AC 2009-715: INCORPORATING EQUIPMENT SIMULATORS INTO A CONSTRUCTION-EDUCATION CURRICULUM

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Incorporating Equipment Simulators into a Construction Education Curriculum

Abstract

Construction equipment simulators have been developed by equipment manufacturers to train operators for the stressful and tough construction environments without the need to employ an actual machine. Equipment simulators present an opportunity for construction engineering and management students to learn appropriate measures of operational performance and factors influencing operations. This study demonstrated that there is significant learning potential associated with integrating a Caterpillar Virtual Training Simulator (VTS) into a construction education curriculum. The simulator could be used to demonstrate and reinforce principles such as material waste, O&M costs, and safety. It could also be used to reinforce concepts such as workforce training and operational learning curves.

Introduction

Construction equipment simulators have been developed by equipment manufacturers to train operators for the stressful and tough construction environments without the need to employ an actual machine. Eliminating machine use saves fuel, mechanical wear, and the inherent risks of damage to machine and man. Simulators are currently available for a variety of equipment types including motor graders, excavators, cranes, haul trucks, and wheel loaders. They can be used to familiarize operators with new equipment controls, evaluate potential operators, or develop operator skills in terms of safety and productivity.

Simulators have been used as training tools for many years in many different industries. However, the objectives of university level construction curriculum do not include construction operator training. Rather the objectives are aimed at educating construction engineers and managers, which includes enabling students to design and manage efficient construction operations. Equipment simulators present an opportunity for construction engineering and management students to learn appropriate measures of operational performance and factors influencing operations.

Students bring to the classroom a variety of life experiences, including equipment operating experience, which may influence the effectiveness of employing simulators in the curriculum. Students lacking operating experience may benefit from the learning potential associated with equipment simulators. Students with operating experience may already possess knowledge regarding operational influences and performance metrics. Alternatively, students with operating experience may draw upon their experiences and learn faster than those without operating experience

Construction equipment simulators can be purchased in a variety of configurations ranging in cost from a few thousand dollars for basic simulation on a personal computer using generic controls to several tens of thousands of dollars for full-motion simulators incorporating high performance graphical displays and original equipment manufacturer (OEM) cabs and controls.

Simulators beyond the generic require a significant capital investment that should be weighed against benefits that may be derived from incorporation into the curriculum.

The construction management program at the University of North Carolina at Charlotte conducted a research study to investigate the learning potential associated with integrating a large wheel loader simulator into its construction education curriculum. The results of the study were used to evaluate the learning potential from the use of equipment stimulators and to identify construction courses that may benefit from their incorporation.

Caterpillar Virtual Training System

The Caterpillar Virtual Training System (VTS) is a personal computer (PC) based equipment operator training simulator used to train inexperienced operators in the basic skills associated with a general family of equipment[1]. The VTS is comprised of a personal computer running the real-time 3D simulation application, a virtual display system, OEM equipment controls, and can be augmented with an OEM operator seat to increase realism. Currently the VTS simulation models available or under development include motor graders, excavators, off-highway trucks, and large wheel loaders.

The large wheel loader model was used in this study. A Caterpillar 992G wheel loader operating in a rock quarry is simulated. Various simulation modules are included and designed to allow the operator to become familiar with the loader controls, maneuvering the loader and bucket, stockpiling operations, load and carry operations, and truck loading operations. The VTS large wheel loader model is shown in Figure 1 and the operator seat and controls are shown in Figure 2.

Figure 1: Caterpillar VTS Large Wheel Loader Model

Figure 2: Caterpillar VTS Large Wheel Loader Operator Seat and Controls

Literature Review

Simulators are used to provide a safe and inexpensive practice environment for persons who operate complex machines such as airplanes, trucks, cars, and construction equipment. Simulators are particularly useful to researchers investigating problems in which the real environment is too hazardous, costly, or difficult to control. Simulation has been widely applied to the vehicle driving environment. For example, simulators have been used to explore the effects of cell phones on driving performance[2], conditions that lead to better in vehicle performance[3], and devices to help mitigate accidents with in-vehicle warning systems[4]. Studies have established correlations between participant behavior in driving simulators and behavior in real vehicles[5,6,7].

Simulators are effective training tools because of the ability to replicate a real environment and the realistic behavior of simulation participants. Two recent studies regarding the use of simulators in training snow plow operators have been sponsored by state departments of transportation[8,9]. In both reports, simulation based training was well received by the participants and found applicable to operators at all levels of experience.

Simulation based training has also been used to train construction equipment operators. Wang and Dunston[10] present a survey of advanced virtual training technologies for training heavy construction equipment operators. Gokhale[11] describes the development of a simulator for training crews to operate the JT2510 directional drilling machine. The objectives of the simulator use were to familiarize operators with the controls, train the operators to steer the machine, and enable evaluation of operator performance. A multifunctional simulator for training operators of haul trucks, excavators, and surface drill rigs in a mining has resulted in improved operator performance and reduced operational damage to equipment[12].

Successful training of operators through equipment simulation demonstrates the learning potential of the technology. However, no references were found in the literature regarding application of equipment simulators to a university level construction education curriculum. In such a curriculum the goal is to enable students to effectively manage the equipment operations, rather than develop or enhance equipment operating skills.

Research Description

The purpose of the study was to:

1) aid in understanding an approporiate application of equipment simulation within a construction curriculum;
2) investigate the potential through simulated operations for learning external factors influencing stockpiling and truck loading operations and the relationship with operating experience; and
3) investigate the potential through simulated operations for learning appropriate performance metrics for stockpiling and truck loading operations and the relationship with operating experience;

The objectives of the study were to:

1) determine whether equipment simulation can aid in achieving specific course learning objectives;
2) determine whether equipment simulation increases the ability of students to identify appropriate operational performance metrics;
3) determine whether equipment simulation increases the ability of students to identify external factors influencing the performance of construction operations; and
4) determine whether previous operating experience influences learning potential from equipment simulation

It was hypothesized that students knowledge of appropriate operational performance metrics and external factors influencing performance would be increased through simulated equipment operation. It was also hypothesized that students with equipment operating experience would already possess this knowledge and not exhibit as great an increase in knowledge as non-experienced operators.

Student knowledge in these areas was measured before and after performing the simulated operations to test this hypothesis. Specific learning objectives requiring such knowledge were identified from courses within the construction curriculum. Results of the study were used to evaluate whether simulated equipment operation could aid in achieving the objectives and whether use of the equipment simulator should be incorporated into the construction curriculum. The identified learning objectives and associated courses are listed in Table 1.

Table 1: Learning Objectives Potentially Aided by Equipment Simulation

Course Title	Learning Objective
Cost Estimating	Compare alternative construction methods.
Construction Practices Lab	Design appropriate construction operations.
Design and Improvement of Construction Operations	Apply the principles of operations analysis and methods improvement.

The ability of students to successfully compare alternative methods, design appropriate operations, and analyze operations is predicated on knowledge of appropriate performance metrics. It is necessary to identify factors influencing operational performance in order to design appropriate operations and to apply approprite improvement methods. Therefore, the three learning objectives identified were suitable for inclusion in this study.

Research Methodology

A total of 15 student participants were recruited from a cross section of construction management courses: a freshman level construction methods course, a junior level cost estimating course, and a senior level project scheduling and controls course. The students:

1) received a brief introduction to the Caterpillar Virtual Training Simulator of a large wheel loader;
2) completed a short pre-test regarding their experience with operating heavy construction equipment, performance metrics, and factors influencing construction operations involving wheel loaders;
3) operated the simulator to perform stockpiling and truck loading operations for 30 minutes; and
4) completed a short post-test regarding performance metrics and factors influencing construction operations involving wheel loaders.

Identical pre-test and post-test questions were developed that asked students to identify performance metrics for and factors influencing stockpiling and truck loading operations using a wheel loader. Students were also asked to identify themselves as a member of one of the following groups based on their experience with operating heavy construction equipment:

1) Experienced Wheel Loader Operator – possessing significant experience in wheel loader operations (truck loading, material stockpiling, load and carry operations).
2) Experienced Loader Operator – possessing significant experience in the operation of loading equipment, such as backhoes, skid steers, and/or track loaders.
3) Experienced Equipment Operator – possessing significant experience in the operation of construction equipment.
4) Non-Experienced Operator – possessing no significant experience in the operation of construction equipment.

Following the pre-test, students were given a 30-minute opportunity to operator the wheel loader simulator for both stockpiling materials and truck loading operations. The material stockpiling simulation required each participant to operate the wheel loader to:

a. excavate material from a rock stockpile,
b. execute a three point turn by reversing from the stockpile while articulating and then proceed to the dumping zone while articulating in the opposite direction,
c. dump the material into the dumping zone,
d. reverse from the dumping zone, and
e. stop the wheel loader and activate the horn

The operator's view from the simulated equipment cab during the stockpiling operation is shown in Figure 3.

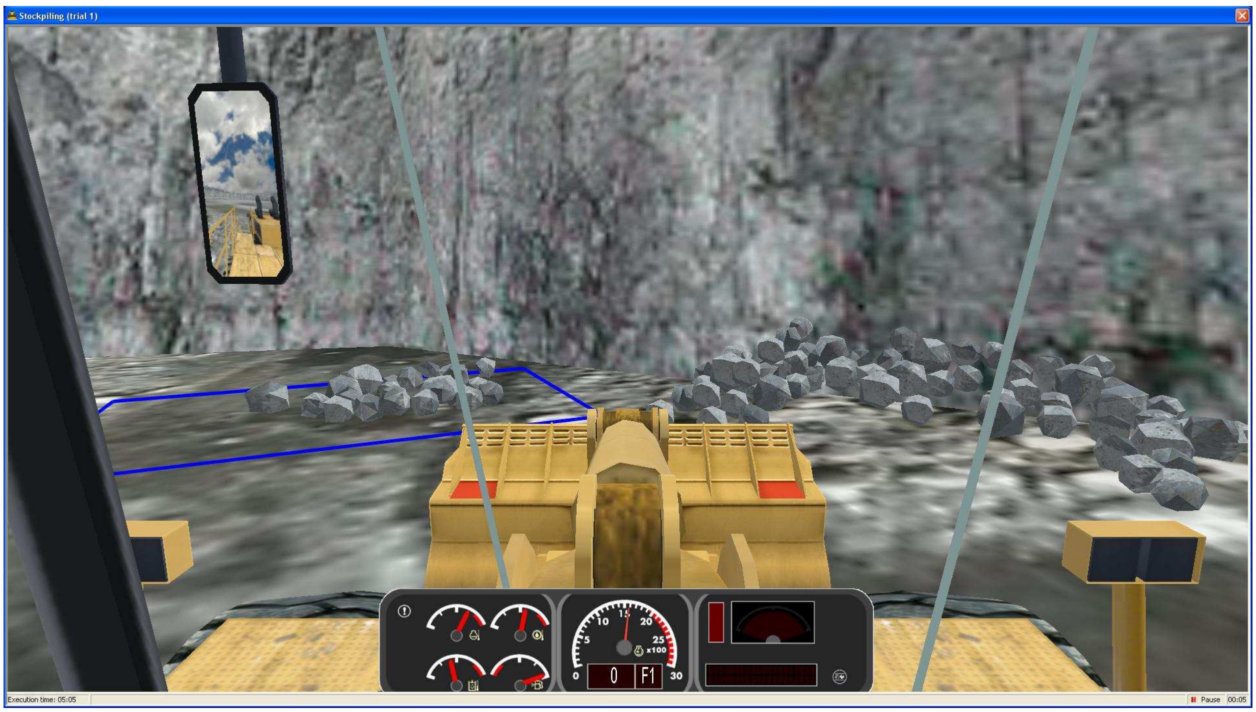

Figure 3: Caterpillar VTS Stockpiling Operation

A large number of operating performance metrics for the stockpiling operation are collected by the simulation software and productivity (tons/hr), mass of material spilled (tons), and time spent with wheels slipping (sec) were recorded during the study.

The truck loading simulation required each participant to:

a. excavate material from a rock stockpile,
b. execute a three point turn by reversing from the stockpile while articulating and then approach the truck while articulating in the opposite direction,
c. dump the material into the truck,

d. reverse from the truck,
e. repeat steps (a) through (d) until the truck is fully loaded (payload indicator becomes solid red), and
f. stop the wheel loader and activate the horn

The operator's view from the simulated equipment cab during the truck loading operation is shown in Figure 4.

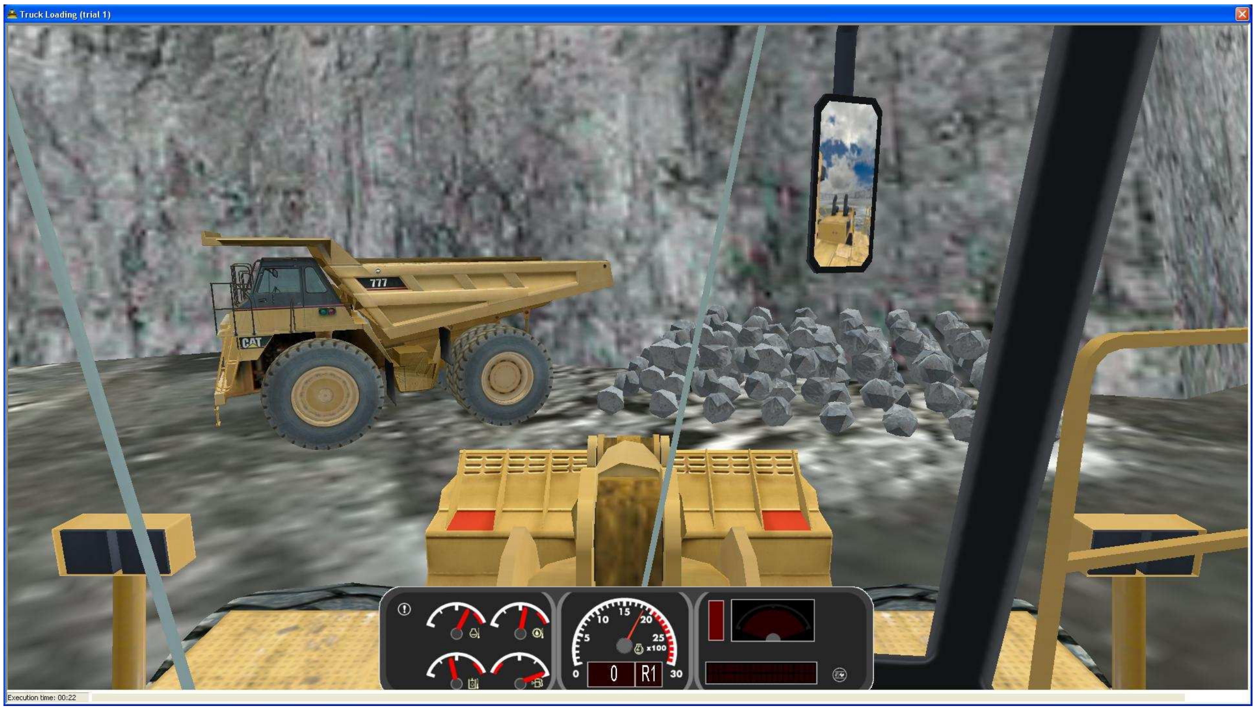

Figure 4: Caterpillar VTS Truck Loading Operation

Student operating performance data for the truck loading operation was collected in terms of productivity (tons/hr), mass of material spilled (tons), number of bucket collisions with truck, and number of lift arm collisions with truck.

Results and Discussion

The 15 students participating in the study identified their operating experience levels to be:

1) Experienced Wheel Loader Operator – 0 students
2) Experienced Loader Operator – 1 student
3) Experienced Equipment Operator – 4 students
4) Non-Experienced Operator – 10 students

Due to the lack of experienced wheel loader operators and only a single experienced loader operator, students were categorized as either "Experienced" or "Non-Experienced" for analysis of the results.

Student responses to pre- and post-test questions requiring the identification of appropriate performance metrics were reviewed to determine the percentage of students identifying productivity rate, material spillage, or safety as suitable metrics. The results for stockpiling and truck loading operations are shown in Tables 2 and 3, respectively.

Table 2: Identified Performance Metrics for Stockpiling Operations

Performance Metric	Experienced Operators			Non-Experienced Operators			All Operators		
	Pre-Test	Post-Test	Increase	Pre-Test	Post-Test	Increase	Pre-Test	Post-Test	Increase
Productivity Rate	60%	80%	20%	30%	80%	50%	40%	80%	40%
Material Spillage	40%	40%	0%	0%	40%	40%	13%	40%	27%
Safety	0%	0%	0%	20%	30%	10%	13%	20%	7%

Table 3: Identified Performance Metrics for Truck Loading Operations

Performance Metric	Experienced Operators			Non-Experienced Operators			All Operators		
	Pre-Test	Post-Test	Increase	Pre-Test	Post-Test	Increase	Pre-Test	Post-Test	Increase
Productivity Rate	60%	80%	20%	30%	70%	40%	40%	73%	33%
Material Spillage	40%	60%	20%	20%	60%	40%	27%	60%	33%
Safety	0%	0%	0%	20%	50%	30%	13%	33%	20%

Productivity rate was the most frequently identified performance metric for stockpiling operations, both before and after simulation. Productivity rate was also the metric most frequently learned through simulation, with an overall increase of 40 percent from simulated stockpiling operations and 33 percent increase from simulated truck loading operations. Students also showed a marked improvement in ability to identify material spillage and safety as performance metrics.

As hypothesized, experienced operators were more likely to identify the performance metrics prior to simulation than non-experienced operators. Following simulation the groups were similar in ability to identify productivity rate and material spillage. Experienced operators did not identify safety either before or after simulation, while non-experienced operators did.

Student responses to pre- and post-test questions requiring the identification of factors influencing operations were reviewed to determine the percentage of students identifying equipment selection, operator ability, material parameters, or site conditions as influencing factors. The results for stockpiling and truck loading operations are shown in Tables 4 and 5, respectively.

Table 4: Identified Influencing Factors for Stockpiling Operations

Influencing Factor	Experienced Operators			Non-Experienced Operators			All Operators		
	Pre-Test	Post-Test	Increase	Pre-Test	Post-Test	Increase	Pre-Test	Post-Test	Increase
Equipment Selection	60%	60%	0%	10%	10%	0%	27%	27%	0%
Operator Ability	60%	60%	0%	30%	80%	50%	40%	73%	33%
Material Parameters	80%	80%	0%	10%	20%	10%	33%	40%	7%
Site Conditions	80%	100%	20%	20%	50%	30%	40%	67%	27%

Table 5: Identified Influencing Factors for Truck Loading Operations

Influencing Factor	Experienced Operators			Non-Experienced Operators			All Operators		
	Pre-Test	Post-Test	Increase	Pre-Test	Post-Test	Increase	Pre-Test	Post-Test	Increase
Equipment Selection	40%	40%	0%	10%	30%	20%	20%	33%	13%
Operator Ability	40%	60%	20%	30%	80%	50%	33%	73%	40%
Material Parameters	60%	80%	20%	0%	10%	10%	20%	33%	13%
Site Conditions	80%	100%	20%	30%	40%	10%	47%	60%	13%

There was also a marked improvement in ability of students to identify influencing factors as a result of the simulations. The greatest increases were in the identification of operator ability and site conditions. Experienced operators again showed less improvement than non-experienced operators. Equipment selection, material parameters, and site conditions were significantly more likely to be identified by experience operators, while non-experienced operators were more likely to identify operator ability following simulation.

Based on the results of this study, the ability of students to identify appropriate performance metrics and factors influencing construction operations did increase as a result of construction equipment simulation. There is greater learning potential for students without previous operating experience, especially in the appreciation for operator ability as an influencing factor. Use of the simulator would have the most significant impact on student learning in courses that address equipment operations, productivity, and costs. The simulator could be used to demonstrate and reinforce principles such as material waste, operation and maintenance costs, and safety of operations. It could also be used to reinforce concepts such as workforce training and operational learning curves.

Use of the simulator is not without difficulty. Students noted difficulty with depth perception as a result of the 2D simulator display. The time required for students to obtain a meaningful simulation experience is also an issue. While the 30 minute sessions used in this study may be decreased, even medium sized course enrollments require a significant amount of time to provide all students with an opportunity to operate the simulator.

Conclusions

The results confirm the hypotheses that knowledge of appropriate operational performance metrics and external factors influencing performance would be increased through simulated equipment operation and that experienced operators would exhibit less increase in knowledge compared to non-experienced operators. The study also demonstrated that there is significant learning potential associated with integrating a Caterpillar Virtual Training Simulator (VTS) into a construction education curriculum.

The simulator could be used to aid in achieving the specific learning objectives identified from the Cost Estimating, Construction Practices Lab, and Design and Improvement of Construction Operations courses. The simulator could be used to demonstrate and reinforce principles such as material waste, O&M costs, and safety. It could also be used to reinforce concepts such as workforce training and operational learning curves.

Additional research should be performed to investigate the actual extent of student learning provided by the simulator. This is best achieved by formally integrating the simulator into an actual course and evaluating student learning so that firm conclusions can be drawn concerning the effectiveness of the simulator as a learning tool in a construction education curriculum.

The results of this study indicate that learning benefits may result from incorporating an equipment simulator into a construction education curriculum. However, incorporating a simulator requires a substantial capital investment and consideration should be given to other pedagogical techniques that may be used to achieve the learning objective, the financial position of the program, and whether the simulator could serve other functions, such as a recruiting tool to generate interest in construction education.

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