APPLICATION OF DISCRETE EVENT SIMULATION AND CONWIP ON INVENTORY CONTROL

Weizhuo Lu, Forskarassistent, Weizhuo.Lu@ltu.se
Thomas Olofsson, Professor, Thomas.Olofsson@ltu.se
Department of Civil, Mining and Environmental Engineering, Luleå University of Technology, Luleå, Sweden
Anders Segerstedt, Professor, Anders.Segerstedt@ltu.se
Industrial Logistics, Luleå University of Technology, Luleå, Sweden

ABSTRACT

Simulation is an effective quantitative analysis tool to compare and evaluate different system design. However, the application of simulation in construction industry has been limited to relatively restricted research fields. This paper presents a discrete event simulation (DES) model using Simphony.net in which quantitative performance evaluation between constant work-in-progress (CONWIP), a pull method that limits the work-in-progress (WIP) level in the production system according to the status of system, and push are provided. A card element in the simulation model is used to authorize the production, collect cards and limit work-in-progress (WIP) level in the system. The purpose of such comparison and evaluation is to explore the utilization of DES and CONWIP on inventory control.

Uncertainty and variation in construction process has an important influence on project performance. The common practice to deal with variation is the holding of inventory. As demonstrated in developed simulation model in this research, suitable inventory improves the performance of project. However, excessive inventory induces no-added value. Simulation experiments show that application of DES and CONWIP provides an effective way of inventory control, simultaneously, maintain throughput and cycle time compared to push system. The research will be of interest to those evaluating the impacting of lean base method on construction project performance with simulation.

Keywords: DES, inventory control, lean, CONWIP

1. INTRODUCTION

Discrete Event Simulation (DES) has been used as a tool for project scheduling since the development of CYCLONE (Halpin, 1977). Halpin developed the CYCLONE modeling system that simplifies the simulation modeling process and makes it accessible to construction practitioners with limited simulation background (Sawhney et al., 2003). Through computer simulation, the planner can experiment with and quickly evaluate process alternatives in an iterative manner. It provides a tool in terms of which the process can be designed and redesigned until it has achieved maximum production and minimum cycle time with allocated resources. Dragados y Construcciones, the largest construction firm in Spain, and one of the top 50 worldwide, have used CYCLONE in over 30 projects and has recorded productivity improvements ranging from 30% to 300% (Halpin and Martinez, 1999).

The introduction of CYCLONE modeling elements brought the study of construction operations to researchers' attention, and there have been many construction simulation programs developed in the past two decades based on CYCLONE concepts, such as UM CYCLONE (Ioannou, 1989), STROBOSCOPE (Martinez, 1996), ABC (Shi, 1999). Martinez and Ioannou (1999) examined the characteristics of DES systems used in construction and grouped them into three general approaches, i.e., activity scanning, event scheduling, and process interaction. They suggested that activity scanning is the natural and effective approach for modeling complex construction operations in detail. Ioannou and Srisuwanrat (2006) presented a sequence step algorithm developed in STROBOSCOPE simulation platform with probabilistic activity durations while maintaining continuous resource utilization. Hajjar and AbouRizk (2002) proposed Simphony.net which allows for the creation of new Special Purpose Simulation (SPS) tools in the form of modeling element templates and provides a highly flexible, yet user-friendly, environment for the simulation modeling process. Using Simphony.net, a project can be represented by an abstracted model at the higher level that contains a limited number of modeling elements and relations. At a lower level, each of these elements can have its own child model, which represents the sub-system working inside that element. Nasereddin et al. (2007) describe elements commonly found in modular manufacturing and summarizes an approach for automating the model development process using ProModel and Visual Basic. González et. al. (2008) developed a discrete event simulation approach with Extend™ to design work-in-progress (WIP) buffer for repetitive project. Study reveals that construction-oriented resource-driven simulation platform is found to be more flexible and straightforward than manufacturing simulation platform in addressing construction systems (Lu and Wang, 2007). Construction simulation enables project managers to compare and evaluate the behaviors of a system under variation. Simulation is considered an effective quantitative analysis tool for the variation process because the effect of uncertainties on construction projects can be modeled and assessed by simulation (Martinez, 1996).

Uncertainty and variation in construction process has an important influence on project performance. Uncertainty and variation is as non-uniformity quality of certain classes of entities closely related to the randomness of a phenomenon (Hopp and Spearman, 2000). Koskela (2000) distinguishes between two types of variability in production: (1) in the process time of a task executed at a workstation and (2) in the flow of arrival of work to a workstation. Tommelein et al. (1999) reported that predecessor activities with a high variation in output or duration could result in idle labour, equipment, and materials in successor activities. In addition, the high uncertainty in task duration or output also enlarged the inventory of material and work-in-progress. That is, waste and inefficiency are evident throughout the materials supply chain. The common practice to deal with variation in materials supply is the holding of inventory. Inventory can meet unexpected demand and absorb variability. If there is no adequate material for production, problems could arise in the project cost, schedule, and quality management (Tserng et al., 2006). Horman and Thomas (2005) claimed a build-up of inventory in the range of 4.5%-7.5% between the fabrication and installation steps of reinforcement bar construction generated the highest performance. A smaller inventory did not seem to effectively shield rebar installation from variability and resulted in reduced labour performance due to disruption. Medium sized inventory provided conditions for best performance as larger inventory provided no additional performance benefits. Substantial quantity of inventory by supplying materials earlier than they are needed increases cost and impedes a quick response to demand variability (Lee et al., 2000). Additionally, excessive inventory creates the needs for floor space, equipment, and manpower to transport, stock, and manage the inventory with no added value (Luh et al., 2000).

Therefore, a proper method of inventory control while considering variability in construction process is crucial for construction projects. However, usually the design and management of inventory is based on intuition and performed informally (Horman and Thomas, 2005). This paper applies DES and CONWIP on inventory control, in which Simphony.net is utilized to compare and evaluate different inventory control strategies in terms of inventory level, throughput and cycle time. For representation of complex and large construction projects, Simphony.net provides a hierarchical modeling feature.

2. CONSTANT WORK-IN-PROCESS (CONWIP)

Both push system and pull system have different advantages and disadvantages, as has been pointed out by many researchers (Speaarman et al., 1990; Sarker et al., 1989). To overcome this point, many researchers try to combine the two types of control systems. CONWIP (CONstant Work-In-Process), proposed by Spearman et al. in 1990, is just such a hybrid system. CONWIP is a production release method that uses cards for continuous regulation of the flow of materials (Spearman et al., 1990). CONWIP control is proposed as an effective pull system to control WIP levels, because it authorizes the release of work based on system status, while a push system schedules the release of work based on demand (Hopp and Spearman, 2000). With the same amount of limited WIP, CONWIP control compared to Kanban control presents a higher throughput rate, less time between jobs out, but the jobs stay on longer in the system (Pettersen and Segerstedt, 2008).

In CONWIP systems, cards are assigned to the whole production line. When the beginning of production, all available cards are located at the beginning of the production line. When materials arrive, and there are enough available cards, the necessary cards are attached to the materials, and they proceed through the production line together. When the material leaves the production system, the card is dropped off and released back to the beginning of the line (Ovalle and Marquez, 2003). Without authorized cards, the materials are not allowed to proceed forward. Under the CONWIP system, the materials are pulled into the production system by the completion of products in order to restrict the level of inventory. And then, the pulled materials are pushed from one station to another through the whole production system.

Some researchers have applied the concept of CONWIP to construction project. Sacks et al. (2007) utilized pull mechanism and reduction of the batch size to one make high-rise apartment buildings to be a CONWIP production system. Arbulu (2006) presented a case study on rebar that illustrates how the application of pull and CONWIP techniques can drastically improve value delivered. Anavi-Isakow and Golany (2003) adapted CONWIP and proposes a new approach to limit the number of active projects in multi-project environments. They demonstrated the superiority of CONWIP whose objective is to achieve a dynamic balance of the loads of the various resources. Sacks et al. (2010) utilize process visualization to make the project manager to control and limit the numbers of tasks, thus implementing the CONWIP approach.

3. DES MODEL ON INVENTORY CONTROL

A stainless steel pipe and fitting supply chain is used to develop a simulation model. The process mapping for stainless steel pipe and fitting supply chain, as shown in Figure 1, is after from Walsh et al. (2004). Rectangles illustrate so-called conversion tasks, such as fabricating steel and on-site construction. Triangles denote possible holding places of inventory between tasks. It represents an accumulation of materials possibly of unlimited amount and for an indeterminate duration. A single line designates the flow of materials. Arrows are transportation of materials or products to the next task. Rhombus means the decisions of different branch according to the setting criterion. The primary outputs of interest were cycle time, throughput (time between packets out), inventory level of specified queue element. Cycle time is the time that all packets pass through supply chain.

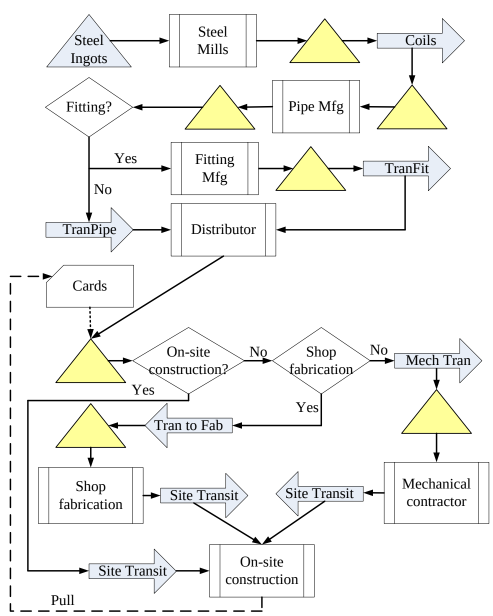
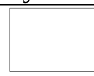
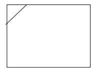
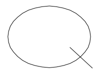
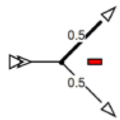
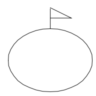


Figure 1: Supply Chain Map for Stainless Steel Pipe and Fitting (After Walsh et al. 2004)

Table 1: Simulation Element Used in this Paper

Element	Symbol	Function
Normal		Represents an unconstrained work task
Combi		Represents a constrained work task
Queue		Represents the waiting situation of the entities
Probabilistic Branching		Enables routing entities into two different branches based on a probability associated with each branch.
Counter		Represents a checkpoint for monitoring the simulation results and collect the productivity
Statistic Element		Statistic element is used to declared to collect statistics on certain parameter in the model
Collect Element		The declared statistic can then be used by collect elements to add observations to it

The simulation module built with Simphony.net simulation environment (Hajjar and AbouRizk, 2002). The model elements used are illustrated in Table 1. The simulation model developed for stainless steel pipe and fitting supply chain is illustrated in Figure 2. In the simulation model, Combi element is used to represent different tasks, such as mill. Combi element is a constrained work task, which can only be carried through when the each resource elements linked with it should contain at least one resource. The parameter of Combi element describes the task duration variability, which follow specified distribution, such as beta distribution or normal distribution. Probabilistic branching elements simulate the probability of following different route. For example, one branch has a probability of 90% then 90% of the possibility of packets passing through this branching, while 10% of the possibility of packets will go through the second branch. Possible holding places of inventory between tasks are denoted by Queue elements between Combi elements. The statistics of Queue elements collects inventory level on the Queue elements. Crew element represents the crew available to perform task. Cycle Time element is used to collect statistics on finish time. This element produces the mean, standard deviation, minimum, and maximum values for the collected observations. The Normal elements represent transportation with constant duration. The counter element is used to count and terminate the simulation model when it arrives specified simulation runs. Additionally, for the rules of Simphony.net simulation environment, virtual tasks such as site/fab are used.

The pipe and fittings were broken into 100 packets. At the initial of production, 100 packets locates at Ingots element. Those packets flow through different conversion tasks operated by corresponding crews based on first-in first-out (FIFO) rule. Crews return to Queue elements of crews and wait for the operation on next packet after operation. For example, 1 packets is operated by mill crews at mill task. After mill operation, crews of mill returns to Queue element and wait for the next packet. At the same time, 1 packet flows out mill task and goes into Queue elements of Fincoil. CycleTime element is used to collect the cycle time of 100 packets. Through the observation of length on Queue elements between Combi elements, the statistical inventory level can be collected.

As shown in Figure 2, a Cards element is located at between distrib and site/fab which is used to simulate the available cards. For CONWIP production system, only distrib element and cards element both contain at least one resource, the production can be authorized. Under CONWIP, the corresponding card is attached to the packet and goes through the production line with packet together. When packet arriving construction site, the corresponding card is dropped off and released back to the cards element (pull signal). For push production system, no card limitation exists in the production system. All packets are pushed to the production system as quickly as possible.

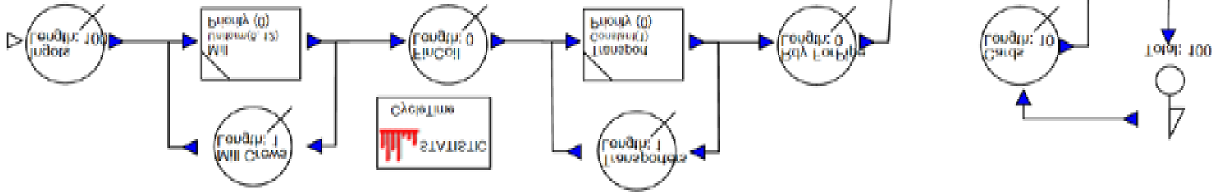


Figure 2: Simulation Model for Stainless Steel Pipe and Fitting Supply Chain

4. SIMULATION RESULTS ANALYSIS

Figure 3 shows the effect of different inventory position on the cycle time. Three scenarios are simulated:

- ✓ Mill: all 100 packets are configured at Mill;
- ✓ Multi Distrib: half of packet(50) configured at Mill, half of the packet(50) located at Distrib element;
- ✓ Distrib: all the packets are located at Distrib element.

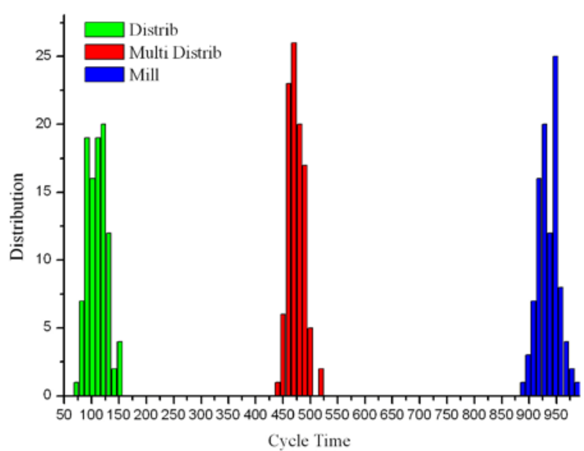


Figure 3: Comparison of Cycle Time of Three Different Inventory Position

As illustrated by the histogram of “Mill” in Figure 3, when all the 100 packets are operated from the beginning of production (Mill), The distribution of cycle time converges around 950. As half of the whole packets (50 packets) are configured as inventory at Distrib element, the histogram of “Multi Distrib” depicts the reduction of cycle time from 950 to 475. Further, when all the packets are located at Distrib element, the histogram of “Distrib” shows that cycle time to construction site reduced greatly. Through the configuration of different locations of inventory, uncertainty and variation demands can be absorbed and met within expected cycle time. For instance, when the uncertainty and variation is high, configuring all the inventory at Distrib element, can decrease the cycle time and buffer uncertainty and variation.

By simulation, the positive effects of different position of inventory are demonstrated. However, as above-mentioned discussion, excessive inventory also impacts the performance of construction project negatively. The key point is how to control the inventory level, at the same time, without crippling performance, such as cycle time and productivity. In this aspect, two scenarios are simulated:

- ✓ CONWIP=6: available cards number in cards element set to 6 in simulation model;
- ✓ Push: no restriction on available cards number in cards element in the simulation model.

The productivity of simulation model is collected by counter element. The comparison of push and CONWIP on throughput is provided by Figure 4 and Figure 5. Horizontal ordinate indicates the time interval between packets out and vertical coordinate is the possibility of different time interval. Figure 4 shows the time between packets out for multi-inventory (Push). Such production system is a push system as packets are pushed to the production system when the production line is idle, no matter what happens in the production system. Figure 5 indicates the time between packets out for multi-inventory (CONWIP=6). CONWIP=6, that means the total available cards number in cards element restricts to 6. The distributions of Figure 4 and Figure 5 present similar characteristics. For instance, the possibility of time between packets out below 10 is around 80% in both figures. Comparison of Figure 4 and Figure 5 identifies that the restriction of card number (CONWIP=6) in developed simulation model does not induce productivity loss.

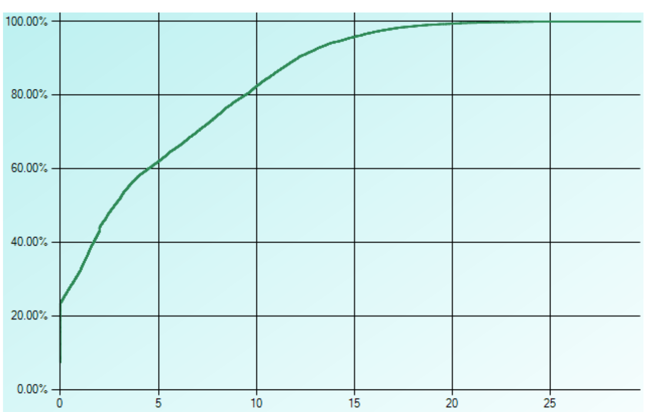


Figure 4: Time between Packets out for Push

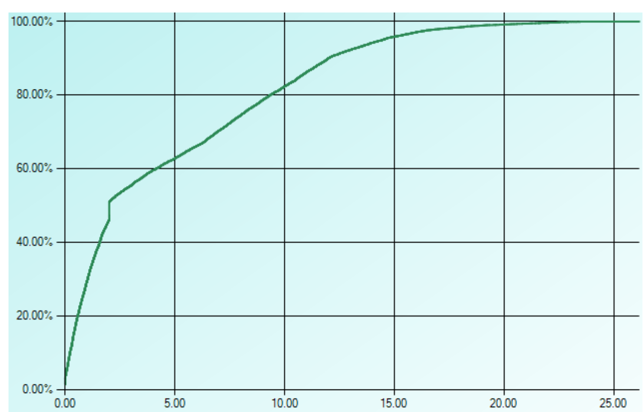


Figure 5: Time between Packets out for CONWIP=6

Figure 6 shows the cycle time of 100 packets between push and CONWIP=6. Horizontal ordinate indicates simulation runs and vertical coordinate is the cycle time for all the 100 packets. The simulation model runs for 100 times in order to collect sufficient statistics data.

For the uncertainty and variation of construction process, the cycle time presents great variation between different simulation runs. For instance, the cycle time of push system ranges from 440 to 520. Two sample independent t-Test are used to assess whether the cycle time between push and CONWIP=6 are statistically significant different from each other. The t-Test shows that at 95% confidence level, the two cycle time are not significantly different, which shows that the restriction of cards number to 6 achieves the same cycle time as push production system.

In summary, it can be concluded that the restriction of cards number (CONWIP=6) does not cripple the performance of production system in terms of productivity and cycle time compared to push system.

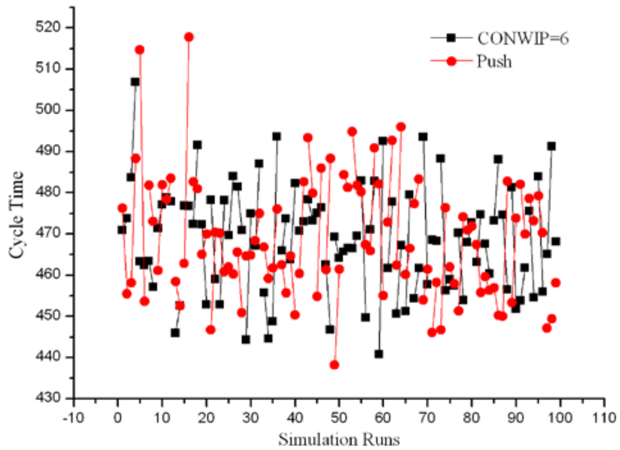


Figure 6: Comparison of Cycle Time for Push and CONW

Figure 7 and Figure 8 show the inventory level at Ready Fab for push and CONWIP=6, respectively. For push production system, the inventory level at Ready Fab ranges from 0 to 18; for CONWIP=6 production system, the inventory level at Ready Fab ranges from 0 to 6. In addition, in Figure 7, the possibility of inventory level smaller than 6 is 80%, while in Figure 8, the possibility of inventory level small than 6 is 100%. Similar characteristics presents in Figure 9 and Figure 10 which show the inventory level at Ready Mech for push and CONWIP=6, respectively. Such comparison by simulation clearly show that CONWIP=6 reduces the inventory level substantially.

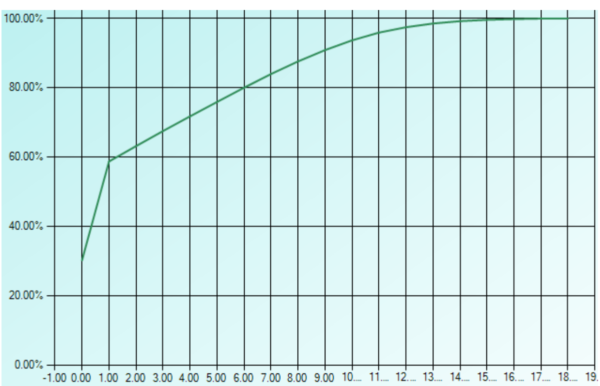


Figure 7: Inventory Level of Push at Ready Fab

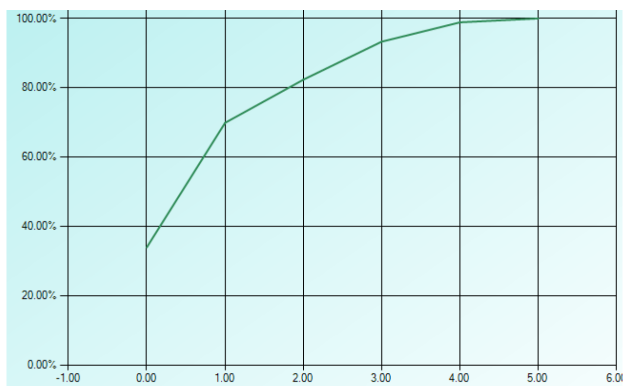


Figure 8: Inventory Level of Pull at Ready Fab (CONWIP=6)

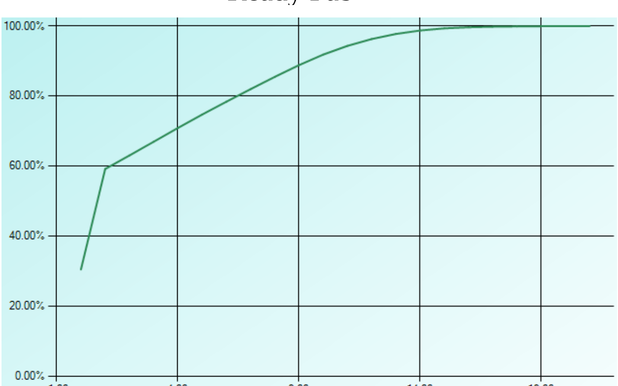


Figure 9: Inventory Level of Push at Ready Mech

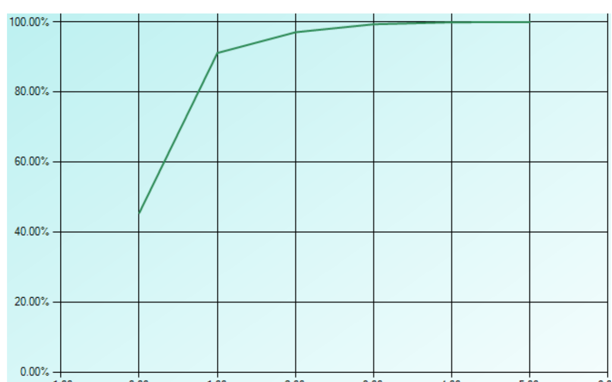


Figure 10: Inventory Level of Pull at Ready Mech (CONWIP=6)

5. CONCLUSIONS

Application of DES and CONWIP reduces inventory level and allows the pull system to achieve the same throughput level as a push system with less inventory level than, as was illustrated in this paper. This paper applies DES and CONWIP on inventory control in order to minimize inventory, maintain throughput and cycle time under process variability. A simulation model is developed to model process uncertainty and assess the performance of different scenarios. A restricted WIP cap (CONWIP) limits the amount of material released into the system, allowing raw materials to stay on paper instead of as inventory on the production line. DES is used to simulate project performance and demonstrate the advantages of CONWIP over push-based production system.

The utilization of DES and CONWIP on inventory control extends the application of construction simulation to inventory control which is a vital research filed of lean construction. The experimented simulation provides quantitative evidences of effectiveness of DES and CONWIP on inventory control. The application of DES and CONWIP also will be beneficial to practitioners that try to introduce lean based method to construction industry.

For any variability production system (e.g. Supply Chain), the work load (WIP) of that system must be restricted and corresponding to production system situation. This point also reflected by Howell (2001) and Ballard (1999). Future work will explore and compare the performance between different work load control mechanisms, such as Drum-Rope-Buffer (Goldratt, 1990) and CONWIP.

REFERENCES

Anavi-Isakow, S. and Golany, B. (2003) “Managing Multi-project Environments through Constant Work-in-process.” *International Journal of Project Managemen*t, 21 (1), 9-18.

Arbulu, R. (2006) “Application of Pull and CONWIP in Construction Production Systems.” *Proceedings of the 14th Annual Meeting of the International Group for Lean Construction*, Santiago, Chile, 215-226.

Ballard, G. (1999). “Improving Workflow Reliability.” *Proceedings of the 7th Annual Meeting of the International Group for Lean Construction*, Berkeley, CA.

Goldratt, E. (1990). *Theory of Constraints*, North River Press.

Hajjar, D. and AbouRizk, S.M. (2002). “Unified Modeling Methodology for Construction Simulation.” *J. of Constr. Engrg. and Mgmt.*, 128 (2), 174-185.

Halpin, D.W. (1977) “CYCLONE-Method for Modeling of Job Site Processes.” *J. Constr. Div.*, 103 (3), 489-499.

Halpin D.W. and Martinez L.H. (1999) “Real World Applications of Construction Process Simulation.” *Proceedings of the 1999 Winter Simulation Conference*, 956-962.

Hopp, W.J. and Spearman, M.L. (2000) “*Factory Physics: Foundations of Manufacturing Management*.” Irwin/McGraw-Hill.

Horman, M.J. and Thomas, H.R. (2005) “Role of Inventory Buffers in Construction Labor Performance.” *J. of Constr. Engrg. and Mgmt*., 131 (7), 834-843.

Howell, G., Ballard, G. and Hall, J. (2001). “Capacity Utilization and Wait Time: A Primer for Construction.” *Proceedings of the 9th Annual Meeting of the International Group for Lean Construction*, Santiago, Chile.

Ioannou, P.G. (1989) “*UM_CYCLONE User’s Guide*.” Dept. of Civil Engineering, The University of Michigan Press, Ann Arbor, Mich.

Ioannou, P.G. and Srisuwanrat, C. (2006) “Sequence Step Algorithm for Continuous Resource Utilization in Probability Repetitive Projects.” *Proceedings of the 2006 Winter Simulation Conference*, 1731-1740.

Koskela, L. (2000). “An Exploration towards a Production Theory and its Application to Construction.” *PhD Dissertation*, VTT Building Technology, Helsinki University of Technology, Espoo, Finland.

González, V., Alarcóna, L.F. and Molenaarc, K. (2008) “Multiobjective Design of Work-In-Process Buffer for Scheduling Repetitive Building Projects.” *Automation in Construction*., 18(2), 95-108.

Lee, H.L., So, K.C. and Tang, C.S. (2000) “The Value of Information Sharing in a Two-level Supply Chain.” *Manage. Sci.*, 46 (5), 626-643.

Lu, M. and Wong, Lap-Chi. (2007) “Comparison of two simulation methodologies in modeling construction systems: Manufacturing-oriented PROMODEL vs. construction-oriented SDESA.” A*utomation in Construction*, 16 (1), 86-95.

Luh, P.B., Zhou, X. and Tomastik, R.N. (2000) “An Effective Method to Reduce Inventory in Job Shops.” *IEEE Trans. Robotics and Automation*, 16 (4), 420-424.

Martinez, J. C. (1996) “STROBOSCOPE: State and Resource Based Simulation of Construction Process.” *Ph.D. Dissertation*, University of Michigan, Ann Arbor, MI.

Martinez, J.C. and Ioannou, P.G. (1999) “General-Purpose Systems for Effective Construction Simulation.” *J. of Constr. Engrg. and Mgmt.*, 125 (4), 265-276.

Nasereddin, M., Mullens, M.A. and Cope, D. (2007) “Automated Simulator Development: A Strategy for Modeling Modular Housing Production.” *Automation in Construction*, 16 (2), 212-223.

Ovalle, O.R. and Marquez, A.C. (2003) “Exploring the Utilization of a CONWIP System for Supply Chain Management: A Comparison with Fully Integrated Supply Chains.” *International Journal of Production Economics*, 83 (2), 195-211.

Pettersen, J.A. and Segerstedt, A. (2008) “Restricted Work-In-Process: A Study of Differences between Kanban and CONWIP.” *International Journal of Production Economics*, 118 (1), 199-207.

Sacks, R., Esquenzi, A. and Goldin, M. (2007) “LEAPCON: Simulation of Lean Construction of High-rise Apartment Buildings.” *J. of Constr. Engrg. and Mgmt.*, 133 (7), 529-539.

Sacks, R., Radosavljevic, M. and Barak, R. (2010) “Requirements for Building Information Modeling Based Lean Production Management Systems for Construction” *Automation in Construction*, 19(5), 641-655.

Sarker, B.R., and Fitzsimmons, J.A. (1989). “The Performance of Push and Pull Systems: A Simulation and Comparative Study.” *Int. J. Production Research*, 27 (11) 1715-1732.

Sawhney, A., Bashford, H., Walsh, k. and Mulky, A.R. (2003) “Agent-Based Modeling and Simulation in Construction.” *Proceedings of the 2003 Winter Simulation Conference*, 1541-1547.

Shi, J. (1999) “Activity-based Construction (ABC) Modeling and Simulation Method.” *J. Constr. Eng. Manage.*, 125 (5), 354-360.

Spearman, M.L., Woodruff, D.L. and Hopp, W.J. (1990) “CONWIP: A Pull Alternative to Kanban.” *Int J of Production Research*, 28 (5), 879-894.

Tommelein, I.D., Riley, D. and Howell, G.A. (1999) “Parade Game: Impact of Work Flow Variability on Trade Performance.” *J. of Constr. Engrg. and Mgmt.*, 125 (5), 304-310.

Tserng, H.P., Yin, S.Y.L. and Li, S. (2006). “Developing a Resource Supply Chain Planning System for Construction Projects”. *J. of Constr. Engrg. and Mgmt.*, 132, (4) 393-407.

Walsh, K.D., Hershauer, J.C., Tommelein, I.D. and Walsh, T.A. (2004) “Strategic Positioning of Inventory to Match Demand in a Capital Projects Supply Chain.” *J. of Constr. Engrg. and Mgmt.*, 130 (6), 818-826.