A Web-Based Project Management Game for Computer-Assisted Instruction

H. Fan and T. Froese

This article was originally presented at the:

6th Construction Specialty Conference / 6e Conférence spécialisée sur le génie de la construction

Toronto, Ontario, Canada

June 2-4, 2005 / *2-4 juin 2005*

https://csce.ca/en/publications/past-conferences/

6th Construction Specialty Conference
6e Conférence spécialisée sur le génie de la construction

Toronto, Ontario, Canada
June 2-4, 2005 / *2-4 juin 2005*

A WEB-BASED PROJECT MANAGEMENT GAME FOR COMPUTER-ASSISTED INSTRUCTION

H. Fan[1] and T. Froese[2]
1. Department of Civil and Environmental Engineering, the University of Alberta, Edmonton, Canada
2. Department of Civil Engineering, the University of British Columbia, Vancouver, Canada

ABSTRACT: Simulation games are a proven technology to enhance and supplement education and training in construction management. Integration of simulation games into the civil engineering curriculum helps bridge the gap between classroom education and field practice, a long-standing problem with the construction education. This paper summarizes a research project called "SimSite .NET" undergoing in the University of British Columbia which addresses this problem by designing an online platform where intelligent virtual projects are hosted for game playing. The users can remotely access an online virtual project to browse through the project documentation, plan the project, as well as implement the project in consecutive time periods. Application of "SimSite .NET" demonstrated that such "learning by example" process is both effective and efficient in enhancing the classroom learning effects and integrating fragmented knowledge learned from different construction management courses.

1. INTRODUCTION

The success of managing the construction of a project primarily relies on the experiences of the project participants. The gap between civil engineering education and industry experience has been a long-standing problem with the civil engineering education. Some people argue that current education program has the following fundamental defects [Sawhney et al. 2001]: (1)Knowledge fragmentation: different courses address different perspectives of project management; the students do not have a holistic view of the project until they practice in the industry for a sufficient length of time; (2)Lack of creativity: the students learn project management concepts, skills and knowledge in the classroom the same way as other science courses, as a result, problem solving skills are not fully addressed, or ignored; (3)Lack of project participation throughout the entire process of construction: the students may participate in the project management during co-op programs, but do not have chance of having a complete view on the project from beginning to the end due to long project construction cycle and short period of participation.

The past and on-going researches prove that simulation games can be integrated into the civil engineering curriculum to bridge this gap and enhance learning effects. The earliest efforts can be traced back to CONSTRUCTO [Halpin et al. 1973], a heuristic game for construction management education, the game confronts the user with a simulated environment where he/she is placed in charge of the project, to make decisions on crew composition, overtime work, etc. in each period to account for the perturbation from environmental and economic uncertainties. Other researches include Internet-based Construction Management Learning System (ICMLS) [Sawhney et al. 2001], a simulation-based system incorporating typical construction scenarios, processes, equipment etc. and SUPERBID [AbouRizk, 1993], a computer game aimed at training students in bidding strategies.

SimSite [Froese et al. 1994] is a computer modulus developed in the University of British Columbia, designed to integrate computer-assisted instruction into the engineering curriculum. By modeling a single-span railway bridge, this computer game allows students to prepare a bid proposal including work plan, schedule, and cost estimation in a guided self-paced process. Compared with the other similar games, SimSite when combined with regular lectures provides students an opportunity of working on a real-life project in a gaming format, the students can get a feel for how different topics such as estimating, scheduling and resources planning relate to each other. Survey results from the students playing the game show that students rate SimSite as having "quite a lot" of basic value and being "fairly easy" to use [Froese et al. 1994].

The idea of building a full-featured, dynamic virtual project to allow users to feel the real-world construction process through a "play-and-learn' process came into being with the success of SimSite as well as rapid development of computer technology. This game concept is expanded to a virtual hosting environment called "SimSite .NET", aimed at capturing the construction data, knowledge, and semantics of real life projects. The system incorporates the construction management technologies, methods, and theories into a gaming environment through an interactive web project. SimSite .NET supports the following features:

- Web-based application. With a web-site as the front end, the simulation application interacts with the user via World Wide Web (WWW), enabling remote access and multi-user environment without any software distribution. What the user needs is a web browser with internet connection.
- A virtual environment capable of simulating general construction projects. SimSite .NET is a general hosting environment focusing on the common concepts, semantics in project management, so that different projects can be accommodated.
- Multi-view modeling. SimSite .NET addresses multiple views of a project, including product view, process view, resource view, time view, cost view, etc. these views are integrated in a virtual environment using different simulation models. For example, the productivity of a work task is modeled as resource-driven under various constraints. Cost view and time view of the task rely on the same productivity model.
- Phased modeling. Both the project planning & scheduling (bidding, or pre-construction) phase, and project implementation (construction) phase are modeled for man-machine interaction.

The web site is comprised of three parts. The first part contains project documents and a reference library that allow the users to browse through the drawings, specifications, and photos of the project, and watch video clips demonstrating typical construction activities; In the second part, the user needs to break down the project into physical components based on structure and constructability, define activities, select work methods for some major activities, define network logic, to get planning and scheduling reports from the system. In the third part, the system generates monthly reports after incorporating perturbations from environmental and economical factors, and the user needs to adjust the resources and working time for the following month to bring the progress back to schedule and costs under control. Delays in completion will subject the user to a liquidated damage charged on a daily basis. A project with excessive duration or cost exceeding the allowable limits will be deemed failure in the game play.

The original project, Alberta Creek Railway Bridge in Lions Bay of BC, is still used as a sample project in the system; modeling and design of the system are expected to address the following issues:

- Establish a framework for online project simulation to allow users to plan and work with a project in a virtual environment.
- Create a gaming environment for students to better understand concepts, methods, and theories in project management.
- Create a gaming environment for students to gain hands-on decision-making experience by playing the game in project planning and execution online.
- Encourage hands-on, active participation by the student in the learning process.

- Supplement regular lectures in construction management and integrate knowledge learned in various engineering courses.

2. MULTI-VIEW MODELING FOR SIMSITE .NET

The purpose of system modeling is to identify all the potential logical and mathematical relations so that the computer program is capable of validating user input and making appropriate responses not much different from the situation in a real life project. Modeling a construction project to account for all possible factors and influences is challenging due to the inherent complexity of construction activities. However, considering that SimSite .NET is primarily designed for educational purposes and our focus is on the representation of common knowledge and general practice in construction, the level of details can be properly chosen to extract only the essence out of reality.

Maintaining consistency among different project planning steps, as well as among different project views (product, resource, schedule, cost, etc), is considered important for the modeled system, so that users can explore how different aspects of a project interact with each other. User flexibility is another important factor in system design so that the user will be able to compare different options, evaluate the impact of different decision, and learn in the process of trial and error.

Figure 1 shows the conceptual framework of the system from user's perspective. The user is guided to walk through the project planning & scheduling phase and project implementation phase. The system responds to the user decisions (such as making choices, drag-and-drop, assigning quantities etc) at each step, either advising an impossible situation, or showing the results later in terms of cost or duration. Online project documentation and help are available for users to understand the project contexts and seek assistance whenever necessary.

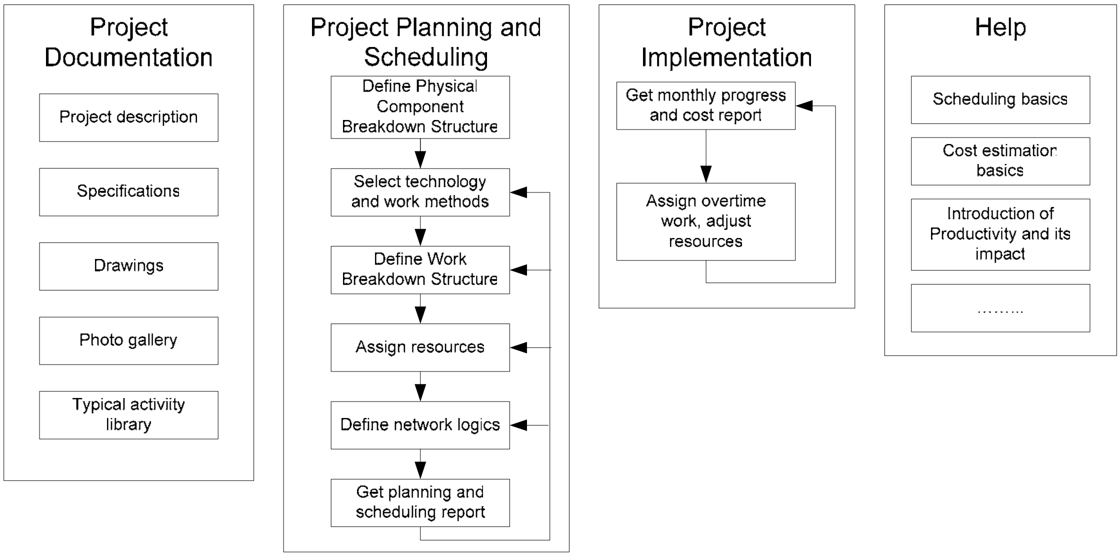

Figure 1. Conceptual Framework of SimSite .NET

2.1. Project documentation

This part is designed to familiarize users with the project to be built, put users in the position of bidding for a project. In order to prepare a plan, create a schedule and estimate the cost of the project, the bidder must know very well the requirements from stakeholders, including design drawings and technical specifications. Some “as-built” photos, video clips of typical construction scenarios are also included to facilitate the users to better understand the project.

2.2. Project planning & scheduling

At the project planning and scheduling phase, the user should prepare a work plan, a progress schedule and a cost estimate, to negotiate a contract with the client. The work plan, comprised of baseline schedule and cost, must be feasible and close to optimum so that the plan will enable project to be delivered with acceptable duration and reasonable cost. As illustrated in Figure 1, this phase involves the following steps which require user input to the system:

2.2.1 Defining Physical Component Breakdown Structure

The Physical Component Breakdown Structure (PCBS) is a hierarchical representation of the project structure in terms of units, partitions and physical components, this part requires users to well understand the physical components of the project and the involved constructability issues. The project is disseminated from the view of a construction engineer in terms of constructability and general arrangements. This is implemented in the application by requiring users to select and define this hierarchical structure in a top-down approach. Validation of user selection by the system guarantees the user gets the right breakdown structure for the project.

2.2.2 Selecting technology and work methods

The routine decisions made by a project management team include methods of building or assembling the aforementioned physical components. Various methods either at a strategic level or at a lower level are evaluated based on their merits and shortcomings from the aspects of cost, duration, quality, reliability, etc. These technology and methods, predefined in the system, provides the user with different alternatives so that the user is entitled to select from which a most appropriate one giving due consideration to cost and progress. The system assumes that each option is feasible but will result in different cost and duration, and allows the user to change it at a later time.

2.2.3 Defining Work Breakdown Structure

The Work Breakdown Structure (WBS) is a hierarchical representation of works required to complete the project. The work tasks are linked to physical components. We choose to define the work tasks based on structural components for planning and scheduling, because at this level, the relationships among structure, work task and resources are defined clearly and concisely, and the level of detail is considered sufficient for cost estimation and scheduling in real project.

In the game, the user must select activities for each physical component from a pool of typical construction activities at different level of details. As a guideline, very large components or these involving complicated work procedures require more details in defining tasks. This work breakdown structure module is designed to allow users to assign appropriate tasks based on the PCBS and selected construction methods.

2.2.4 Resource Assignment

Project activities require assignment of resources (equipment, labor, material, etc), subject to various constraints. The resources required can be limited across project duration; the resources required by different tasks may have conflicts too, therefore, assigning optimal resources to work tasks is challenging and requires experience. The resource assignment in the system challenges user with two issues:

- How to assign appropriate resource types, and quantities, in optimal proportions to achieve maximum productivity; and
- How to consider resource constraints or conflicts.

Each project activity is considered as resource-driven; it consumes resources and generates an end-product (physical component) or a part of it. Resources have to be of appropriate type, quantity and quality. Minimum amounts of resources are required to undertake the work task, and the assigned resources cannot exceed maximum amounts due to space limitation and conflict. In the game, the user is required to select an equipment fleet for the work task from the pool of equipment and then define the crew and other labor types from the pool of labor. The number of each type of equipment or labor is restricted to an appropriate range to successfully define the resources.

The productivity of the task depends on the resources assigned by the user, the same holds true for task duration and cost. Over-assigned, under-assigned or inappropriately assigned resources may cause problems such as in-feasibility of work tasks (which is not permitted by the system), low productivity, and high cost. The system defines this relationship in the project database and further maps this relationship to business classes. At this step, the user will have to assign right type of resources with quantities within allowable ranges. The system calculates and displays the productivity, duration and cost of the task immediately after the user assigns appropriate resources for a task.

2.2.5 Defining Logic Relations for CPM Scheduling

The system uses Critical Path Method for project scheduling calculation and analysis. The project is broken down into work tasks through the WBS definition, and the task cost and duration are determined from its productivity based on the user-assigned resources. To formulate a complete network schedule, the user has to define appropriate sequence and interdependence by using the relationship of Finish-Start (FS), Start-Start (SS), or Finish-Finish (FF). Therefore, this step requires the user to select precedence tasks for each task that has dependences. The user must define sufficient dependencies, appropriate relations, and lag/advance value for the each task. The system will check for the minimum set of relationships for each task after the user input. The user-defined network, even though validated, will not guarantee an optimum one, so the user must define the logic with due care.

Upon the completion of the five steps, the system will generate a planning and scheduling report based on user decisions, some changes to the previous user decisions are allowed before finalizing the project planning and scheduling phase.

2.3. Project Implementation

Upon the approval of the project plan and schedule, the project can be commenced. Since construction activities are carried out in a constantly changing open environment, labor and equipment performances may deteriorate under extreme and unfavorable weather conditions. Consequently, the productivity, cost and duration of each task is in constant change due to perturbation from weather effects, and the material costs vary every month because of consumer price fluctuation. Under these influences from the environment, the project progress and cost may deviate from the baseline plan.

The job of the project management is to make decisions at the beginning of each month to bring the project back on track. Such decisions may be adjustments in resources, assigning overtime work for some activities, and so on.

The project periods repeat until the completion of the project. Two exceptional scenarios, which may cause termination of the contract, are as follows:

- The project is delayed so seriously that the owner and stakeholders lose confidence in the contactor.
- The project construction has unacceptable cost overruns, and the financial losses from this project may be serious enough to drive the contractor to bankruptcy.

The project period play phase, simulating the real world construction process, puts the user in the position of a project manager to make monthly decisions to counterbalance the adverse effects from the environmental and social factors. This process involves interaction among three models proposed by Dr. Halpin in CONSTRUCTO game [Halpin et al. 1973], which are environmental model; project monitoring model, and decision model. The following paragraphs describe the three models we created in SimSite .NET.

2.3.1 Environmental Model

The environmental model conceptualizes the environmental factors and their effects on construction activities. Weather effects, represented by the Average Monthly Temperature (AMT) and the Average Monthly Precipitation (AMP) in the system, affect productivity of weather-sensitive tasks. The weather model, generated with a Random Variant Generation (RVG) technique, updates task productivity on monthly basis. Economic conditions are also a contributing factor to project cost variation. Raw material prices are known to be sensitive to the change of economic index. The cost of construction materials, usually procured on a monthly basis, will differ from the planned cost. The consumer index goes up and down irregularly, and the system simulates this pattern of change to track the cost overrun from material procurement.

2.3.2 Decision Model

The user makes management decisions every month to control the progress and cost. The system models two management decisions, the resource adjustments and overtime work. At the beginning of each month, the user can adjust resources (subjected to system validation). The user can also assign overtime work for the work tasks, if necessary. In this case, the system deducts the activity duration to account for working overtime (decrease the activity duration using 8-hour working calendar).

2.3.3 Project Monitoring Model

As a response to both environmental attacks and user's decisions, the system evaluates progress at the end of each month, compares this with the baseline schedule, and generates a monthly progress report.
The monthly progress report summarizes the work planned for the month and the work actually done in the month, indicating progress delays and cost overflows. The system also re-schedules the project for the remaining works. Furthermore, the system illustrates the inter-dependence among all these decisions made in construction process; the project management works to meet multiple project objectives by making balanced decisions.

3. PRODUCTIVITY MODELING

Mathematical models of work productivities focus on productivity variations which arise from resource assignment and climate effects. The resources assigned to the activity should be in reasonable amounts, categories, ratio and subject to various constraints, in other words, improperly assigned resource will result in low productivity leading to high cost and long duration. Climate factors, such as temperature and precipitation, tend to change work productivity through their effects on worker and equipment performance, while adjustment to the assigned resources by the project management can compensate these adverse effects.

3.1. Productivity models

The core of the productivity modeling is to capture the productivity changes; many researches have been performed to quantify the productivity for predication [Srinavin et al. 2003]. As a simulation game, we simplify the productivity variation by pre-assigning an industry average productivity each task in the system, and then modifying by various factors as shown in Eq. 1:

[1] $$P_1 = P_0 \times K_c \times K_r \times K_e$$

Where P_0= optimum productivity; K_c = Crowding factor; K_r = Skilled/unskilled labor ratio factor; K_e = Trade coordination factor

Influences of resources on productivity also depend on the type of work tasks, therefore, we categorize typical work tasks as Equipment-Driven (ED), Single-Trade Labor Driven (SL), Multiple Trade Labor

Driven (ML) and Composite Tasks (CM); and create different mathematical models for each category based on Eq. 1.

The final productivity is obtained after further updating from weather effects

[2] $$P_2 = P_1 \times K_t \times K_p$$

Where Kt=Temperature factor; K_p = Precipitation factor

3.2. Productivity Variations resulted from assigned resources

The major factors of Productivity variation related to resources are identified as: labor and equipment crowding, skilled/unskilled labor ratio, trade labor ratio, equipment allocation etc. Their influences on productivity are measured using designated factors. For examples:

Labor crowing factor [Hinze, 2004] can be expressed as:

[3] $$K_c = 115\% - 15 \bullet \frac{\sum m}{\sum m_0}\%$$

Where Σm = total number of labors working on the site; Σm_0 = ideal number of labors working on the site

Skilled/Unskilled Labor ratio factor can be expressed as:

[4] $$K_r = \left[1 - e^{-\left[\frac{m_1}{m_3} + (3 - r_0)\right]}\right] \cdot \frac{1}{0.95}$$

Where m_1 = Number of skilled labor; m_3 = Number of unskilled labors; r_0 = ideal skilled/unskilled labor ratio

Trade Labor coordination factor can be expressed as:

[5] $$K_e = [r_1, r_2, ... r_n]^{\frac{1}{n}}$$

Where r_1, r_2,..r_i… r_n = ratio between assigned and ideal number of workers for Trade i; n= Number of trades working on the task

3.3. Productivity Variations resulted from climate effects

The climate effects on productivity depend on both the climate factors, including temperature and precipitation, and the characteristics of work tasks. We modeled these effects in the system through generation of simulated climate conditions and classification of work tasks as per their responsive behaviors to the environmental factors.

The system generates the monthly weather conditions based on historical observations in Vancouver International Airport station. Average monthly temperature is generated randomly assuming normal distribution of temperature data series, the reverse transform method of generating normally distributed variate proposed by Knuth [Knuth, 1969] is used in the system. Monthly precipitation amounts can be best modeled by two-parameter Gamma distribution according to past research [Dubrovsky, 1996]. The random variate to gamma distribution is generated by acceptance-rejection method proposed by Cheng [Cheng, 1977]

The work tasks are classified as Non-Temperature Sensitive (NT), Equipment – Operating (EO), Heavy Manual (HM), Light Manual (LM) ones based on their responding behavior to temperature. The temperature factor Kt is assigned to these tasks at different temperature band. To account for the influence from the monthly precipitation, the work tasks are classified as Non-Precipitation Sensitive (NPS), Low-Precipitation Sensitive (LPS) and High-Precipitation Sensitive (HPS). The precipitation factor is calculated by establishing mathematical relations between the precipitation amount and productivity drop.

4. SYSTEM ARCHITECTURE DESIGN

The overall virtual project is represented in a simulation model as shown in Figure 2; this model is comprised of five distinct components as listed in Table 1.

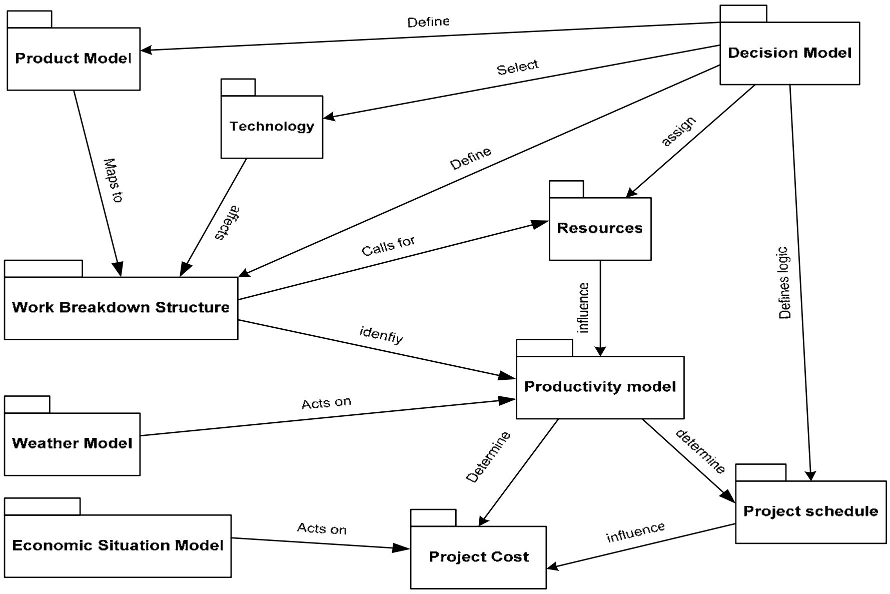

Figure 2. Project Components Interaction Diagram

Table 1. System Model Components

Model Component	Description
Project definition model	Five steps in the project planning and scheduling phase for user definition
Productivity model	Core mathematical model used to represent, update baseline productivity of work tasks
Project report model	Generate cost and estimation report based on project database
Decision Model	Validate user input, define how user input affects project performance
Environmental Model	Define weather (temperature and precipitation), economic situation (consumer index), and how they update project schedule and cost.

SimSite.Net is physically designed as an interactive web site comprised of distributed elements that collectively deliver the system functionality. The system uses the web site as a front end to communicate with users. Implementation of the system is realized through communication and interaction among three distinct parts: the web browser as a client tool, an ASP .NET web application running on the .NET application server and Internet Information Services (IIS), and a Database and database management system on SQL server. These three logical layers of the application, as shown in Figure 3, communicate and interact with each other to realize the system function.

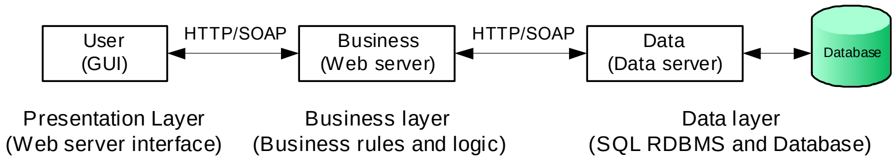

Figure 3. Three-layer Development Model

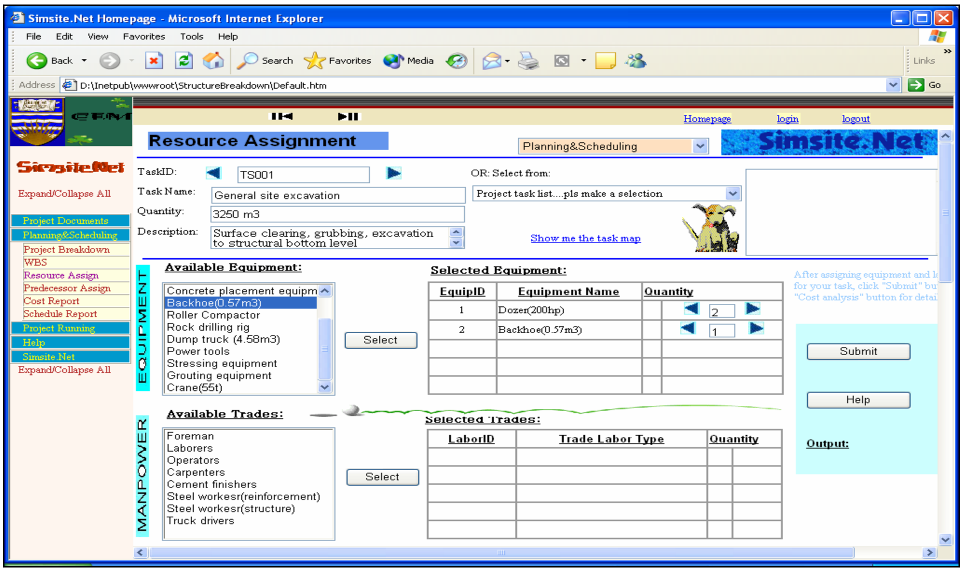

Figure 4. Graphical User Interface for Resource Assignment

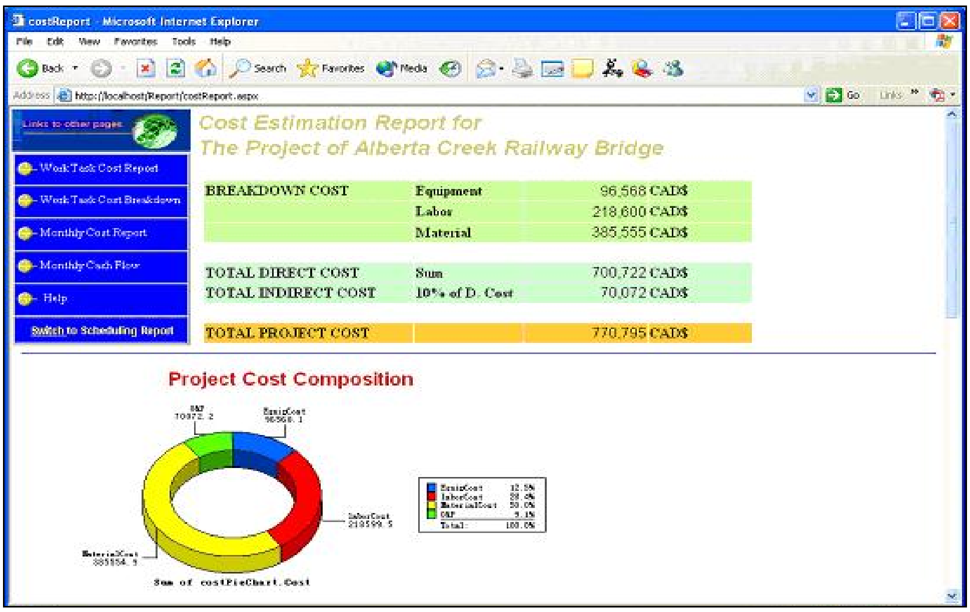

Figure 5. Project Cost Report

Microsoft .NET technology allows for complete separation of the three logical layers in the system. Namely ASP .NET web pages, Project database, logical and mathematical object classes can be developed independently and assembled together.

5. IMPLEMENTATION

The system was tested on a standalone workstation. Windows XP Professional Edition is installed as the operating system, with Internet Information Service 6.0 web server. Other servers are Microsoft .NET enterprise server and Microsoft SQL Server 2000 Enterprise Edition.

Evaluation of the system was carried out on a number of occasions to the graduate students and faculty members through presentation, evaluation meeting and individual discussions. Responses from the users were positive and encouraging; feedbacks indicate that the system was generally rated as useful and well-designed, even though there are some issues, including user flexibility and web interface design etc, to be improved. Figure 4 show the graphical user interface for resource assignment and Figure 5 shows a project cost report after user input in the planning and scheduling phase.

6. CONCLUSIONS

This research project proposes a method for computer assisted instruction through an online virtual project. The virtual project mimics different “views” of a construction facility, addressing common issues in project management. The project modeling covers project planning and scheduling phase as well as the project implementation phase, to allow potential users not only feel how different aspects of a project interact with each other, but also experience the process of how to control a construction project against its baseline plan. Application of e-commerce technology of Microsoft .NET simplified the process of web application development.

The future development of the project will focus on the user flexibility and addition of developer’s mode, so that different project can be hosted on a common platform with easy creation, maintenance of a project library. The fully developed system is expected to supplement the civil engineering curriculum. By playing the game, the students will enhance the concepts, skills and methodology learned in the course lectures, and more importantly, knowledge learned from different courses can be integrated to improve their abilities in handling with real life project managment.

REFERENCES:

AbouRizk, S., 1993. Stochastic Simulation of Construction Bidding and Project Management, *Microcomputers in Civil Engineering*, p343~353, (1993)

Cheng, R., 1977. The generation of gamma variables with non-integral shape parameter. *Applied statistics*, Vol 26, pp. 71-75

Dubrovsky, M. 1995. Validation of the stochastic weather generator Met&Roll. *Meteorologicke Zpravy*, vol 49 (1996), p. 129-138

Froese, T., Prasad, S., Friesen, J., and Zollman, D.,1994. Computer-Assisted Instruction in Civil Engineering, *Computing in Civil Engineering: proceedings of the First Congress*, Khalil Khozeimeh, Ed. , ASCE, Washington DC, June 20-22 (1994)

Halpin, D.W., and Woodhead, R.W., 1973. CONSTRUCTO – a Heuristic Game for Construction Management, University of Illinois Press (1973)

Hinze, J. 2004. Construction Planning and Scheduling, Prentice Hall, 2004

Knuth, D.E., 1969. The art of computer programming, vol 2: Semi-numerical Algorithms, Addison-Wesley publishing Co., 1969

Sawhney, A., Mund, A., and Koczenasz, J., 2001. Internet-based Interactive Construction Management Learning System, *Journal of Construction Education*, Fall 2001, Vol 6. No.3 pp. 124-138

Srinavin, K. and Mohamed S.,2003. Thermal environment and construction workers’ productivity: some evidence from Thailand, *Building and Environment*, 38 (2003) 339 – 345