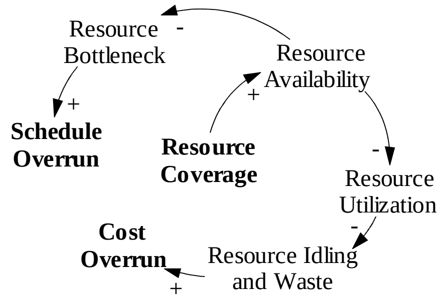

Figure 5: Tradeoff in Resource Management

Resource Management Gaming

With the capability to simulate the dynamics of the construction progress and the tradeoff in resource management, DRMSim provides an automated tool that is capable of assessing the effectiveness of resource policies for a virtual construction project, using Vensim (Ventana Systems Inc., 1996-2002) as a simulation engine. As shown in Figure 6, the value of the parameters used in simulation can be adjusted through the tool's easy-to-use interface. Target resource coverage can be controlled at each simulation time interval. Manipulating construction settings such as work quality, and time variables for monitoring, procurement, and labor control is also allowed. DRMSim is simulated with optional time intervals, and results are displayed graphically and in the numerical format. The simulation output includes material inventory coverage, labor utilization ratio, productivity, cost incurred, estimated completion time, and the construction progress. It also identifies dominant project progress determinants at a certain control time.

This tool helps students to appreciate the dynamics involved in the construction progress, and the tradeoff between target resource coverage and project performance. While attempting to achieve the targeted project performance in terms of schedule and cost, students can acquire decision-making ability for effective construction resource management and obtain policy implications.

Some examples of implications are:

- Project performance does not change linearly with different resource coverage. This nonlinearity is mainly caused by the feedback process involved in the construction progress.

- Schedule performance is more sensitive to resource coverage than cost performance due to the construction progress dynamics.

- Lowering target resource coverage does not always lead to project cost saving because of a situation where heavy resource bottleneck causes considerable material waste as well as long workforce idling times.

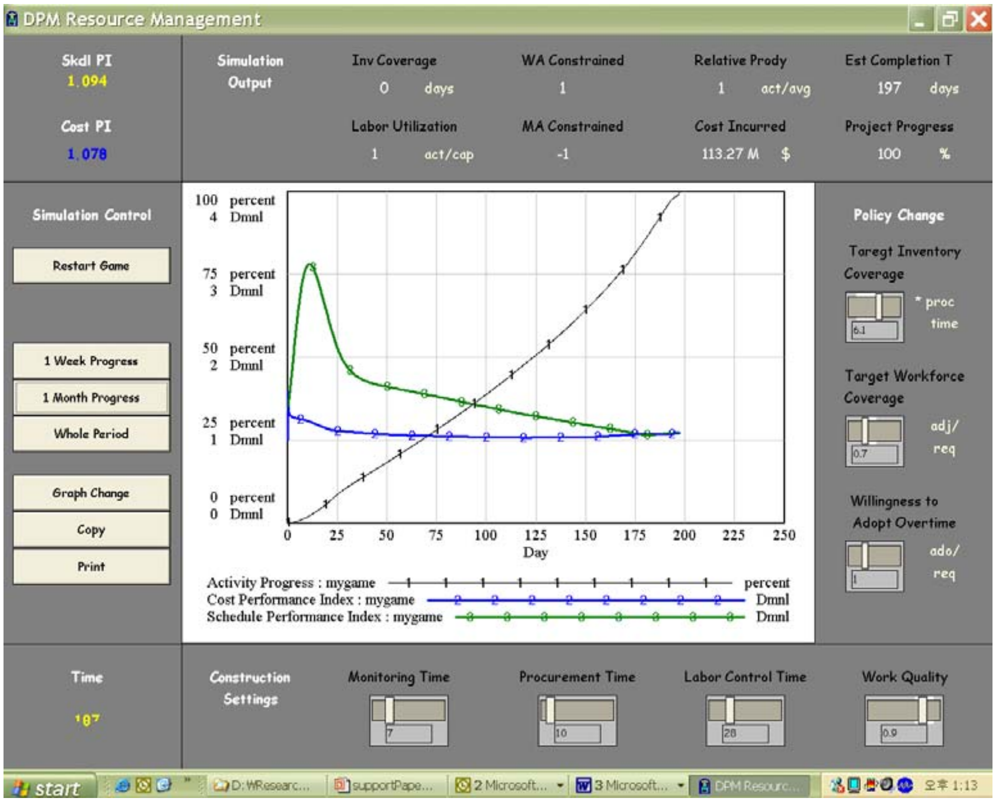

Figure 6: Resource Management Gaming

Applications

The validity, usability and applicability of the simulators presented in this section have been tested in the classroom environment. Taking the application of DRMSim as an example, students are lectured about the basic concepts and terminologies associated with resource management before using DRMSim. Then, the instructor allots an assignment and a standalone executable file of DRMSim to students. The assignment is structured to find resource management policies that can achieve the best combination of the time and cost performance of a project under different conditions, by manipulating the parameters in the simulator. The outcomes from students' assignments are discussed in class. During these processes, learning happens, as students think about the factors that drive project performance in terms of time and cost. Students compare different decisions made by different individuals and see how the construction system responses to the given policies. To enrich educational contents and increase usability, students' feedbacks are incorporated into the advancement of the tool.

By applying these two simulators, we found that students' understanding on construction resource management and fast tracking was considerably improved. Particularly, focusing on human factors and tradeoff in the construction process and decision-making process helped students appreciate the project manager's role under uncertain conditions, while maintaining the application process simple. In addition, the provision of standalone files made it possible for students to operate the simulators in their own computers, which was found to facilitate the learning process.

Conclusions

With the world advancing towards higher level of computer and Internet technologies, construction practices have to change in tandem to improve its productivity and production quality. Education in this field has a role to play in bringing about this change. It needs to emphasize more on practical knowledge and efficient tools that will enhance the students' thinking, problem solving and interpersonal skills so that they can face the challenges ahead and emerge as competent leaders in the industry after they leave the universities. In this context, simulation has emerged as an important approach to provide practical construction knowledge. However, simulation based tools are greatly under-represented in today's education on construction curricula.

As an effort to address this issue, we demonstrated that a simulation based education tool can be an effective vehicle to teach students how to handle abstract, complex and uncertain issues commonly found within the construction process. For a simulation based tool to be more widely used in construction education, we proposed three important factors for the successful implementation of simulation tools: 1) taking into account human factors and feedback effects triggered by them; 2) focusing on tradeoffs associated with managerial decisions and construction policies; and 3) developing an easy-to-use standalone tool that runs on any platform without other supporting programs. Two case studies presented in this paper demonstrated that the application of these success factors helps represent real world situations, while keeping their application simple and easy to access. Although the effectiveness of the proposed success factors needs to be further investigated by more industry-linked research and applications in class, the findings obtained from this research would provide useful guidelines to the development of simulation tools for construction education.

References

Al-jibouri, S. and Mawdesley, M. (2001), *Design and Experience with a Computer Game for Teaching Construction Project Planning and Control*, Engineering, Construction and Architectural Management, Blackwell Science Ltd., Vol. 8, pp. 418-427.

Banks, J., Rogers, R., Oren, T., and Sarjoughian, H. (2000), *Conceptions of Curriculum for Simulation Education*, Proceedings of the 2000 Winter Simulation Conference, Orlando, FL.

Burr, K. (2001), *Progressive Service-Learning: Four Examples in Construction Education*, Journal of Construction Education, ASC, Fort Collins, Colorado, Vol. 6 (1), pp. 6-19.

Caldwell, J. (1991). "Computer Simulations for Teaching, Estimating, and Bidding", ASC Proceedings of the 28th Annual Conference, Brigham Young University-Provo, Utah.

Chinowsky, P. (1998), "Strategic Management in Construction Education, Journal of Construction Education", ASC, Fort Collins, Colorado, Vol. 3 (1), pp. 21-30.

Davies, R. and O'Keefe, R. (1989), "Simulation Modeling with PASCAL", Pretice-Hall International, Hertfordshire, UK.

DeSantis, M., (1999), "System Dynamics In Education: Commonality of Structure and Behavior", Available from http://www.ftlcomm.com/ensign/desantisArticles/desantis40/sysDyn_Mar29_99.html

Fazio, P., Moselhi, O., Theberge, P. and Revay, S. (1988), "Design Impact of Construction Fast-Track", Construction Management and Economics, Whiteknights, London, Vol. 6 (2), pp. 195-208.

Ford, D and Sterman, J. (1997), "Dynamic Modeling of Product Development Processes, Sloan School of Management, Working Paper 3943-97," MIT, Cambridge, MA.

Gann, D. (2000), "Putting Academic Ideas into Practice: Technological Progress and the Absorptive Capacity of Construction Organizations," Construction Management and Economics, Whiteknights, London, Vol. 19, pp. 321–330.

Gibbons, M., Limoges, C., Nowotny, H., Schwartzman, S., Scott, P. and Trow, M. (1994), "The New Production of Knowledge: The Dynamics of Science and Research in Contemporary Society", Sage, London.

Gokhale, A., (1996), "Effectiveness of Computer Simulation for Enhancing Higher Order Thinking", Journal of Industrial Teacher Education, Scholarly Communications Project, Vol. 33, pp. 36-46.

Karaa, F. and Nasr, A. (1986), "Resource Management in Construction," Journal of Construction Engineering and Management, ASCE, Reston, VA, Vol. 112(1), pp. 28-34.

Kwak (1995), "Policy Analysis of Hanford Tank Farm Operations with System Dynamics Approach", Doctoral Thesis, Department of Nuclear Engineering, MIT, Cambridge, MA, pp. 34-36.

Mead, S. (1995), "Using Computers to Simulate the Construction Bid". ASC Proceedings of the 31st Annual Conference, Arizona State University - Tempe, Arizona.

Nassar, K. (2002), "Pricing Construction Contracts in a Competitive Market: A Simulation Game", ASC Proceedings of the 38th Annual Conference, Virginia Polytechnic Institute and State University - Blacksburg, Virginia.

Ng, W., Khor, E., and Lee, J. (1998), "Simulation Modeling and Management of Large Basement Construction project", Journal of Computing in Civil Engineering, ASCE, Reston, VA, Vol. 12 (2), pp. 101-110.

Park, M. (2001), "Dynamic Planning and Control Methodology for Large-Scale Concurrent Construction Projects," Doctoral Thesis, Department of Civil and Environmental Engineering, MIT, Cambridge, MA.

Peña-Mora, F. and Park, M. (2001), "Dynamic Planning for Fast-Tracking Building Construction Projects", Journal of Construction Engineering and Management, ASCE, Reston, VA, Vol. 127 (6), pp.445-456.

Perreault, R. (1989), "External Audit Simulations: A Must for Construction Management Education", ASC Proceedings of the 25th Annual Conference, University of Nebraska-Lincoln-Lincoln, Nebraska.

Richardson, G. (1985), "Introduction to the System Dynamics Review," System Dynamics Review", Wiley, Hoboken, NJ, Vol. 1 (1), pp. 1-5.

Russell, A. and Ranasinghe, M. (1991), "Decision Framework for Fast-track Construction: A Deterministic Analysis", Construction Management and Economics, Whiteknights, London, Vol. 9 (5), pp. 467-479.

Senior, B. (1998), "Infusing Practical Components into Construction Education," Journal of Construction Education, ASC, Fort Collins, Colorado, Vol. 3(2), pp. 92-101.

Sterman, J. (2000), "Business Dynamics: System Thinking and Modeling for a Complex World," McGraw-Hill Companies, New York, NY.

System Dynamics Society (2003), "System Dynamics in Education Project," Available from http://sysdyn.clexchange.org.

Tighe, J (1991), "Benefits of Fast Tracking are a Myth, International Journal of Project Management," Vol. 9(1), pp. 49-51.

Turek, M. (1995), "System Dynamics Analysis of Financial Factors in Nuclear Power Plant Operations," Thesis (M.S.), Dept. of Nuclear Engineering, MIT, Cambridge, MA.

Wallace, G., Killingsworth, R., Cooper, T. and Love, T. (1990), "The Use of CADD Interactive Software in an Advanced Estimating Course", ASC Proceedings of the 26th Annual Conference, Clemson University Clemson, SC.