THE USE OF SIMULATION AS A PEDAGOGICAL TOOL IN CONSTRUCTION EDUCATION

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ABSTRACT

The construction industry's use of simulation has greatly evolved since its introduction in the mid-70s. Aside from its use in day-to-day activities, it has been shown to be a vital tool for the transfer of specialized construction management knowledge and skills to students, which would otherwise have been acquired through a lengthy, risky, and expensive learning process on the jobsite. The construction industry has experienced considerable changes and development with respect to public & client expectations, project size, and complexity, necessitating the delivery of graduates who are already proficient in managing construction projects. This paper presents details on how simulation is used to teach a construction analysis and design course at the University of Alberta, using Simphony.NET, simulation software developed by the third author. The paper introduces Simphony.NET along with the functionality of its various modeling elements and discusses the various aspects of simulation taught in the course. Two case studies which are also covered in the course, a paving and a building operation, are then presented, as well as an exploration of other issues which arise when using a simulation-based approach to teaching a course in construction engineering.

Keywords: Simulation, Simphony, Construction engineering and management research and education, simulation-based approach.

1. INTRODUCTION

Simulation was introduced to the construction domain when Halpin (1977) first proposed CYCLONE, a simple simulation modeling language. Thereafter, many practitioners and researchers realized and began to explore the potential of simulation in academia and in practical settings in industry.

Simulation has since been used in construction engineering and management education for both instruction and research purposes. It serves as a vital complementary tool for traditional approaches used for teaching special courses that require the transfer of knowledge and skills to students, which would otherwise have been acquired through an expensive and lengthy learning process on the jobsite.

With the evolution and growth of the construction industry, with respect to project size, complexity, uniqueness and other stringent project requirements, it is becoming more apparent that simulation is an irreplaceable tool with respect to its utilization as a teaching aid in classroom settings. The general public and the construction industry at large expect fresh graduates to possess sound decision making skills and the technical expertise to overcome any challenges that they are likely to face while working on the job site. A number of simulation software packages have emerged over the years through different research initiatives at a number of universities, and several have been used to cope with this ever growing need. Some of the more well-known simulation software packages include CYCLONE (Halpin 1977), DISCO (Huang et al. 1994), ABC (Shi 1999), INSIGHT (Paulson 1978), RESQUE (Chang and Carr 1987), UM-CYCLONE, COOPS (Liu 1991), CIPROS (Odeh 1992), STROBOSCOPE (Martinez and Ioannou 1994), HSM (Sawhney and AbouRizk 1995) and Simphony (AbouRizk and Mohamed 2000).

The Hole School of Construction Engineering at the University of Alberta offers a construction process design and analysis course specifically designed to fill this need in the construction industry. The course is designed to teach students the science of analyzing and designing construction operations. Given that the nature of the course dictates the use of simulation, students are introduced to and taught how to use Simphony to implement practical modeling exercises covered in the course.

The general sequence of instructing the course is as follows: first, students are introduced to the concepts of generating meaningful abstractions of any process, and different aspects of creative modeling, with emphasis being placed on construction related operations. A typical earth-moving operation is usually used for this purpose. The CYCLONE template is used to introduce students to the concept of building simulation models on computer because of its simplicity. Students are then taught how to process simulation models by hand and then subsequently introduced to modeling using the Simphony General Purpose template. Other key concepts in simulation are taught, such as statistical aspects of simulation (input and output modeling), model verification and validation besides the instruction on the use of Simphony software for process modeling.

Several examples and case studies are used during the course to help students appreciate the merits of adopting simulation-based approaches for solving problems in a practical setting. A paving operation and a building construction project are presented and discussed as case studies in this paper in order to illustrate the extent to which practical construction problems are covered in the course.

1.1. Current Use of Simulation in Construction Education

Lansley (1986) postulated that human beings learn best when they start from a scenario that they are familiar with and then progress to those which are new to them. Simulation-based approaches used in construction education adopt this same approach because they require that the students first get a good understanding of the systems they plan to simulate (analyze and design). This knowledge ensures that students make accurate abstractions of those systems when modeling using general purpose simulation templates.

The use of games and simulation modeling tool kits are the two commonly used applications of simulation-based approaches in construction education. Examples of games used in construction management education include CONSTRUCTO by Halpin (1976); a road game by Harris & Evans (1977); a dam construction game by Al-Jibouri & Mawdesley (2001); bidding games by Au et al (1969), AbouRizk (1993) and AbouRizk et al (2009). Others include Easy Plan by Hegazy (2006); an equipment replacement game by Nassar (2002), and STRATEGY by McCabe (2000). These games were developed at Universities and are applied in teaching students the concepts of construction management.

A number of simulation modeling tool kits exist on the market which can be used for simulation modeling. Examples of other packages in use in the simulation domain include Promodel, ARENA® (Rockwell Automation), Repast Suite (Argonne National Laboraties), SLAM (Pritsker et al. 1989) and AnyLogic® (XJ Technologies). Some of these software packages support multiple simulation paradigms such as discrete event simulation, system dynamics and agent-based simulation, while others only support one paradigm.

These tools provide an environment in which the students can be immersed so that they interact with uncertainty and variability associated with real systems that they will be dealing with when they graduate.

2. SIMPHONY IN CONSTRUCTION MANAGEMENT EDUCATION

Simphony is a simulation environment which supports a discrete event simulation paradigm. It is comprised of a simulation engine, templates, modeling features and an interface. The interface of the current version of Simphony, Simphony.NET 4.0, is shown in Figure 1. Simphony supports the development and use of different simulation templates. A simulation template is defined as a collection of abstract elements that are used in simulation modeling. Templates that comprise elements which are generic are referred to as general purpose templates, while those with elements customized for modeling a specific domain are referred to as special purpose templates.

Simphony.CYCLONE and Simphony.General are general purpose templates with generic, easy to use modeling elements that can be used to represent a wide spectrum of systems in the construction domain. The general purpose template has a total of 6 categories of modeling elements and a total of 27 generic modeling elements. Each element has a unique appearance, properties and simulation behavior. When building a model, elements are dragged from the templates' window and dropped onto the modeling surface and then linked by relationships (arrows) which provide a route for the flow of entities throughout the entire model. Relationships also enable the modeler to represent their logic as they build the model.

The special purpose templates supported by Simphony in previous versions and the current version include tunneling, steel fabrication, aggregate production, range estimating, earthmoving and PERT (Hajjar and AbouRizk 1999; AbouRizk and Mohamed 2000). These special purpose templates enable practitioners to make use of their knowledge and skills in solving real problems using simulation-based approaches. This is made possible by ensuring that all modeling elements developed in each of these templates have a close resemblance with each aspect of the domain they represent.

Simphony also supports the development of other user specific simulation software (special purpose templates). This provision gives Simphony a competitive edge over other simulation modeling software as a research tool and as a tool for use in regular class instruction. It should be noted that developing these special purpose templates in Simphony requires computer programming proficiency, time and effort, and a clear understanding of the domain for which the template is being developed.

Students in this course are taught how to develop their own templates and how to use general purpose templates and special purpose templates for real construction applications.

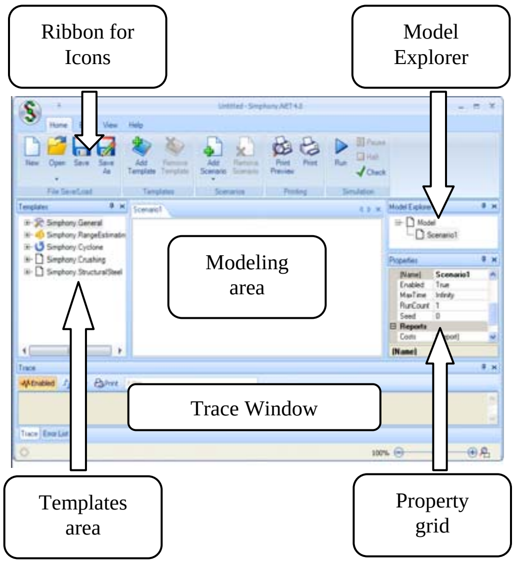

Figure 1: The User Interface of Simphony

The following sections discuss other aspects covered in the course using a simulation-based approach.

2.1. Creating Abstractions of Systems to be Simulated

Constructing an accurate abstraction of a system to be simulated is a skill which is developed over time as one continuously engages in simulation modeling. It is a process referred to as abstraction and is the first phase in modeling a process or a system.

Abstracting a system involves determining the level of detail to which the system will be emulated in the modeling environment, the servers (resources) in our system, the customers, the different state changes (events) and the interaction of the different parts of the system. Once all this has been established, it is drawn on paper in the form of a schema. This diagram is then transferred onto computer modeling elements.

This stage of the modeling process helps the students understand the system they are attempting to model. Visually representing this abstraction on the modeling surface using arrows and modeling elements and the modeling surface within Simphony reinforces that and enables them to assess the validity of their final model and possible outcome.

2.2. Processing Simulation Models by Hand

Students are taught how to process simulation models by hand so that they gain an appreciation of what takes place behind the scenes when a simulation model is run on computer. This knowledge helps the students to verify and validate the models they build. Students are taught how to populate events on an event list, how to transfer events that have occurred onto a chronological list, and how to advance the time of the whole system using MS Excel. They are also taught how to compute system production rates and vital statistics such as utilization. The same models are then run on the computer to validate the results obtained from the hand calculations.

2.3. Statistical Aspects of Simulation

Simulation is used when analyzing complex systems which are affected by multiple factors resulting in random behavior. One effective way of modeling such systems in a simulation-based approach is to represent uncertain behavior of the system in the form of statistical distributions. These statistical distributions may be constructed from previously collected empirical data or from expert knowledge.

Simphony can be used for statistical modeling of such systems because it supports a number of commonly used statistical distributions and also provides a framework for performing Monte Carlo simulations. In order for modelers to perform successful stochastic simulation studies, they have to carry out comprehensive input modeling, a Monte Carlo simulation, and an output analysis.

Input modeling is the process of fitting statistical distributions to data, and testing how well the selected distributions fit to that dataset (i.e., goodness of fit tests). “Fitting” distributions is simply computing their statistics, such as their boundaries, shape and location parameters. Triangular distributions are commonly fitted to data captured from expert opinion because they don’t require complex techniques to be constructed. The distributions often fitted to empirical data include triangular, uniform, beta, exponential, uniform, lognormal, etc. Tests for goodness of fit include visual assessments of shapes of empirical and theoretical probability density functions (PDFs) and cumulative density functions (CDFs), Kolmogorov-Smirnov tests, and Chi-Square tests. Simphony does not support these types of analysis, although there are a number of commercial packages available such as BESTFIT, Crystal Ball® (Oracle) and @Risk (Palisade) which do. The choice of the distribution to use ultimately depends on whether it is supported by the intended simulation engine to be used and how well it fits to the dataset.

After input modeling has been completed, the selected distributions are entered into a pre-built simulation model and then the simulation is run. This type of simulation is referred to as Monte Carlo simulation. Monte Carlo simulation is defined as a numerical solution to a problem in which the system or phenomenon associated with the problem is modeled through a random sampling process (Bielajew 2001). Reliable results can be guaranteed for experiments with higher number of simulation runs (i.e., higher sample size).

Output analysis, on the other hand, involves investigating to determine whether the simulation results are accurate. This is done by carrying out tests for normality of the output (i.e., Shapira-Wilk) and by computing confidence intervals for the output data. Figure 2 shows a flow chart of a typical process of carrying out an authentic stochastic simulation experiment.

In this course, students are taught how to do input modeling by hand calculation and then by using @Risk (Palisade). Monte Carlo simulation using Simphony is also covered, together with output analysis.

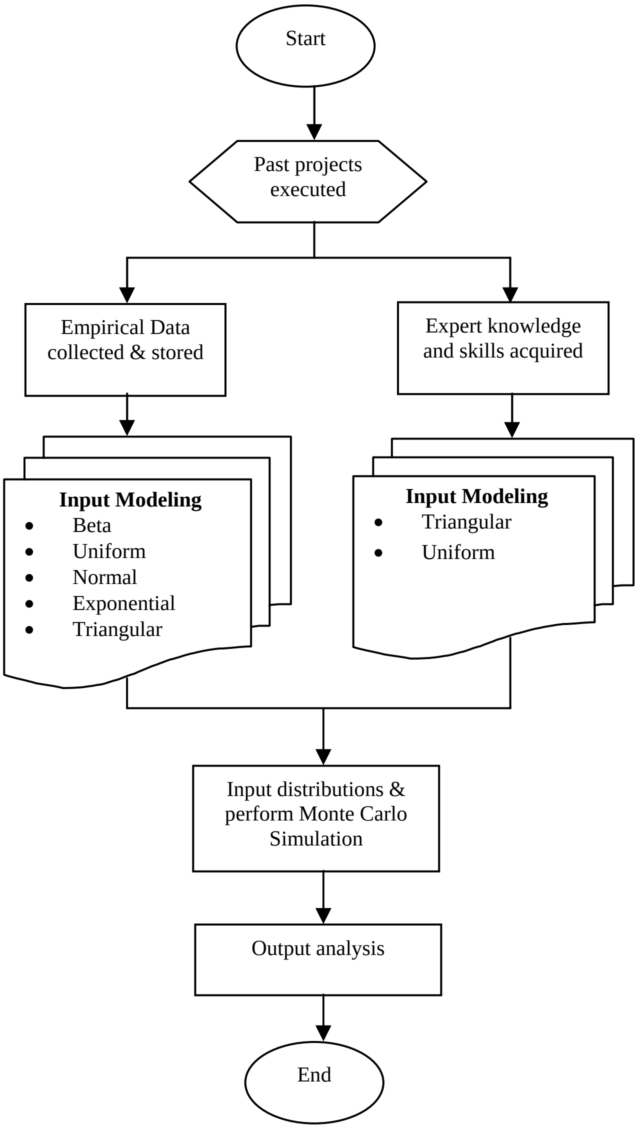

Figure 2: A Flow Chart of a Typical Stochastic Simulation Process

2.4. Validation and Verification of Simulation Models

After building a simulation model, it is important to review the model layout and inputs to ensure that it is an accurate abstraction of the domain represented; a process referred to as model validation. Thereafter, verification has to be done, which involves confirming that the logic embedded within the model is compatible with the way the modeler wanted the model to behave.

Simphony provides a number of features that assist modelers to verify the behavior of their models. For example, it has a counter element, charting elements, trace properties for each modeling element and a trace window. A counter is used to track the flow of entities in any part of the model and also provides insight into time the time entities last flowed through a specific part of a model. The trace features allow a modeler to display simulation results or events in text format, as the model runs. Charting elements allow for the visualization of data generated from the simulation.

Iconic visualization is another feature that is very useful for verifying models in simulation. Although the current general template does not have features for visualizing events as they unfold during simulation, some special purpose templates such as an earthmoving template support iconic visualization of trucks flowing through a model. There are also a number of integrity checks which Simphony performs before a model is run. These checks serve as warnings to modelers of any problems in logic that may exist in their models. The process of validation and verification is a very important phase in simulation modeling to guarantee accurate results. However, this process takes a lot of time and it is challenging.

3. CASE STUDIES

A number of different case studies are presented when instructing the course so that students get an appreciation of what is required to successfully model construction processes. The emphasis is to enable students to develop a sense of the some of the key issues in process interaction modeling. Examples of these issues include:

- Identification of what the entity or entities in the model will represent
- The parts of the system to model explicitly as resources
- The time units to use for modeling and
- The stopping criteria for the simulation.

The two cases studies presented in this paper include a high-rise building construction project and an asphalt paving operation. Both are repetitive construction processes which are resource intensive and have a number of interacting cyclic processes.

3.1. Building Construction Project

The project presented has 26 identical rectangular floors to be constructed, each with 15 bays @ 34ft by 34ft (10.3 m by 10.3 m), as shown in Figure 3. First, forms are installed for a given floor. Once the forms for the entire floor are installed, reinforcing steel is placed for that floor. Then concrete placement commences, with each bay requiring 70CY (54 m^3) of concrete, which is moved from a hopper to the placement area via buggies. Once concrete placement is done, forms can be removed after the concrete has cured. Once forms are removed they are moved by cranes to the next floor and the process repeats until the 26 floors are done.

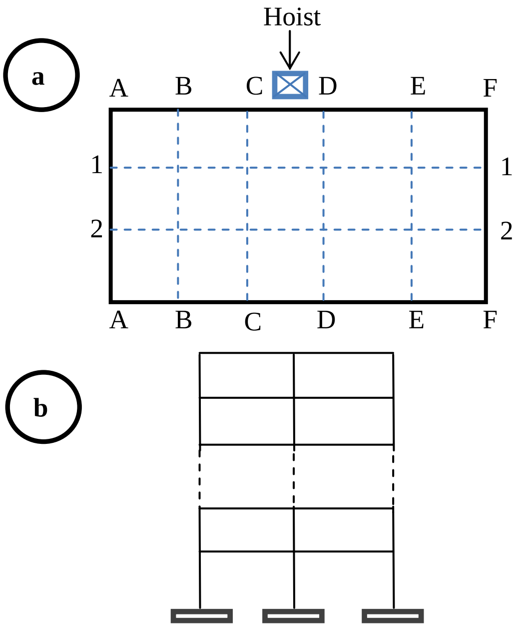

Figure 3: (a) Schematic Layout of Building Construction Project Floor Plan. (b) Right Side Elevation of Building Construction Project

An abstraction of the entire building construction process is summarized in the flow chart presented in Figure 4. When the base model was run, results showed that the average production rate of the project would be 0.55 completed floors per month and the total duration would be 565,600 minutes or approximately 47 months, assuming a 10 hr, 5 day, 4 week-month work shift configuration.

The benefit of using simulation in such an analysis is that the modeler can easily identify and experiment with numerous issues with the objective of arriving at an optimal system, hence saving time and money. For example, resource utilization results can be used to identify resources which are idle most of the time, allowing for waste to be eliminated. In this analysis, it was decided that the number of buggies were to be optimized since they had a very low utilization value. Sample results of the optimization experiment for getting the adequate number of buggies are summarized in Table 1. Results were plotted on a graph in MS Excel (shown in Figure 5) from which it was deduced that the optimal number to use for the project without increasing the project duration is 8, instead of the originally assigned number of 14.

Table 1: Summary of Results of Buggy Optimization

Parameter	Scenario 1	Scenario 2	Scenario 3
# of Buggies	12	6	3
Utilization (%)	2.5	5.0	10.0
Queue Length	0	0.1	0.26
Waiting Time (Min.)	0	0.30	1.30
Project Duration (Min.)	565600	565800	565900

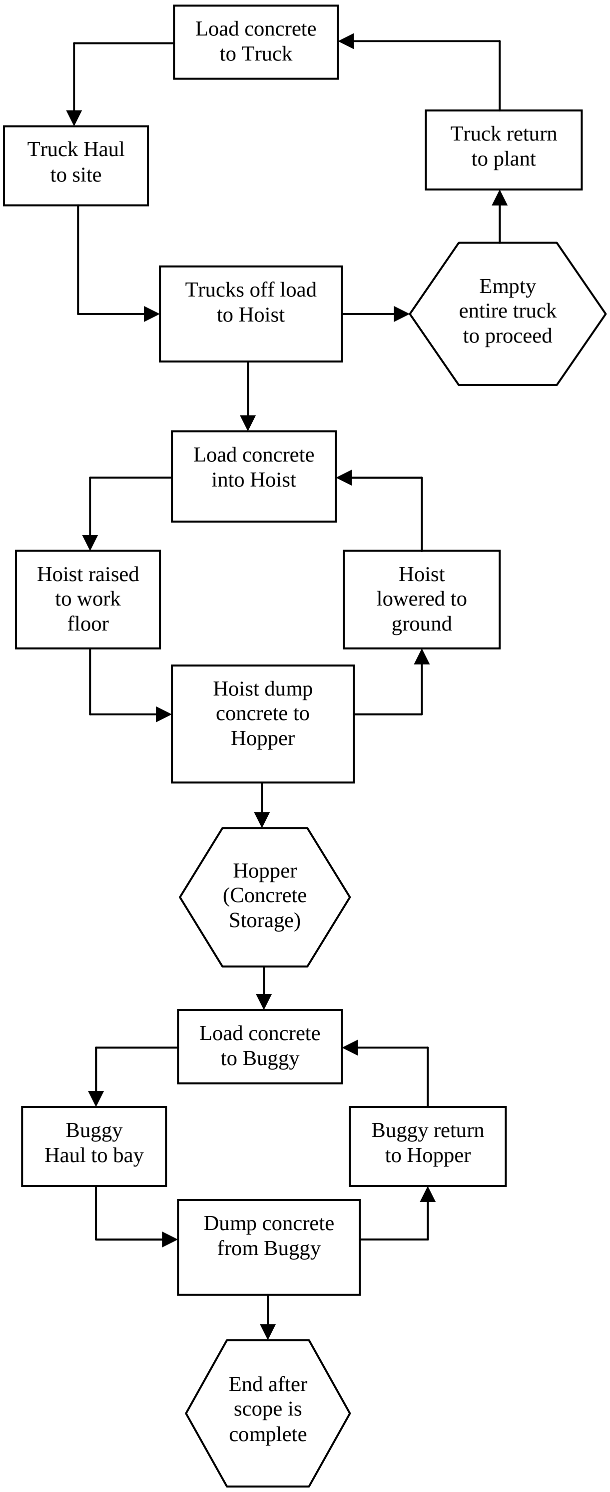

Figure 4: Flowchart of the Building Construction Processes

A sensitivity analysis was carried out for this building construction project to identify the bottle-neck activities. The results for this analysis are summarized in Table 2 for some activities in this project.

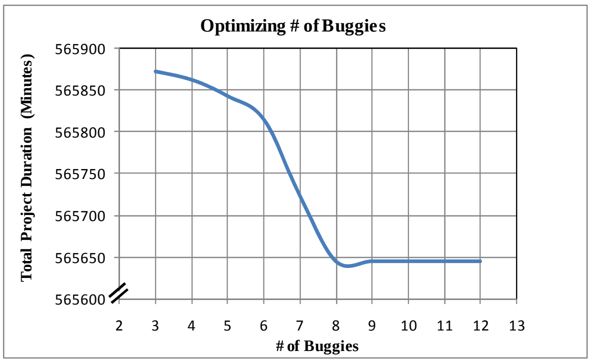

Figure 5: Number of buggies vs. total project duration in minutes

Table 2: Results of a Sensitivity Analysis on selected Activities in the Building Project

Activity Eliminated	Total Project Duration (Min.)	% Project time reduction
Erect & level forms	563200	0.4
Place rebars	562400	0.6
Concrete truck travel to plant	565700	0
Concrete truck returning to site	565600	0
Fill buggy, transport & dump concrete	565700	0
Curing slab	549400	2.9
Fly forms	562300	0.6
Hoist Concrete	280400	50.4
Lower Hoist	373900	33.9

From the results summarized in Table 2, it is evident that hoisting of concrete and lowering the hoist are the activities mainly controlling the project duration. This result was confirmed by a mean utilization value of 100% obtained from running a simulation on the base model. This implies that improvements would have to be made to the hoist cycle if the project duration is to be reduced. Increasing the capacity or number of hoists could be one option. Another option could be to buffer the truck cycle and hoist cycle with a sizeable hopper.

Curing of concrete is another activity that has an impact on the overall project duration, although it is not as large as the hoisting of concrete and lowering of the hoist. If its impact is to be reduced, the use of accelerators and other super setting additives in the concrete could be considered in order to reduce the curing time.

3.2. Asphalt Paving Operation

The paving operation presented assumes that the sub-grade and base course construction have been completed. The surfacing is to be done in asphalt concrete which is delivered by trucks and dumped onto a paver that spreads it. The spread asphalt is then compacted by a drum compactor, after which a pneumatic compactor makes finishing passes, as shown in Figure 6. Some constraints are imposed on the sequence of the operation which include: a paver has to spread a complete parallel pass before it releases the pass to a drum compactor. A pass requires 15 paver skips to be spread, after which the paver repositions for another pass. The drum compactor also releases a completed section to the pneumatic compactor. Each section requires 5 paver skips. The parking lot being paved is completed after 4 parallel passes have been made by the pneumatic compactor. It can be assumed that the operation is not constrained by the delivery of asphalt by trucks.

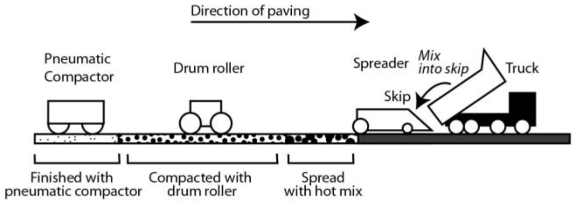

Figure 6: Paving Equipment Diagram (adapted from Halpin 1987)

The objective in this case study is to obtain the total project duration and plot a velocity diagram in Simphony. The generated velocity diagram can then be used to analyze the operation to ensure continuous resource utilization, which is good for the equipment condition and the overall project production rate. Simphony provides a favorable framework in which to experiment with the construction buffers, in order to achieve a continuous construction process without increasing the overall project duration.

A schematic layout is presented in Figure 7 which represents an abstraction of the operation. After the simulation is run, a total project duration of 1006.5 minutes is obtained. The velocity diagram shown is Figure 8 is also generated for the base scenario.

The construction buffer between the paver and the drum compactor is then reduced from 15 paver skips to 5 paver skips in order to synchronize all three cyclic processes and achieve continuous liner production lines for the drum and the pneumatic compactor. The same total project duration of 1006.5 minutes was obtained with this adjustment with production lines for all three pieces of equipment, almost parallel and linearly continuous throughout the project. This is illustrated in Figure 9.

A modeler can opt to explore the option of reducing the total project duration while maintaining continuous linear production lines by either increasing the number of resources for each construction cycle or by proposing to use equipment with higher production rates. This scenario-based analysis is very simple in this case, since a simulation model for the operation exists which can be experimented with.

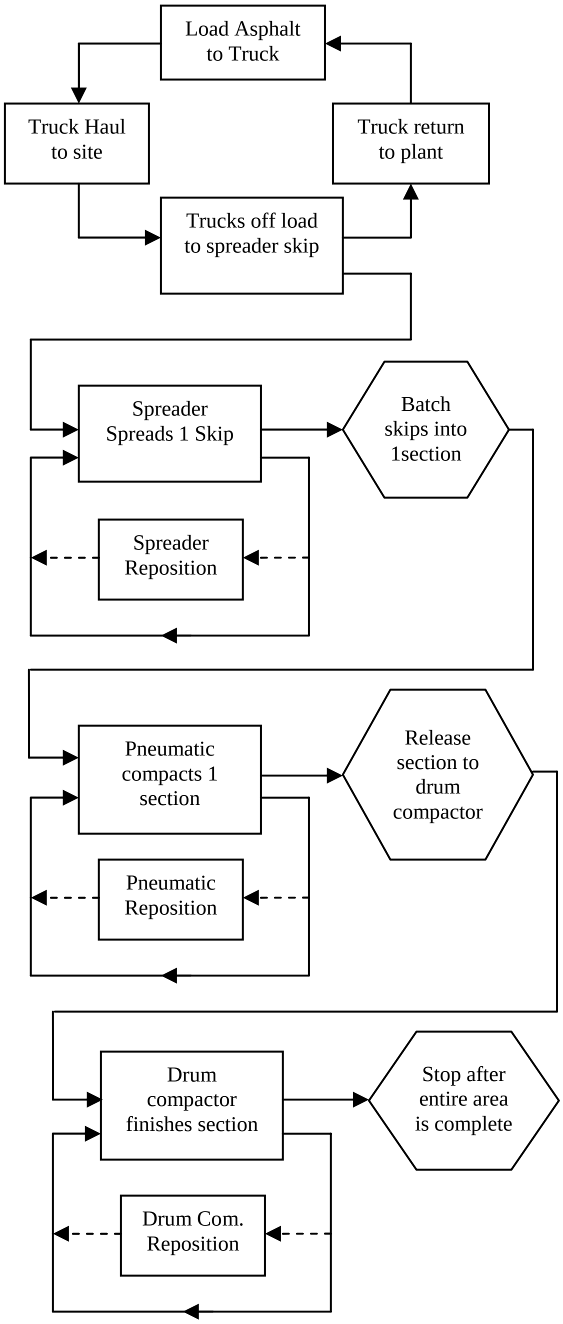

Figure 7: A Flowchart of the Paving Operation

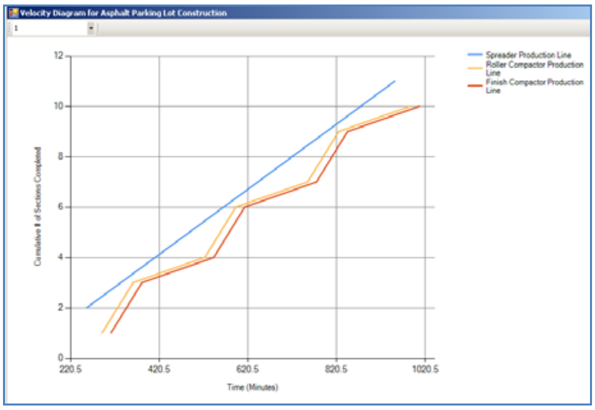

Figure 8: Velocity Chart for the Base-Case Scenario

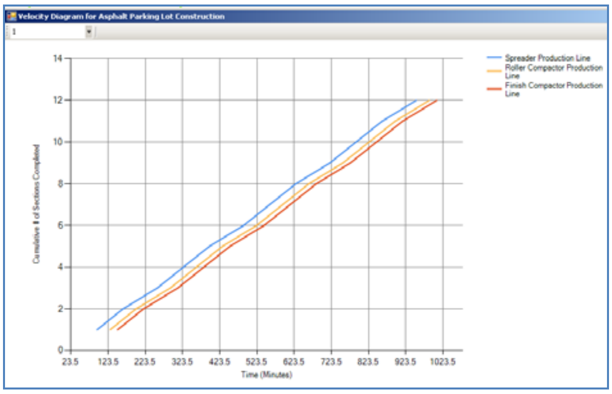

Figure 9: Velocity Chart for the Synchronized Operation

The issues dealt with in these two case studies are easy to investigate once base models for the operations are constructed in a simulation environment. It would be time consuming and tedious to carry out the same analysis without a simulation based approach hence its use in teaching this course.

Other issues that can be easily studied include the impact of the impact of equipment maintenance programs and uncertain events such as plant failure on the duration of such project.

4. CONCLUSIONS

Simulation is a popular approach which provides an environment conducive to modeling and experimentation of problems which cannot be solved analytically due to their complex nature. Its use in academia is wide spread and continues to grow because it allows for instructors to bring uncertain and variable phenomena into typical classroom settings, giving students the chance to interact with them and develop the necessary knowledge and skills required to deal with them in a real life setting. Simulation also provides a relatively cheap test bed for students to experiment with complex systems before they go into the field to implement them, especially during in their research phase of their University programs.

Simphony is an easy-to-use simulation software package which allows the construction of models using its general purpose or special purpose templates, but also allows for the development of user specific simulation tools (i.e., other special purpose templates). It has been successfully used in courses at the University of Alberta during lectures for demonstrating case studies, and by students in solving their course assignments and exams. Simphony is also used by students who decide to pursue research in the area of simulation and has been shown to yield acceptable results.

When used appropriately, simulation-based approaches in construction management education can be very effective, especially when there is a good balance in the use of construction management games, simulation modeling tool kits and traditional methods of instruction.

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