COMPARING PROCESS IMPROVEMENT INITIATIVES BASED ON PERCENT PLAN COMPLETE AND LABOUR UTILIZATION FACTORS

VIJAY R. CHITLA[1] AND TARIQ S. ABDELHAMID[2]

ABSTRACT

The Last Planner System® is a process-based system developed to enable production planning and control under a lean construction paradigm. The Percent Plan Complete (PPC) is a metric that reflects the effectiveness of production planning and the reliability of workflow from one trade to another. Process improvement initiatives are identified when 100% PPC is not achieved. In contrast to this system, conventional construction management derives its production process improvement initiatives from productivity improvement studies that use metrics of non-utilization such as non-productive time or Labor Utilization Factors (LUF) as the metric of superior production performance. This paper investigates the differences, if any, in process improvement initiatives predicated on PPC compared to those predicated on LUFs. This was accomplished by conducting a study in a Manufactured Housing plant where workers' utilization at 10 production stations were measured using productivity ratings while also measuring PPC at the same stations. The average LUF for the 10 stations was 52% and the average PPC for the same was 78%. Attempts to improve PPC through constraint analysis techniques revealed more fundamental problems than those revealed by trying to improve LUF. In addition, the PPC metric exposed the 'hidden-factory' despite that the production goals were being met. The study confirms that PPC is a global measure of production system planning efficiency while LUF is a measure of local production *activation*. A linear regression analysis was also performed revealing that PPC and LUF are not strongly correlated ($r = 0.4$, p-value $= 0.3$) in non-lean production systems. Thus, the only viable way to increase workflow reliability in production systems is to increase PPC.

KEY WORDS

Lean construction, Manufactured Housing, Percent Plan Complete (PPC), Labor Utilization Factors (LUF).

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INTRODUCTION

Lean principles have evolved at and were successfully implemented by Toyota Motor Company. Toyota strived to work towards the ideal of 100% value-added work with zero (or minimum) waste. Popularized by the book *The Machine That Changed The World* (Womack et al. 1990), these lean principles are being increasingly employed in many other industrial sectors. Since 1992, ushered in by Koskela's seminal report (Koskela 1992), the adoption and adaptation of lean production concepts in the construction industry has been ongoing. An increasing number of construction academics and professionals have been storming the ramparts of conventional construction management in an effort to deliver better value to owners while making real profits. As a result, lean-based tools have emerged and have been successfully applied to simple and complex construction projects. In this paper, the focus will be on one such tool; the Last Planner System® (LPS®) or production planning and control (Ballard and Howell 1994a).

The LPS® promotes production control as opposed to the dominant project control paradigm under conventional construction management. The system empowers front-line planners, the Last Planners, to schedule day-to-day production assignments according to the prevailing conditions on the site (Ballard and Howell 1998). Production assignments are established based on the ability to perform them and not only based on what "should" be done. To measure the effectiveness of the production system to carryout assignments (commitments), the number of completed assignments is expressed as a ratio of the total number of assignments committed in a given week. This ratio is known as the Percent Plan Completed or PPC which is a metric reflecting the effectiveness of production planning and the reliability of workflow from one trade to another (Ballard and Howell 1994b, Howell and Ballard 1994, Ballard et al. 1996).

Using the LPS® as a planning tool uncovers a myriad of constraints that threaten the execution of assignments as well as production progress. By removing these constraints, Last Planners are more confident in making and keeping their commitments. Notwithstanding the removal of these constraints, construction always has a 'monkey wrench" in store for even the best prepared, and, hence, prevents the honoring of commitments made. When used as a production control tool, i.e., tracking the PPC metric, the Last Planner System allows management of such circumstances. Production process improvement initiatives are identified when 100% PPC is not achieved.

In contrast to this system, conventional construction management derives its production process improvement initiatives from productivity improvement studies that use metrics of non-utilization such as non-productive time or Labor Utilization Factors (LUF) as the metric of superior production performance (Oglesby et al. 1989). This paradigm, as will be shown in this paper, confuses action for motion or, as stated by Goldratt (1992), considers activation and utilization as synonyms.

This paper was inspired by a simple question: How different are process improvement initiatives as inspired by PPC compared to those inspired by LUFs? To investigate this question, a research project was conducted in a Manufactured Housing plant where workers' utilization[3] at 10 production stations were measured using productivity ratings while also measuring PPC at the same stations. The results of this research are described after a brief rounding on Manufactured Housing is presented.

MANUFACTURED HOUSING PLANT

Manufactured Housing (MH) is a relatively new industry in terms of its presence in the market and in the world of academic research (Syal et al. 2001). Evolving from a trailer industry, manufactured houses have not been recognized in the construction industry until the 1970s. The creation of the National Mobile Home Construction and Safety Standards Act, also known as the HUD code, in 1976 has catapulted the mobile homes industry and its image in the eyes of the public and soon the name Manufactured Housing emerged.

With the increasing demand for housing over the years and the rising cost of site-built housing, manufactured houses provided an affordable option compared to site-built housing. The houses were being manufactured in bigger spans, growing from 8 to 16 feet wide and up to 70 feet long. According to the Manufactured Housing Institute, "In the year 1999, 21.4 million Americans (about 7.6 percent of the US population) lived full time in 8.9 million manufactured homes" (Vermeer and Louie 1997).

Manufactured housing plants are essentially manufacturing facilities where houses move down an assembly line while construction activities are taking place at workstations. Depending on the complexity of houses a plant manufactures, a typical manufactured housing plant assembly line will have 12-18 main stations (see Figure 1). While large numbers of sections are produced each day in a manufactured housing factory, some customization is required depending on customer needs (Chase et al. 1998).

All manufactured houses are built on a steel base frame called chassis. Some parts of the house are pre-assembled at sub-assembly stations located along the main assembly line and some adjacent to the main stations. The sub-assembly stations fabricate and manufacture major parts of the house, like the roof truss assembly, interior walls, cabinets, etc. Feeder stations, either along the assembly line or at some fixed positions, supply the necessary material to the main stations and the sub-assembly stations. Plant workers are assigned to a workstation to perform a specific job. The units typically move through the main assembly line when a successor station is empty and not based on a specific takt[4] time.

An example of a main station is the roof truss station, which has a fixed crew, its own feeder stations, and a subassembly station in its proximity. The major activities at this main station are placing the pre-assembled roof truss, roof insulation, and at the same time, work takes place in the lower part of the house such as installing doors and windows, exterior boards, and siding. A detailed description of the activities taking place at other stations can be found in Senghore (2001), Mehrotra (2002), Chitla (2003), and Barshan et al. (2003).

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3 Labor utilization is the percentage of paid labor time productively employed. Labor fruitfulness is the output per unit of productive labor time. The combination of the two gives labor productivity. (see acknowledgement section).

4 Takt time (German for rhythm = rate at which customers are demanding a product = Time (i.e., available seconds per working day) / Volume (i.e., daily production requirements)

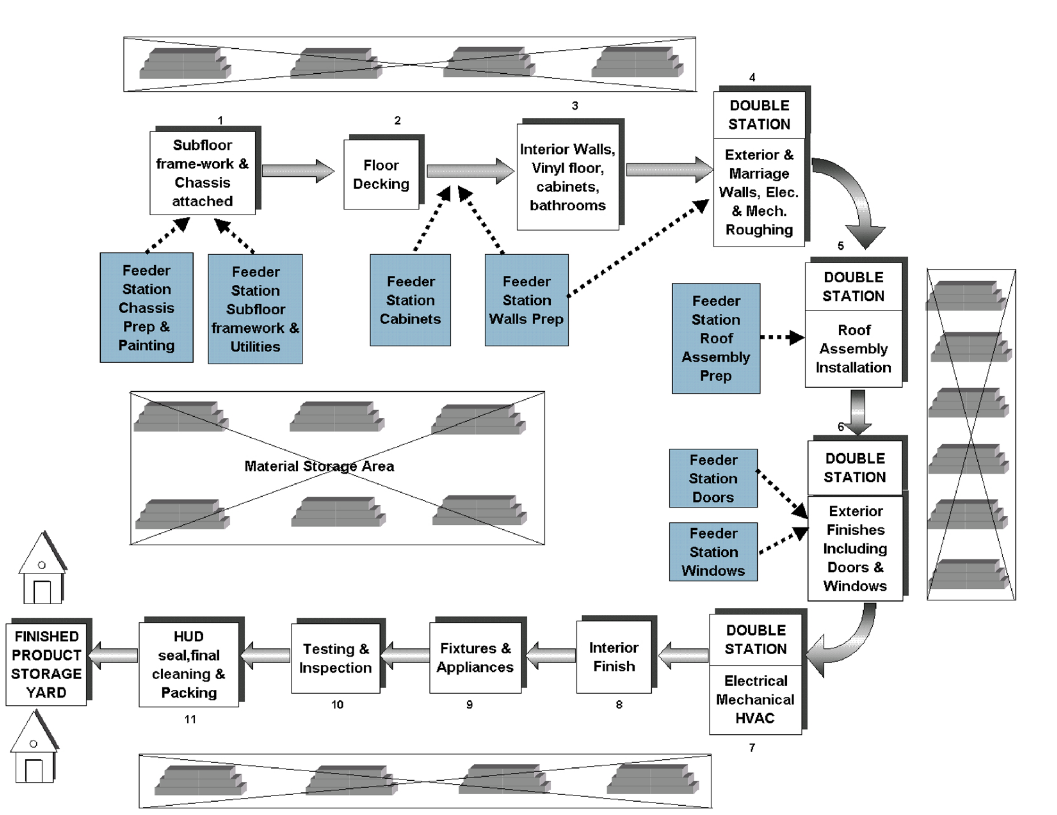

Figure 1: Manufactured Housing Production Process Layout (Barshan et al. 2003)

Manufactured housing is an exceptional sector of the construction industry. It is a different kind of manufacturing and less sophisticated in comparison to other manufacturing industries. Though large numbers of sections are produced each day in a manufactured housing factory, some customization is required depending on customer needs. These features make manufactured housing a prime candidate for the application of Lean Construction principles.

THE LAST PLANNER SYSTEM® IN MANUFACTURED HOUSING

The LPS® is a process-based system developed to enable production planning and control under a lean construction paradigm. The LPS® provides a framework for management and workers to plan and control daily production assignments. Daily assignments are viewed as commitments that a production unit makes to other downstream units. A detailed explanation of the LPS® is beyond the scope of this paper and can be found in Ballard (2000).

To measure the quality of the commitments made and the reliability of workflow, the number of completed assignments is expressed as a ratio of the total number of assignments made in a given week. This metric is termed as Percent Plan Complete (PPC). PPC can take on values from 0 to 100%, with the latter being the best case. A high PPC reflects a well-planned production process with high workflow reliability between production units. A PPC less than 100% reflects a failure in the production planning process. Understanding the reasons for the failure will enable future improvement of the planning process.

It is important to note that PPC does not provide a measure of how efficiently the assignments were conducted. In other words, a PPC of 100% does not indicate the level of utilization of the crew. Instead, PPC is a measure of production planning effectiveness *and* workflow reliability, i.e., PPC is a measure of production planning system reliability and performance. Under a lean construction paradigm, increasing planning reliability increases system throughout, which is the rate of production or output. Essentially, PPC is considered the critical performance measure of a production system as opposed to the focus on point speed in conventional construction management wherein point speed is typically increased by maximizing capacity utilization.

In this study, the effectiveness of the production planning process and workflow reliability in a manufactured housing plant was assessed using the LPS®. Daily assignments at ten assembly stations were collected for a period of 2 weeks. Five stations were observed for five days each week. For a manufactured housing plant, the PPC reflects the effectiveness of production planning at individual stations as well as the reliability of workflow from one station to another.

It is critical to note that the LPS® was not fully deployed in this study. Thus, assignments were not planned to satisfy the 5-criteira of the LPS® nor was the look-ahead planning process used. Basically, each station foreman worked from a list of 'shoulds' that were converted to 'wills' most of the time. However, the full application of the LPS® is appropriate in this production system because, though crude, a pull mechanism was used to coordinate workflow between the workstations wherein the units moved through the main assembly line when a successor station was empty.

The planning performed at the plant investigated in this study was quite station–specific. Each station on the line received a work order (a directive) detailing the production goals for the day (how many units will be built, the type of house, types of carpets used, cabinets, etc) because the manufactured houses are not always identical. The production manager and the sales manager generate the work orders based on both actual orders from dealers and forecasted sales. A foreman at each main station makes assignments to the crews on what needs to be done for the day. That's what was tracked using the LPS® metric PPC. As will be explained later, the same crews were observed for productivity ratings as described in Oglesby et al. (1989).

The number of assignments planned at each station in the study was collected from the foreman. The number of completed assignments at the end of the day was determined by asking the foreman/workers and, when possible, through visual inspection. A daily PPC was determined (the ratio of completed assignments to those planned) for each station over a 5-day period. Finally, for each station, an average PPC was calculated based on the five daily PPCs determined. The resulting 5-day average PPCs for all observed stations are summarized in Figure 2. The average PPC for all stations is 78%. Detailed results are found in Chitla (2003).

The research efforts were then directed at measuring the capacity utilization level of the production units, i.e., stations. The same workstations used for PPC measurements were observed and analyzed using work sampling techniques (Oglesby et al. 1989). The technique used and results obtained are explained in the next section.

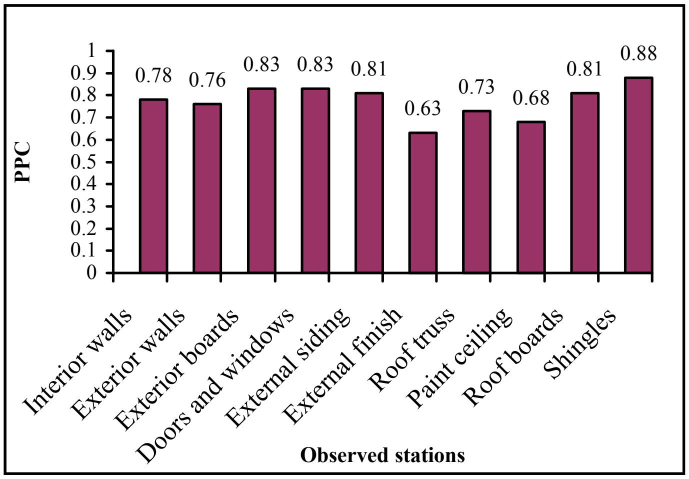

Figure 2: 5-day Average PPC for observed stations[5]

WORK SAMPLING IN MANUFACTURED HOUSING

One of the common work sampling techniques for productivity improvement studies is the productivity ratings method. Under the productivity ratings method, work is classified into three main categories as follows (Oglesby et al. 1989):

1. *Effective work:* Work or activities that are directly involved in the actual process of making a unit or adding to the unit is considered effective work. Work such as, assembly of a roof truss unit, or the work involving activities essential to the process of building a roof truss unit in a manufactured housing plant is effective work. Basically, effective work is work that leads to a change in shape, size, or form of material resulting in an end product to emerge.

2. *Essential Contributory work:* Work done through associated processes essential in finishing the unit, such as material handling, cleanup, checking drawings, making measurements, rework, etc. In lean 'lingo' this is Type I muda (Womack and Jones 1996).

3. *Non-useful or Idle work:* Ineffective work such as being idle or doing something that is unnecessary to complete the job can be classified as non-useful work or idle work. In lean 'lingo' this is Type II muda (Womack and Jones 1996).

After work activities are classified to their respective productivity-rating category, a labor-utilization factor (LUF) is calculated using the following equation (Oglesby et al. 1989):

[5] $$PPC_{station} = \frac{PPC_{day1} + PPC_{day2} + PPC_{day3} + PPC_{day4} + PPC_{day5}}{5}$$

$$\text{Labor - utilization factor} = \frac{\text{Effective work } + \text{ ¼ Essential contributory work}}{\text{Effective} + \text{Essential contributory} + \text{Non - useful}}$$

The same ten stations observed for PPC were video taped for later productivity rating analysis. Depending on the stations, the total observation time for each crew varied from 35 minutes to one hour. The main goal was to have enough time to allow a minimum of 384 observations at 5-second intervals. Crews were videotaped in the morning and afternoon so that the sampling was more representative of the entire day. After productivity ratings were obtained, the station Labor Utilization Factor (LUF) was calculated. The 5-day average LUF data for each station is shown in Figure 3. The average LUF for all stations is 52%.

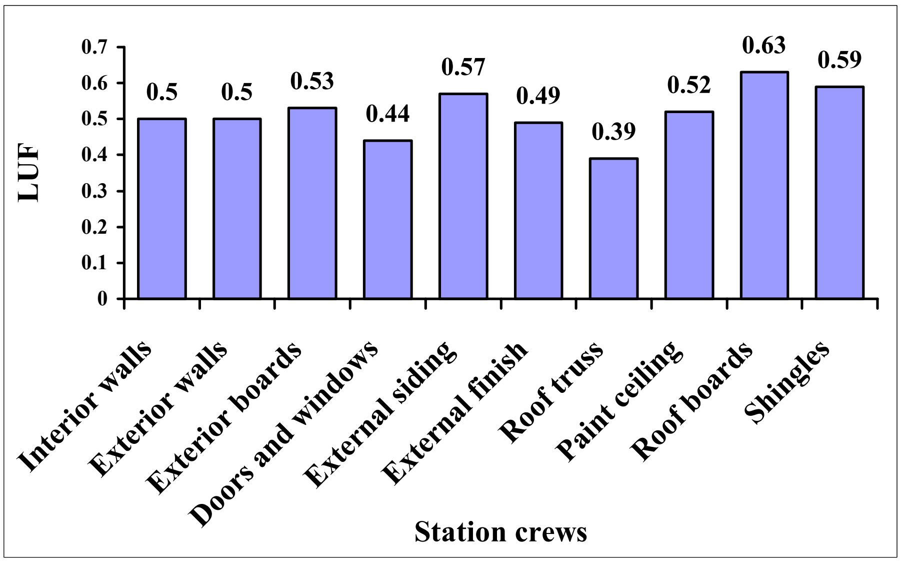

Figure 3: 5-day Average LUF for observed stations/crews[6]

PROBLEMS REVEALED BY PPC VS. LUF

The PPC data shown in Figure 2 indicates problems with production planning and fluctuations in the reliability of work flow. A constraint analysis was conducted to identify why assignments were not completed. The results, shown in Table 1, reveal that workflow between stations was a major cause followed by problems related to the production unit itself. The problems were further analyzed using Pareto analysis and a Fishbone diagram (also Ishikawa diagram) was constructed. The fishbone revealed that some of the root causes of the problems mentioned in Table 1 included labor issues (work pace, skill, pride, education), material supply, unclear directions, equipment breakdowns, sales forecasts, and regulatory requirements. Plant Managers agreed that addressing these root causes would improve throughput (plant production) and acknowledged the need for dedicated process improvement initiatives.

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6 $$LUF_{station} = \frac{LUF_{day1} + LUF_{day2} + LUF_{day3} + LUF_{day4} + LUF_{day5}}{5}$$

Table 1. Problems in production operations of a MH production plant

Problem	Number of assignments not completed
Release of Upstream Work	14
Directives for Operations	7
Planning Failure	7
Material Failure	7
Rework/Repairs	4
Others	2

It is important to note that while PPC data was measured for each station individually, PPC still captures the dynamics between the stations because clearly a PPC <100 was affecting work at subsequent stations. However, we always found that workers were instructed to move with the unit and complete their work at the next station once a successor station was empty. In other cases, overtime work was necessary to get work ready for the following day. This was always the reaction to falling behind and not how the assignments were initially made. When assignments were not completed in the time allotted or at the station where they were assigned, the assignments were considered incomplete. This is exposed the 'hidden factory', which was masked by the fact that production goals (# of houses per day) were always met.

It is worth noting here that when demand for houses went up in the late '90s, the manufacturer built another adjacent plant to increase production because the existing plant (the one under study) was producing at its maximum. The new plant has been shutdown since April 2001 because the demand spike has turned into a slump. Needless to say this was not a profitable investment. One would not be faulted to argue that had the 'hidden factory' been exposed and dealt with through better workflow, more production could have been possible using the existing plant. It is heartening to see that lean construction principles do in fact 'pan-out' in practice.

In contrast to the problems revealed by the PPC-based constraint analysis, the LUF data primarily pointed towards local improvements in the procedures performed by the crew. For example, the foreman and crew suggested using jigs to reduce time spent on measurements and locating material closer to the workstations to reduce travel time. Surprisingly, to cut down crew idle time, which was mainly caused by waiting for upstream work, the foremen suggested that the crews could work at the sub-stations or feeder stations to build 'sub-assemblies'. While these improvements may increase LUF and productivity at individual stations, they will result in an increase in inventory (WIP), which then leads to increased costs. These LUF-based improvements will not increase plant throughput because the improvements are clearly targeting symptoms and not the root cause of the problem - unreliable workflow. There is ample evidence in the lean literature that the precondition for improving system throughput is reliable workflow, which in turn is possible using the LPS® (Ballard 2000).

RELATION BETWEEN PPC AND LUF

Out of sheer curiosity, and perhaps in an *ex post facto* fashion, the PPC and LUF data collected were plotted together as shown in Figure 4 according to the normal flow of work. Through observation only, Figure 4 shows that PPC and LUF co-vary in a random fashion. For example, while the LUF at the station “Paint Ceiling” is higher than that at the “Roof Truss” station, the PPC at “Paint Ceiling” is lower than that at “Roof Truss”.

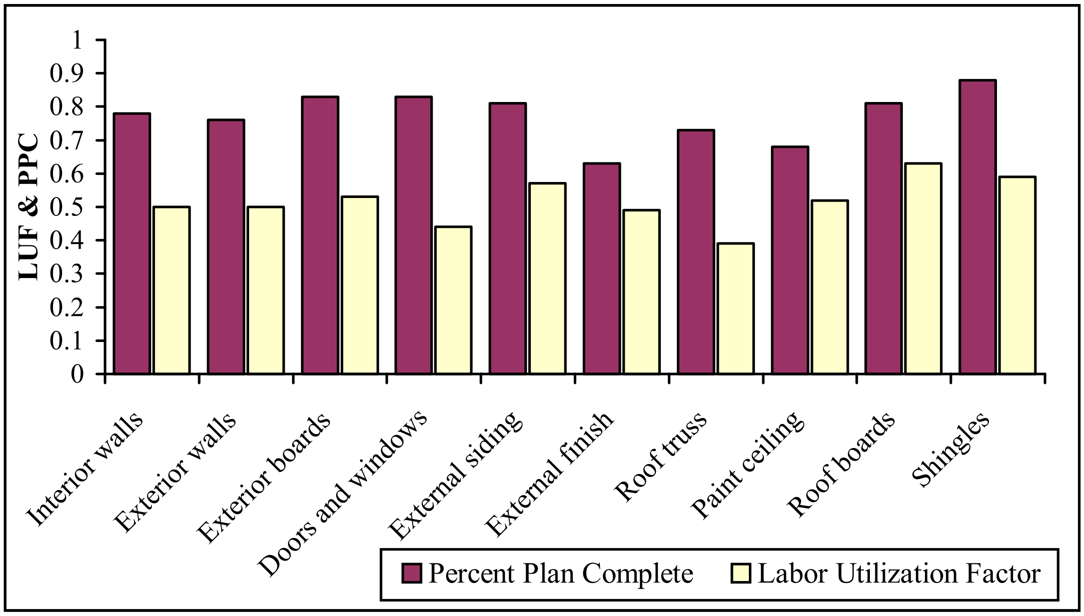

Figure 4: LUF vs. PPC for all the observed stations

To formally describe the correlation between Labor Utilization Factor (LUF) and Percent Plan Complete (PPC), a scatter plot was constructed as shown in Figure 5 with LUF on the X-axis and PPC on the Y-axis of the graph. This choice should not be interpreted to mean that LUF is the independent variable and PPC is the dependent variable because a regression model does not imply that Y necessarily depends on X in a “causal” or “explanatory” sense. Moreover, the scatter plot is based on a quasi-experiment, i.e., there was no manipulation of the independent variable.

Using regression analysis, the coefficient of correlation can be calculated as follows:

Using the formula, $$r = \frac{n\sum_{i=1}^{n} X_i Y_i - \sum_{i=1}^{n} X_i \sum_{i=1}^{n} Y_i}{\sqrt{\left[n\sum_{i=1}^{n} X_i^{2} - \left(\sum_{i=1}^{n} X_i\right)^2\right]\left[n\sum_{i=1}^{n} Y_i^{2} - \left(\sum_{i=1}^{n} Y_i\right)^2\right]}} = 0.41$$

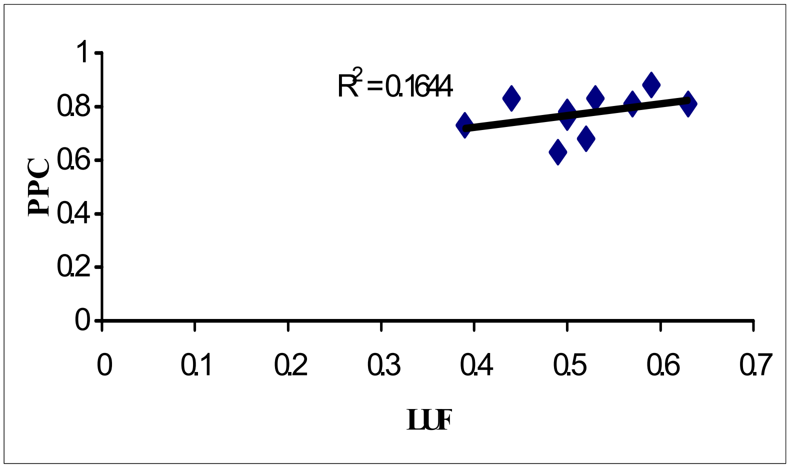

Figure 5: Scatter plot for the 5-day average PPC and LUF

In order to check the statistical significance of the relation between LUF and PPC, a two-sided hypothesis test with α =0.05[7] was constructed as follows:

- H_o: $\rho_o = 0$
- H_a: $\rho_o \neq 0$

The test statistic, z, is calculated as follows (note r = 0.41, $\rho_o = 0$, and n=10):

$$z = \frac{\left(\frac{1}{2}\right)\ln\left(\frac{1+r}{1-r}\right) - \left(\frac{1}{2}\right)\ln\left(\frac{1+\rho_0}{1-\rho_0}\right)}{1/\sqrt{n-3}} = 1.14$$

The rejection region for H_o is given by $z_{calc} > z_{(\alpha/2)}$, where $z_{(\alpha/2)} = z_{(0.05/2)} = 1.96$. Hence, Ho cannot be rejected at the chosen level of significance, α =0.05,because $z_{calc} = 1.14 < z_{(\alpha/2)}$.

Another way to state the result of the test performed is to find the *p-value* or attained significance level. The *p-value* is the smallest level of significance, α, for which the observed data indicates that the null hypothesis should be rejected. The following equation can be used for the *p-value*:

$$P\text{-}value = 2 \times P(z > z_{calc})$$
$$\therefore P\text{-}value = 2 \times P(z > 1.14) = 2 * 0.15 = 0.3$$

Based on the calculated *p-value*, it can be concluded that for any value of α less than 0.3, the null hypothesis cannot be rejected. (note that H_o is *rejected* when *P-value* $\leq \alpha$, i.e.,. H_o *cannot be rejected* when P-value > alpha, which is the case in this test).

It is worth noting that when the daily PPC and LUF values were used (50 data points coming from 5 (PPC, LUF) pairs for each of the 10 stations), the conclusion was also that H_o couldn't be rejected (n=50, r = 0.15, and z = 1.1).

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7 α is the probability of Type I error, i.e., the error of rejecting Ho while it should be accepted.

The regression results provide evidence that in *non-lean* production systems, PPC and LUF are not *linearly correlated.* This statement should not be interpreted to mean that a *cause and effect* relation does not exist between the pair because there was no control over either metric. Such a causal conclusion is only justified in experiments where the independent variable is controlled and the dependent variable is observed. However, while linear correlation results are reciprocal, i.e., the math works regardless of which variable is labeled independent, causality is not. For example, temperature and the height of the mercury column in a thermometer are positively and directly correlated. Increasing temperature (the independent variable) will increase the height of the mercury column (the dependant variable). The relation is also casual between the two. However, this does not mean that if the height of the mercury column is increased that temperature will increase[8]. Consequently, the only way to assess the causal relation between LUF and PPC is to control one and observe the changes in the other. Neither were possible to control in this study because of resistance from the plant production staff to embark on what they deemed a major change in production planning, especially that increasing PPC involves the full implementation of the LPS®.

Despite that it was not possible to control PPC and LUF in this study, the Lean Construction literature does provide insights into this issue. For example, using queuing theory, Howell et al. (2001) illustrated, as shown in Figure 6, that independently seeking 100% capacity utilization will increase idle (wait) times for assignments and, thus, reducing workflow reliability (curves A, B, or C). Note that the wait time represents the time that a customer waits to be served or the time that another server waits to receive a customer. In addition, Ballard (1997) states that 100% capacity utilization is possible if production was predictable and deterministic. Because neither is realized in practice, utilizing a crew at their capacity reduces the ability of completing assignments as planned and workflow reliability is compromised. Therefore, Ballard (1997) recommended the 'underloading' of production units, and other related actions, to realize better workflow.

Figure 6 also illustrates that implementing the LPS® system leads to increasing planning and workflow reliability which in turn enables a reduction in wait time and/or an increase in capacity utilization (direction 2 and 3 in Figure 6). Direction 1 in Figure 6 shows that for the same utilization level, PPC can increase while the wait time is reduced.

Dr. Glenn Ballard informed the authors that experimental results from industry do in fact support the proposition that increasing PPC has resulted in an increase in resource utilization for a particular trade. It is critical to note here that this does not imply that the converse is true, i.e., that increasing resource utilization would increase PPC. This is primarily because increasing PPC leads to an increase in workflow reliability[9], which leads to reduced idle times, and, hence, increased utilization. However, it is clear that attempting to increase resource utilization would have no bearing on workflow reliability because the target is to achieve higher point speeds with disregard to the overall system throughput. The evidence supporting direction 2 and 3 of Figure 6 is testimony that the casual relation between PPC

[8] Another example is recession and unemployment. There is direct correlation between the two as well as a causal relation – when recession occurs unemployment follows but the reverse is not true.

[9] The increase in workflow reliability as a result of increased PPC is well documented in numerous case studies involving the full implementation of the Last Planner System® (Ballard 2000).

and LUF is unidirectional, i.e., an increase in PPC causes an increase in LUF but an increase in LUF does not cause an increase in PPC.

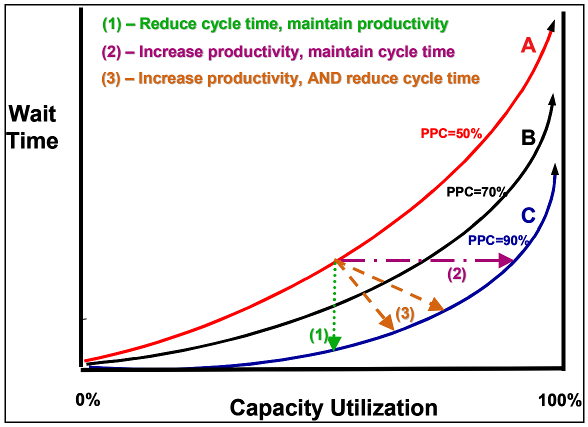

Figure6: Possible PPC and Capacity Utilization Relations (source: Howell et al (2001); LCI Workshop (March 2002) East Lansing, MI)

CONCLUSION

This paper described a research project conducted in a manufactured housing plant where labor (capacity) utilization at 10 production stations was measured using productivity ratings while also measuring PPC at the same stations. The average LUF for the 10 stations was 52% and the average PPC for the same was 78%. A constraint analysis was conducted using Pareto analysis and fishbone diagrams revealing a myriad of process improvement opportunities. Constraint analysis techniques revealed fundamental problems that did not surface by trying to improve LUF. In addition, the PPC metric exposed the 'hidden-factory' despite that the production goals were being met. This confirms that PPC is a global measure of workflow reliability while LUF is a measure of local production *activation* (see Goldratt 1992). The study also confirms the conclusion made by Howell et al. (2001) that owners and contractors should focus their efforts on increasing PPC and stop wasting resources on improving capacity utilization (or LUF).

Common sense, or perhaps the 'prevailing' sense, leads Managers (whether representing owners or contractors) to believe that achieving higher capacity (labor) utilization leads to higher production unit performance and, therefore, higher throughput. The problem with LUF-based improvements is that they lead to a myopic view of the production system, or a 'tunnel-vision' of sorts. Notwithstanding its shortcomings, the productivity ratings procedure may still have its place in the Lean Construction tools arsenal that target waste identification and removal.

An *ex post facto* analysis of the relationship between percent plan complete and the capacity utilization metric LUF was conducted using linear regression. The regression analysis suggested that PPC and LUF are not linearly correlated in *non-lean production system*. This corroborates the supposition that the only viable way to increase throughput is to increase workflow reliability through PPC.

This study focused on construction activities in one manufactured housing plant and data collection was limited to 10 stations over a period of two weeks. Additional research is needed to investigate the relation between PPC and LUF in other construction settings. Future investigations should be conducted over longer periods of time and with more control over the different parameters (PPC, wait times, and capacity utilization) to confirm the directions suggested in Figure 6.

ACKNOWLEDGEMENT

The authors would like to thank Dr. Glenn Ballard for his insightful and enriching comments during the paper writing stages.

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