The impact of construction commencement intervals on residential production building

Ehsan Gharaie[1] Ronald Wakefield[2] Nick Blismas[3]

Abstract: One model of operation that production builders can use is continuous construction. They build typical house models and generally work with the same subcontractors. In this continuous operation, an order from the sales department triggers the process, which only commences construction when the first required crew becomes available. In this system the decision to commence construction relies on the readiness of the first activity. However the effects of this decision on the whole construction process are often ignored. This research aims to shed light on the importance of construction commencement decisions by highlighting the consequences of this decision on the whole production system. To investigate these effects, the production of 200 houses was modelled. Simulations of various scenarios based on different construction commencement intervals were undertaken and their results compared. While the aim of the research was to show the importance of construction commencement decisions to project managers, critical parameters like resource utilization, project duration, construction duration and capital cost were also simulated as a result. The results show that a decrease in the commencement interval can increase resource utilization; however there is a maximum possible utilization that cannot be exceeded regardless of the number of jobs in the construction process. Further, project duration can be affected by the construction commencement rate. It likewise has a minimum duration that cannot be reduced without changing the operation structure. This research has shown that production rate is dictated by the slowest activity, and it is therefore essential that the project manager make the construction commencement decisions fully aware of the slowest production rate. In addition, this work emphasizes the importance of the production structure and the logic behind the activities' relationships. It shows that as long as a construction process is established and unchanged, it has its own capacity and production rate, beyond which the addition of more house commencements does not necessarily lead to higher productivity.

Key words: Production Building, Construction Commencement, Modelling, Resource Utilization.

1. INTRODUCTION

The importance of construction commencement intervals in residential construction is usually ignored by project managers. In the case of large residential contractors, the commencement of construction for each house is decided based on the sale and availability of the first crew that starts construction. Therefore as soon as conditions for the start of a new job are met and there is an order for the house, construction starts. However, residential construction does not simply consist of a single activity. It includes many activities with their related essential human and material resource limitations. These activities affect each other as well as the whole process of construction. It means that the start of a new house can affect the whole construction operation and should be decided under the consideration of the whole process and not just the first activity of the process.

This paper shows the importance of construction commencement decisions and the parameters that are affected by this decision. For this purpose a production construction process has been modelled. The details and specifications of the process are derived from a real production building process for transportable houses.

A simulated project of 200 houses was used as a benchmark to compare different commencement interval scenarios, enabling an analysis of the resultant operations.

2. DEFINITIONS AND ASSUMPTIONS

There are some terms and assumptions used in this research that can affect the understanding of the results. The following are used in this paper: *Project* in this paper refers to the construction of 200 identical houses; *Project duration* to the duration of all 200 houses; *Construction duration* refers to the duration for the construction of a single house, starting with the first construction activity and finishing with commissioning; *Commencement interval* refers to the time between two successive construction commencements; *Commencement interval decision* is the decision determining the commencement interval duration, which is assumed to remain constant during the project; *Job* refers to work undertaken by a particular crew; *Resources* in this paper refers to human resources alone.

Further assumptions underpinning this model, are that there is only one crew available for each activity, and that these do not change during the project in terms of size or productivity.

3. LITERATURE REVIEW

A Production planning perspective of construction has only gained attention since the 1990's. In this view a construction project consists of a series of interconnected work processes that can be running serially or concurrently (Sawhney, 2009; Palaniappan, 2007). The focus is on the flow of work instead of the work processes. It suggests that a project manager with the production

[1] PhD Candidate, School of Property, Construction and Project Management, RMIT, Melbourne, Australia; PH (61) 3 99251724; FAX (61) 3 9925 1939; Email: ehsan.gharaie@rmit.edu.au
[2] Professor, Head of School, School of Property, Construction and Project Management, RMIT, Melbourne, Australia; PH (61) 3 9925 3448; FAX (61) 3 9925 1939; Email: ron.wakefield@rmit.edu.au
[3] Associate Professor, Head of Construction Management Decipline, School of Property, Construction and Project Management, RMIT, Melbourne, Australia; PH (61) 3 9925 5056; FAX (61) 3 9925 1939; Email: nick.blismas@rmit.edu.au

planning concern should manage, control and maintain the flow of work either within the processes or between them (Koskela, 1992; Howell, 1993; Tommelein, 1999; Koskela, 2000; Ballard, 1998).

O'Brien et al. (2000) have suggested the homebuilders who want to refine their existing field processes use production modelling, analysis and simulation systems. They divided homebuilders into four groups; namely small-volume, medium-volume, high-volume and production homebuilders. The construction process in the medium and high volume homebuilders tend to be on-site. Although production builders work in a factory-like environment, surprisingly they tend to follow the same construction process as conventional on-site homebuilders. In all three groups, the homebuilders use trades and subcontractors to undertake each process and the product of one process becomes the raw material for the next one. Willenbrock (1998) argues that the production planning view can be adopted in residential construction with such a system.

Simulation allows project managers to experiment with different planning strategies that can help them modify their production process. The use of simulation methods in construction did not receive much attention until late 1960's, after the emergence of desktop computers (Abourizk, 1992). The application of simulation became popular in construction with the development of CYCLONE (Halpin, 1977). This methodology became a foundation for other researchers to develop new simulation tools for use in construction (Palaniappan, 2007). Research into production planning, has favoured simulation as evidenced in the literature (Sawhney, 2001; Sawhney, 2005; Wang, 2006; Sacks, 2009; Sawhney, 2009).

As mentioned above, production planning attempts to manage the flow of work within and between work processes. With this view the parameters like cycle time (Koskela, 1999; Bashford, 2005a; Bashford, 2005b), work in progress (González, 2009; Sacks, 2009), work variability (Sawhney, 2009; Tommelein, 1999), work continuity (Machine, 20090) and buffers (Howell, 1993; Thomas, 2004; Horman, 2005) should be considered.

Hopp and Spearman (2001) suggest that one of the conditions for having a production line with a constant and predictable cycle time is that commencement decisions are made based on the production line specification. The fact that the number of commencements can affect the cycle time has been mentioned in Bashford et al.'s (2005b) work. However this paper is trying to take a closer look at commencement interval decision and investigate the consequences of this decision on resource utilization, project duration and capital cost, as well as cycle time.

4. MODELLING

Palaniappan et al. (2007) suggest that to model a generic construction process and capture the work flow characteristics, four constructs should be considered in the model, which are described as following:

i. Generating a set of work items per time period

This construct produces work items per time period. In the case of residential construction, this part of the model manages the commencement of construction.

ii. Computing the number of work items per time period at any downstream step

The work flow variability can be calculated by counting the number of work items before or after a process per time.

iii. Work in Process (WIP)

This construct counts the number of work items in production, in this case, the number of houses under construction.

iv. Number of work items waiting for a resource

The bottlenecks in the process can be identified by the number of work items waiting before a process component. In production building the number of the waiting work items is known as the number of idle houses.

4.1 Modelling the Case Study

The sample process that has been modelled is based on a real production building process. The whole process consists of 23 activities undertaken by 18 sub-contractors or crews. The list of activities and their related durations are shown in table 1. These durations were obtained by observation and interviews at the construction site with sub-contractors and the site manager. They are generally the most probable time needed for completion of the activities.

These activity durations are probabilistic. However considering this parameter as probabilistic adds to the complexity of the model and affects the basic understanding of the production building operation. Therefore the analysis has been completed with a deterministic approach. The activity durations are indicated in table 1.

The other specifications of the model include the relationship between activities, the structure of the operation and the human resources related to each activity. Figure 1 is a schematic of the model. In this figure the relationship between activities and resources can be seen. Note that the first work centre is the implementer of the first construct mentioned above and the second work centre component is a WIP or NHUC controller.

As illustrated in figure 1, there are 18 crews assigned for completion of the whole process. It is assumed that the size of the crews is limited and constant during the project. This assumption is based on observation where resources were limited. The capacity of the resources and their production limitations also have considerable influence on the design of the production process.

4.2 Simulation of different commencement intervals scenarios

The decision to commence construction and the interval between commencements is the starting point for the operation. Production building like any other operation can be influenced by this decision. Determining this influence and to what extent it modifies production capacity is the subject of the following sections.

In this regard, different scenarios for commencement intervals were used and other parameters like resource utilization, construction duration, project duration and number of houses under construction were monitored against these scenarios. The reasons for selecting these parameters and the way that they affect the project's success will be explained at the beginning of each related section. It should be noted that in this paper construction commencement refers to the start of the construction of each house.

The scenarios for commencement intervals are between 1 day to 10 day intervals. The commencement interval is a part of project planning and is decided before the project starts. This means the intervals remain unchanged during project implementation. It is assumed that the intervals keep constant during the project.

Table 1: Construction process activities and their durations

Activity number	Activity	Duration (day)	Activity number	Activity	Duration (day)
1	Floor Slab	1	13	2nd Fix Carpentry	2
2	Wall Framing	1	14	Kitchen Fitting	1
3	Wall Cladding	2	15	Tiling	4
4	Electrical Rough In	1	16	Painting	5
5	Plumbing Rough In	0.5	17	Electrical Fit Out	0.5
6	Roof Trusses	0.5	18	Plumbing Fit Out	0.5
7	Roofing	1	19	Shower Screen	0.5
8	Insulation	0.5	20	Carpeting	0.5
9	Gyprocking	1	21	Cleaning	1
10	Joint Finishing	2	22	Transportation	2
11	Cornicing	1	23	Commissioning	1
12	Sanding	1			

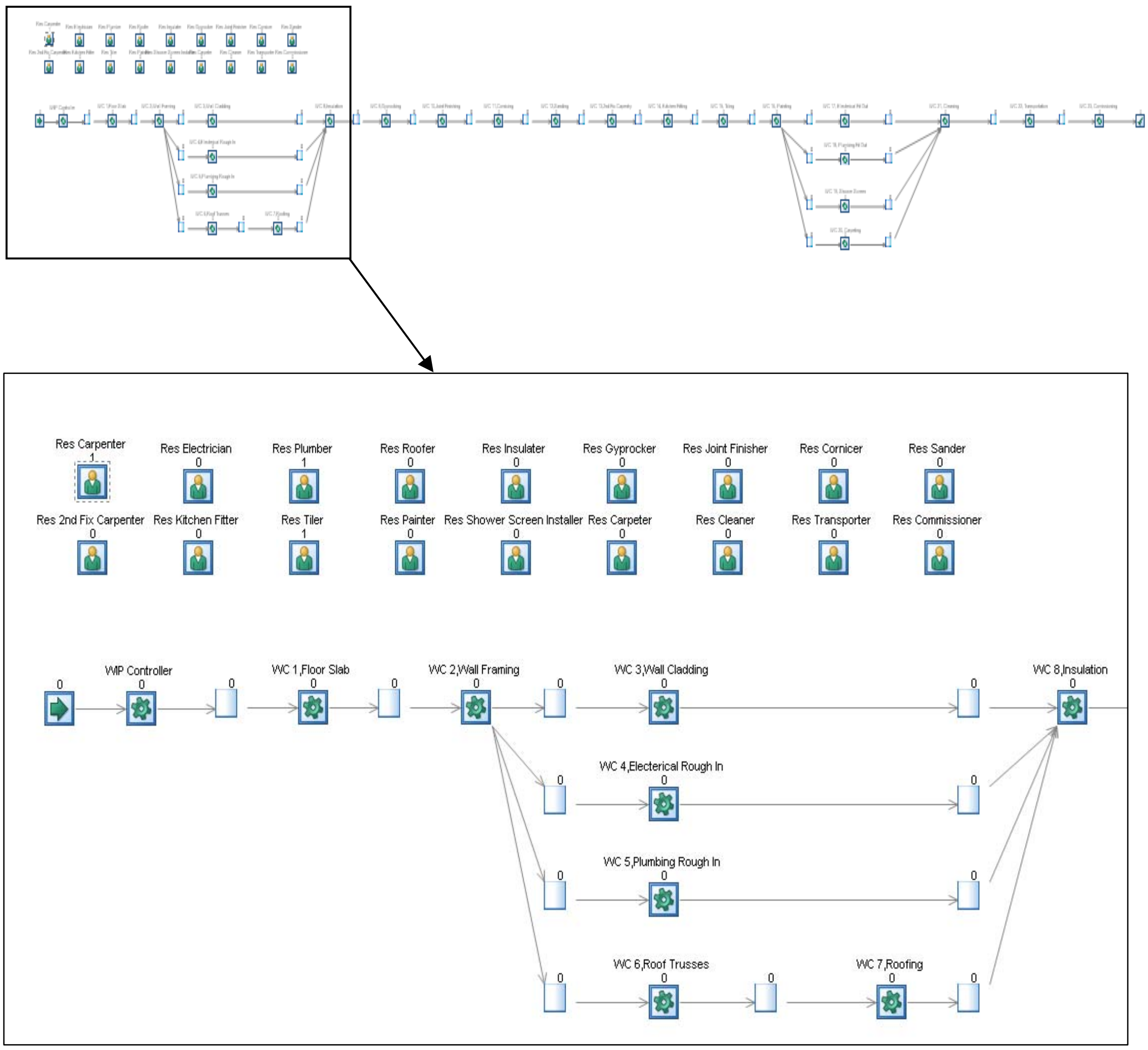

Figure 1: Schematic model of a production building projects (SIMUL8 software)

4.3 Resource utilization

As described above, one of the reasons for project managers starting a new house is the availability of work crews. An available crew is one without a job but ready to work. This availability is costly for the contractor. Therefore one of the responsibilities of a project manager is to keep the crews busy and therefore increase resource utilization. In this regard, project managers, whenever possible, will start new construction and push the production process.

To investigate the level of utilization, it is assumed that all the crews are employed in-house by the general contractor. Their contracts start on the first job assignment and finish on the completion of the last job. It should be noted that job refers to the activity performed by the crew and does not mean the construction of the whole house. With this assumption if a special crew needs 1 day to finish its job and the project consists of 200 houses, it has to work for 200 days during the project. In this case if the crew is employed for 400 days, the utilization would be 200 days out of 400 or 50 percent.

Figure 2 shows the utilization of some of the crews in different commencement interval scenarios.

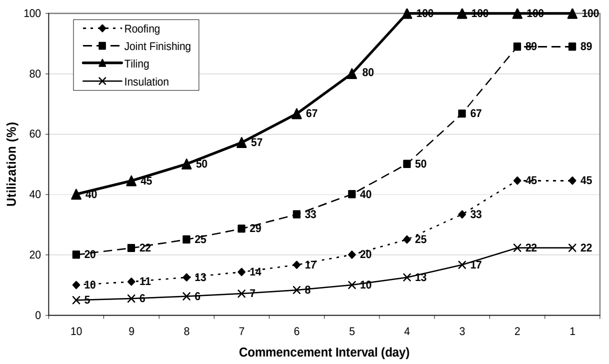

Figure 2: the resource utilization for some of the crews in different interval scenarios

Figure 2 clearly shows that shortening the commencement interval leads to an increase in utilization. Therefore from a utilization perspective it could be a beneficial decision for the project manager to push the production process and start new houses with shorter commencement intervals.

In addition to the trend of utilization, figure 2 shows that there is a maximum utilization for all four activities. The graph shows 100 percent utilization for the tiling activity with the commencement intervals equal to or less than 4 days. But the maximum utilization for roofing is about 45 percent. It means pushing the production line with shorter commencement intervals can increase the utilization of the resources but it loses its effect at some point in time. Therefore there are other parameters in the production line that affect the resource utilization and prevent it from reaching 100 percent.

The existence of this maximum utilization can be insightful for managers. This maximum level can be crucial for an activity like insulation where it reaches only 22 percent utilization (fig.2). For an activity with only 22 percent utilization the best decision could be outsourcing. Therefore it can be concluded that although faster commencements or shorter intervals can increase the utilization, there is a limitation to this utilization. This provides information to project managers allowing them to recognize the low level utilized resources and outsource them.

4.4 Project and Construction Duration

Project duration is always one of the main concerns for a project manager. Extension of this duration can result in an unbearable overhead or penalty for the project and loss of reputation for the contractor. In production building, decreasing the project duration can be another incentive for the project manager to push the production operation. It seems logical to think that if construction starts sooner, it would be finished sooner and consequently the project duration would be shorter.

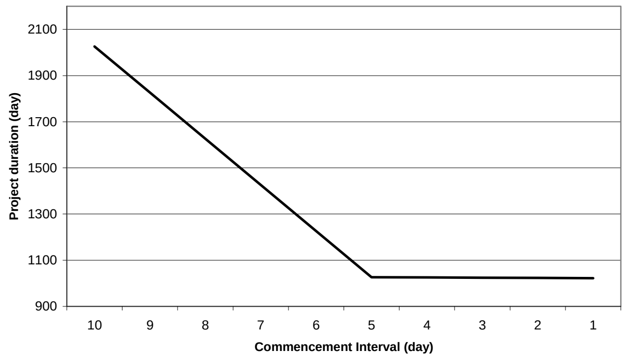

Figure 3: project duration in different commencement intervals scenarios

Verification of this perception led to an investigation of the effect of commencement interval on the project duration. Figure 3 is the result of this investigation. This graph shows that the project duration shortens if the intervals decrease up to an interval of 5 days. But it almost keeps constant after this point. This means the perception that a sooner start results in a sooner finish can only be true to some extent. The shortening of the intervals can affect the project duration and make it shorter but this loses its effect after some point. In this case a 5 day interval is the point at which shortening of the intervals loses its effect.

Beside the project duration, construction duration also affects the project's success. Construction duration is an important factor in holding cost and cash flow of the project. Longer construction duration means a slower return of investment and higher holding cost for the project. Therefore this part of the research attempts to clarify the impact of commencement interval decisions on the construction duration. For this purpose, the construction duration of each house has been derived from the simulation and illustrated in figure 4.

In figure 4 the horizontal axis is the house number and the vertical axis is construction duration. For example this graph shows that it takes 300 days for house number 75 to be completed in a 1 day commencement interval production scenario. Knowing that construction of a house can be completed in 26 days (less than a month), in the extreme case the construction duration for house number 200 which takes 800 days (more than 2 years) can clearly show the disastrous effect of pushing a production building operation to have more jobs at the starting point.

Figure 4 shows that lengthening commencement intervals shortens the construction durations. This trend goes on up to the 5 day intervals where it reaches the minimum level. But these intervals do not only affect the construction duration, but also affect the project duration. Figure 3 showed that as long as the intervals are under 5 days, lengthening the intervals does not harm the project duration. But intervals longer than 5 days extend the project duration. Therefore considering both figure 3 and 4, it can be concluded that the best interval for this particular project that can keep the construction duration and project duration at a minimum is 5 days.

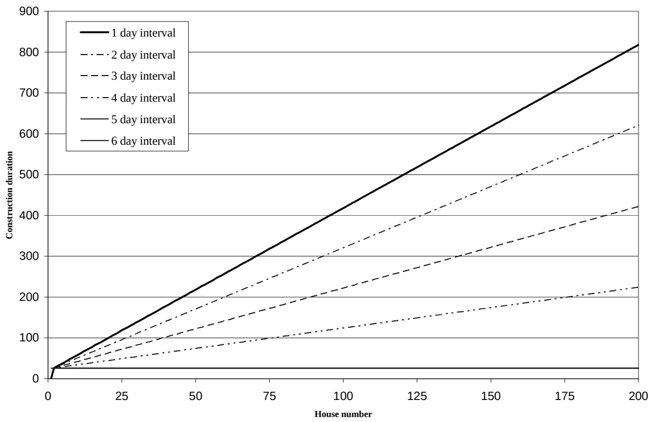

Figure 4: construction duration for each house in different commencement interval scenarios

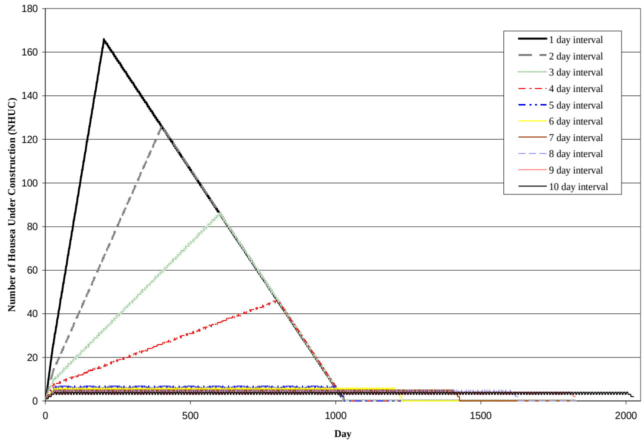

Figure 5: number of houses under construction during the project

It should be mentioned that keeping production on a commencement interval of 5 days prevents the construction operation from reaching its maximum resource utilization (fig. 1). Therefore a trade-off should be made between construction/project duration and resource utilization.

4.5 Number of houses under construction

Long construction durations can be very disadvantageous. However knowing how and to what extent are not clearly understood. It is clear that a house under construction represents a case where capital has been invested but the income has not yet been realised. Therefore more houses under construction means more investment funds tied up, higher risk of success and more finance cost.

Figure 5 shows the effect of decreasing the intervals between each construction commencement on the number of houses under construction (NHUC). NHUC in construction operation is basically the same concept as WIP in operations management. The horizontal axis in this figure is time and the vertical axis is NHUC. The graphs show the number of houses under construction for each day of the project. The project is complete when there are no more houses under construction and the graph reaches zero NHUC.

Simulation of 1 day intervals shows that there is a time when there are more than 160 houses under construction, which requires huge investment. The upward slope in figure 5 shows the rate of construction commencement and the declining slope of the graphs represents the completion rate. The higher rate of commencement or steeper upward slope does not lead to a higher rate of completion; instead the completion rate keeps constant for intervals between 1 day and 5 days. Based on this figure, the result of pushing the production line to start the new construction faster is a higher NHUC.

The project's capital cost is a function of duration and volume of investment. Figure 5 showed that a decrease in commencement intervals results in an increased volume of investment. At the same time this decrease makes the construction duration or investment time longer (figure 4). Therefore with larger volume and longer time of investment, it can be concluded that the direct consequence of shortening the intervals is an increase in capital cost.

It should be noted that the minimum project and construction duration could be achieved by 5 day interval. This interval could also maintain the NHUC at the minimum level. Looking at the activity durations shows that the longest activity is painting with the duration of 5 days. This is the activity which dictates the production rate and consequently the finish date of the project and the best interval rate for reaching maximum profit. Therefore it can be concluded that the construction commencement decision in production building process should be decided based on the slowest activity.

5 CONCLUSIONS

In residential construction the commencement of construction is usually decided based on the existence of an order and availability of the related crew for the first activity. These two preconditions for construction commencement ignore the rest of the construction process and the limitations of resources and activities. On the other hand, reaching higher resource utilization and the perception of "sooner start-sooner finish" encourage project managers to start the construction of houses as soon as it is possible. This research has tried to show the result of this perception on production and the importance of the commencement decision.

It has shown that a shorter interval can increase the utilization of the resources but this utilization has a limitation and in many cases the resources do not reach 100 percent utilization. In fact there is a maximum possible utilization for all resources. This maximum utilization can be a decision making point for outsourcing.

The perception of "sooner start-sooner finish" was also investigated. The simulation of shorter than 5 day commencement intervals showed a constant project duration. Therefore that perception of sooner start is not essentially correct. In addition, monitoring the number of houses under construction during the project proved that the shorter intervals can be disastrous for the contractor instead of being beneficial.

The common point between different parts of these analyses was the importance of the production rate of the slowest activity; in this case 5 days. It has been shown that if the commencement interval is decided based on the slowest activity, the minimum project and construction duration and minimum capital cost will be achieved. Therefore finding the slowest activity is vital for the project manager in this type of production building process. The construction commencement decision should be decided based on the slowest activity and not the availability of the first crew or existence of a construction order.

REFERENCES

Abourizk, S., M, Halpin, D. W. & Lutz, J. D. (1992) "State of the art in construction simulation." *Proceedings of the 24th conference on Winter simulation*, 1271-1277, Arlington, Virginia, US, ACM.

Ballard, G. & Howell, G. (1998) "What kind of production is construction? ", *6th Annual Conf. of Int. Group for Lean Construction*, Univ. of California, Berkely.

Bashford, H., Sawhney, A., Walsh, K. & Thompson, J. (2005a) "Residential Construction and the Influence of Inspections on Cycle Time." *IN IRIS, D. T. (Ed.) Construction Research Congress 2005*, 15-21, ASCE.

Bashford, H. H., Walsh, K. D. & Sawhney, A. (2005b) "Production System Loading-Cycle Time Relationship in Residential Construction." *ASCE Journal of construction engineering and management*, 131, 15-22.

González, V., Alarcón, L. F. & Molenaar, K. (2009) "Multiobjective design of Work-In-Process buffer for scheduling repetitive building projects. ", *Automation in Construction*, 18, 95-108.

Halpin, D. W. (1977) "CYCLONE: Method for Modeling of Job Site Processes", *Journal of the Construction Division*, 103, 489-499.

Hopp, W. J. & Spearman, M. L. (2001) *Factory Physics*, McGraw Hill Higher Education.

Horman, M. J. & Thomas, H. R. (2005) "Role of Inventory Buffers in Construction Labour Performance", *ASCE Journal of construction engineering and management*, 131, 834-843.

Howell, G., Laufer, A. & Ballard, G. (1993) "Interaction between Subcycles: One Key to Improved Methods." *ASCE Journal of construction engineering and management*, 119, 714-728.

Koskela, L. (1992) *Application of the New Production Philosophy of Construction*. CIFE.

Koskela, L. (1999) "Management of Production in Construction: A Theoretical View." *Proceedings of 7th Annual Conererence of Inernational. Group for Lean Construction*. 241-252, Univ. of California, Berkley, Calif., International Group for Lean Construction.

Koskela, L. (2000) "An Exploration Towards a Production Theory and its Application to Construction." PhD thesis, Espoo, Finland, VTT Building Technology.

O'Brien, M., Wakefield, R. & Beliveau, Y. (2000) *Industrializing the Residential Construction Site.* Washington, DC, U.S. Department of Housing and Urban Development, Office of Policy Development and Research.

Palaniappan, S., Sawhney, A., Bashford, H. H. & Walsh, K. D. (2007) "Special purpose simulation template for workflow analysis in construction." *Proceedings of the 39th conference on Winter simulation*. 2090-2098, Washington D.C., IEEE Press.

Sacks, R. & Partouche, R. (2009) "Production Flow in the Construction of Tall Buildings." *Prodeedings of Construction Research Congress*, 1019-1028, Seattle, Washington, ASCE.

Sawhney, A., Bashford, H., Palaniappan, S., Walsh, K. & Thompson, J. (2005) "A Discrete Event Simulation Model to Analyze the Residential Construction Inspection Process." *ASCE International Conference on Computing in Civil Engineering*, 179, 134-144.

Sawhney, A., Bashford, H., Walsh, K., ANDR & MUND (2001) "Construction II: simulation of production homebuilding using simphony." *Proceedings of the 33rd conference on Winter simulation* , 1521-1527, Arlington, Virginia, IEEE Computer Society.

Sawhney, A., Walsh, K. D., Bashford, H. H. & Palaniappan, S. (2009) "Impact of Inspected Buffers on Production Parameters of Construction Processes". *ASCE Journal of construction engineering and management*, 135, 319-329.

Thomas, H. R., Michael, J. H. & Ubiraci Espinelli Lemes De, S. (2004) "Symbiotic Crew Relationships and Labor Flow." *ASCE Journal of construction engineering and management*, 130, 908-917.

Tommelein, I. D., Riley, D. R. & Howell, G. A. (1999) "Parade Game: Impact of Work Flow Variability on Trade Performance." *ASCE Journal of construction engineering and management*, 125, 304-310.

Wang, P. (2006) Production-based large scale construction simulation modelling. PhD Thesis, University of Alberta (Canada).

Willenbrock, J. H. (1998) *Residential building design and construction*, Upper Saddle River, N.J., Prentice-Hall.