MODELING THE IMPACT OF MULTISKILLING AND CONCRETE BATCH SIZE IN MULTI-STOREY BUILDINGS

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ABSTRACT

This paper illustrates the use of a simulation model to explore ways to decrease idle time due to the lack of available working inventory during the primary phase in the construction of a multi-story building. Two strategies are analyzed: increased frequency of concreting operations and the use of multi-skilled workers who use their additional trade when there is a lack of work in their area, or when there is a shortage of employees in another area in which they are proficient.

The work involved field observations in a multistory building to obtain data to build and calibrate a simulation model. In the first strategy, the results show that it would be possible to complete the primary phase using 16% less workers or in 10% less time, if concrete is poured daily instead of every other day. In the second strategy, the results show that, in average, it would be possible to complete the primary phase using 14% less workers or in 6% less time, when 30% of the workers are assumed to be multi-skilled. Upon implementing both strategies simultaneously, the results show it would be possible to complete the primary phase using 22% less workers, or in 16% less time.

KEYWORDS

Multiskilling, lean construction.

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INTRODUCTION

In the last few years, there has been a growing interest in improving the productivity in the Chilean construction industry. There is evidence that the productivity of the construction industry in Chile is lagging with respect to that of other industries. Given the importance of the construction industry for the Chilean economy, it is very important to try to improve its productivity. As an effort in this direction, a multidisciplinary team of researchers undertook a three-year R&D project with the participation of several construction firms and with governmental funding. The main idea of this project was to study different approaches that could be applied to construction management practices that improve productivity.

In the study we describe in this paper, which is part of this research project, the objective was to find ways to improve the productivity of building multi-story buildings. The assumption was that since the construction of each story is a repetitive process, any improvement we could find in constructing one story would have an important impact in the overall productivity.

The study began with a field study in the construction site of a multi-story building. The researchers looked for ways to apply lean construction principles (Howell, 1999) to improve the productivity. It soon became apparent that one of the main problems was the idle time of the workers induced by lack of the working inventory during the primary phase of construction. This lack of work inventory was due to the variability of the speed in which each crew advances. If one crew slowed down, the crew that was working behind it would "bump" into them and be forced to be idle until enough space became available. The impact of work flow variability was described by Tommelein et al. (1998) and Alarcón (1999). Another important cause of the idle time was the need to wait for the concrete to be poured, which was only done every other day.

In order to deal with the work flow variability, we proposed the use of multiskilling, which has been used in both manufacturing and construction firms (see Haas, Stanley, and Tucker 1997 and Haas, Tucker, and Villalobos 1997). We also proposed to study the possibility of pouring concrete more often.

In the next section, we discuss different methodologies that could be used to estimate the impact of multiskilling and concrete batch size reduction in the productivity in the construction of a multi-story building. We then present the model used to estimate the impact and the results. We finish with some concluding remarks.

ESTIMATING THE IMPACT OF MULTISKILLING AND CONCRETE BATCH SIZE REDUCTION

Multiskilling consists of a workforce in which workers possess several skills that allow them to perform different tasks. We propose using multi-skilled workers who perform their primary skill in their normal construction unit as much as possible, and who use their additional trade when there is a lack of work in their area or when there is a shortage of workers in another area in which they are proficient.

Multiskilling is not easily implemented. It requires significant investments, training, and changes in labor management. Therefore, it is important to estimate the benefits of implementing this strategy in order to convince management to make this change. Some studies (Haas, Tucker, and Villalobos 1997) have shown that it is possible to obtain a reduction of 30 to 35% in the number of required workers. Furthermore, most of these benefits can be obtained with only a partially multiskilled workforce.

There have been several different approaches that have been proposed to estimate the impact of the use of multiskilling using mathematical models and simulation. Gomar et al. (2002) developed a linear programming model to help optimize the multiskilled workforce assignment and allocation process in a construction project. Burleson et al. (1998) developed an analysis model to assess four multiskilling strategies on the construction of a $70 million project. They estimated benefits of 5-20% in labor cost savings, a 35% reduction in required workforce, a 47% increase in average employment duration, and an increase in earning potential for multiskilled construction workers. Campbell (1999) developed a nonlinear programming model for allocating cross-trained workers at the beginning of a shift in a multidepartment service environment. He used this model in a series of experiments to investigate the value of cross-utilization as a function of factors such as demand variability and levels of cross-training. Grag et al. (2002) developed a simulation-based model to examine the trade-offs between absorbing demand variability by the use of multiskilled operators or by holding finished goods inventory.

THE MODEL

We developed a Montecarlo simulation model that describes the interactions between different construction units, or crews, in the primary phase of the construction of a multi-story building. Each unit was assumed to have a fixed number of workers and, if not impeded by any obstacle, the more workers a unit has, the faster it can advance.

We identified 25 processes required to build a single story, in the primary phase. However, it was not hard to reduce the number of most important processes to the following ten:

Table 1: Most important processes

Process	Description
A	Removal of Wall forms and Slab forms
B	Wall treatment
C	Slab steel reinforcement
D	Electric installations in slabs
E	Water and gas installations
F	Heating installation
G	Slab concreting
H	Wall reinforcement
I	Wall forming
J	Wall concreting

Each of these processes is carried out by the following units:

Table 2: Units assigned to each process

Unit	Unit Description	Process
[A+I]	Holding carpenters	A and I
[B]	Wall treatment worker	B
[C+H]	Steel reinforcement crew	C and H
[D]	Electricians	D
[E]	Plumbers	E
[F]	Heating Installers	F
[G+J]	Concreting crew	G and J

The following figure illustrates the sequence of the different processes:

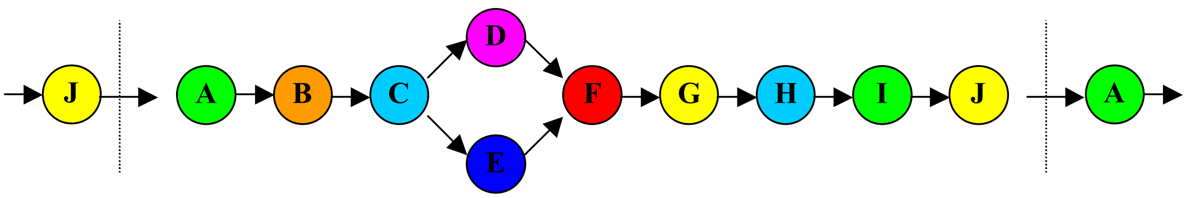

Figure 1: Sequence of main processes

From Figure 1 we can see that only two processes, D and E, can be carried out at the same time. All the other processes are sequential. It can also be seen that these processes are cyclical; after J comes A.

Based on our field observations, we made the following assumptions to build the model:

- Each iteration lasts for half an hour.
- The work day is 9 hours long.
- The model considers that the construction of a story takes 6 days.
- The building is three stories high.
- Since the model is cyclical, we will use degrees instead of square meters to describe the advance of the construction. The construction of one story is 360º and the construction of three stories is 1080º, which should take 324 iterations.
- Each worker possesses only one skill.
- Each worker requires some space, which depends on the process.
- Absenteeism is 5%
- Concrete pouring of the floor is performed every other day during the last 9 iterations (half day). The concrete is dry and it is possible to continue work at the beginning of the next day.
- Concrete pouring of the walls is performed every day during the first 6 iterations. The concrete takes the rest of the day to dry. The molding can be removed early next day.

These assumptions allowed us to build a model that could be used to explore ways to decrease the idle time we had observed in the field. Therefore, many of the assumptions we made, such as the duration of the work day, the time required to build a story, the absenteeism, and the way concrete was poured, tried to duplicate the conditions that we had observed in the field. Of course, this limits the applicability of the results to cases which are similar to the one we observed.

We also assumed that when workers can be assigned to more than one process, such as holding carpenters, steel reinforcement, and concreting crews, they can be reassigned every iteration, according to the needs of that moment. We use a priority function for determining which process should have more workers.

The initial number of workers in each unit is shown in the next table:

Table 3: Number of workers per unit

Unit	Workers
[A+I]	20
[B]	1
[C+H]	20
[D]	6
[E]	4
[F]	2
[G+J]	6
Total	59

As long as each process has the same priority, and there is enough space for the workers, there is a standard number of workers assigned to each process. The model assumes that each worker advances at a certain speed, which is subject to a certain degree of variability. The speed of the crew is determined by the individual performance of the workers. The model also considers a certain space required by each worker, which is different for each process. In some processes, such as the slab steel reinforcement, can have a larger number of workers in a certain amount of space. If, at a certain point of time, there is not enough space for all the workers of the crew, some must remain idle.

The model assumes that each process has certain variability. We assumed the same variability function for all processes. This variability represents the differences in individual performance, delays from lack of materials, the need to redo some work, etc.

The model was implemented in an Excel worksheet using the random function to simulate the uncertainties. For example, the 5% absenteeism is simulated as a 5% probability that any single worker will not show up on any given day. The model also considers there is variability in each process, which is also implemented using the random function in Excel.

The model has some limitations that are worth noting:

- The model only considers the main processes, ignoring the rest
- In the real world, when workers are idle, they can be sent to perform other tasks, which require very little skill.

- Although the parameters of the model were calibrated based on the field study, it would be important to perform more measurements in other construction projects.

The model was used to estimate the impact of multiskilling and concrete batch size reduction. The use of multiskilling is modeled by assuming that when a process does not have enough space to enable all of the workers to be active, inactive workers are sent to work in another process which has enough free space to allow the extra workers to become active. The unit that gives up workers slows down, while the unit that gains workers speeds up. When the conditions allow it, the workers return to their original unit. Workers must be multiskilled in order to be sent to another unit. Not all workers are multiskilled. In fact, we will assume only 30% of workers are multiskilled. This is enough to achieve most of the benefits of multiskilling.

The increase in the frequency of concrete pouring from every other day to every day reduces the batch size, which allows more continuity in the work flow.

RESULTS

The questions we were interested in answering using the model were the following:

- What is the improvement that can be achieved by using a multiskilled workforce in the primary phase of the construction of a multistory building?
- What is the improvement that can be achieved by increasing the frequency of concrete pouring during the primary phase of the construction of a multistory building?

In order to answer these questions, we considered a scenario in which three stories are built in 18 working days. There is variability and absenteeism. The model was then modified to allow multiskilling of 30% of the workforce and an increase in the frequency of concrete pouring.

Besides the main scenario, we assumed two other scenarios, one which considers that workers require 33% less space to perform their tasks and another in which they require 33% more space. This reflects our uncertainty respect to the true value of this parameter. Having these scenarios gives us an idea of the sensitivity of the results with respect to the value of this parameter. The different versions of the model were run 100 times for each scenario.

For the first question, the use of multiskilling, the results we obtained are the following. When the objective is to advance faster with the same resources, multiskilling allows finishing in 7,3%, 5,7%, or 4,3% less time, depending on the scenario. When the objective is to advance at the same speed, but using less resources, multiskilling allowed using 13,6% less workers, in any of the three scenarios.

For the second question, that is, increasing the frequency of concrete pouring, the results we obtained were the following. When the strategy is advancing faster with the same resources, more frequent concrete pouring allowed finishing in 7,9%, 10,6%, or 12,4% less time, depending on the scenario. When the objective is to advance at the same speed but with less resources, more frequent concrete pouring allowed using 10,2%, 15,3% or 22,0% less workers.

If both multiskilling and more frequent concrete pouring are simultaneously put into practice, the results are as follows. When the strategy is advancing faster with the same resources, more frequent concrete pouring allowed finishing in 12,6%, 18,0%, or 17,5% less time, depending on the scenario. When the objective is to advance at the same speed but with less resources, more frequent concrete pouring allowed using 15,3%, 20,3% or 28,8% less workers.

The following table summarizes these results.

Table 4: Summary of main results of the simulation model

	Advance faster objective			Minimize resources objective		
Scenarios	***1***	***2***	***3***	***1***	***2***	***3***
Multiskilling	7,3%	5,7%	4,3%	13,6%	13,6%	13,6%
More frequent concrete pouring	7,9%	10,6%	12,4%	10,2%	15,3%	22,0%
Both	12,6%	18,0%	17,5%	15,3%	20,3%	28,8%

Based on these results we estimated the savings with respect to the total cost of the primary phase of the construction costs, which are given in the following table.

Table 5: Savings with respect to the total construction costs of the primary phase

	Advance faster objective			Minimize resources objective		
Scenarios	***1***	***2***	***3***	***1***	***2***	***3***
Multiskilling	3,5%	2,8%	2,1%	4,0%	4,3%	4,1%
More frequent concrete pouring	3,8%	5,1%	5,9%	3,9%	4,9%	6,7%
Both	6,1%	8,6%	8,4%	5,0%	6,8%	8,7%

It is important to note that this is a conservative estimate, since we don’t take into account the additional income that could be possibly generated by finishing earlier and being able to undertake new projects.

The results clearly show that the best option is to follow both strategies: use multiskilling and use more frequent concrete pouring. However, the technical feasibility of this last option depends on the design of the building. Since the slab tends to weaken in the boundaries of the concrete pouring zone, more frequent pouring may not be feasible for certain designs.

CONCLUSIONS

Multiskilling and increased frequency of concrete pouring are two strategies we proposed for reducing the idle times of workers we observed in the primary phase of the construction of a multistory building. In order to estimate the benefits of each of these strategies, and of both of them together, a simple Montecarlo simulation model was developed and implemented in a spreadsheet. After some experimentation we conclude that it would be possible to complete the primary phase using 13,6% fewer workers or in 5,7% less time, in average, when 30% of the workers are assumed to be multi-skilled. If concrete is poured daily instead of every other day, the results show that 15,3% fewer workers or 10,6 % less time would be required. Upon implementing both strategies simultaneously, the results show it would be possible to complete the primary phase using 20,3% fewer workers, or in 18% less time.

We believe the results are interesting enough to explore in more detail the feasibility of both approaches. Multiskilling requires investing in cross-training of part of the workforce and complicates workforce management, especially when subcontractors are involved. Increased frequency of concrete pouring, on the other hand, may not be technically feasible in certain cases.

We conclude that the approach we used to look for strategies to increase productivity worked very well, thanks to the collaboration of the participating firm. This kind of collaborative effort, that combines research with a real problem, can yield results that are of interest to both researchers and practitioners, and can ultimately help to close the productivity gap the Chilean construction industry has with respect to other industries.

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REFERENCES

Alarcón, L. F. and Ashley, B. (1999) Playing Games: Evaluating the Impact of Lean Production Strategies on Project Cost and Schedule. *Proceedings of the 7th Annual Conference of the International Group for Lean Construction, IGLC-7*.CA, USA, 26-28 July 1999, pp. 263-274.

Burleson, R., Haas, C., Tucker, R., and Stanley, A. (1998) "Assignment and Allocation Optimization of Partially Multiskilled Workforce." *J. Constr. Engrg. and Mgmt.*, ASCE, New York, NY, 124 (6) 480-489.

Campbell, G. (1999) "Cross-utilization of workers whose capabilities differ." *Management Science*, 45 (5) 722-732.

Garg, S., Vrat, P., and Kanda, A. (2002) "Trade-offs between multiskilling and inventory in assembly line operations under demand variability." *International Journal of Operations & Production Management*, 22 (5-6) 565-583.

Gomar, J., Haas, C., and Morton, D. (2002) "Assignment and Allocation Optimization of Partially Multiskilled Workforce." *J. Constr. Engrg. and Mgmt.*, ASCE, New York, NY, 128 (2) 103-109.

Haas, C., Stanley, A., and Tucker, R. (1997) "Multiskilling Labor Strategies in Construction: Experiences with Multiskilling Labor Strategies in the Construction Industry." *A Report to the Construction Industry Institute (CII)*, The University of Texas at Austin, Austin, TX, USA.

Haas, C., Tucker, R., and Villalobos, J. (1997) "Multiskilling Labor Strategies in Construction: Implementation of Multiskilling in the Construction Industry." *A Report to* *the Construction Industry Institute (CII)*, The University of Texas at Austin, Austin, TX, USA.

Howell, G. (1999) "What is Lean Construction — 1999." *Proceedings of the 7th Annual Conference of the International Group for Lean Construction, IGLC-7.* Berkeley, CA, USA, 26-28 July 1999, pp. 1-10.

Tommelein, I., Riley, D., Howell, G. (1998) "Parade Game: Impact of Work Flow Variability on Succeeding Trade Performance." *Proceedings of the 6th Annual Conference of the International Group for Lean Construction, IGLC-6*. Guaruja, Brazil, 13-15 August 1998, 14 pp.