# PRIORITIZING PRODUCTION PLANNING PROBLEMS AND NORMALIZING PERCENT PLAN COMPLETE DATA USING SIX SIGMA

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## ABSTRACT

The Last Planner System (LPS), with its now-famous PPC metric, has been used on many projects and has proven to be an effective production planning and control tool. Application of the LPS typically results in unearthing numerous problems with the production planning process and procedures that a contractor utilizes. With limited time and budgets, the construction manager needs a method to prioritize the process improvement initiatives to undertake. This paper explores the use of six-sigma based metrics and techniques to better reveal the efficacy of the production planning process as well as identify the common-cause and special-cause deviations in the production planning process. The paper will report on the adaptation of six-sigma metrics and techniques to data collected from an actual construction project. The results suggest that the developed tools will assist in focusing process improvement efforts. The six-sigma metric developed also provides a better basis for the normalization of the PPC metric such that intra-company and inter-company production processes can be compared for benchmarking and process improvement purposes.

## KEY WORDS

Lean Construction, Percent Plan Complete, Control Charts, Last Planner System

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## INTRODUCTION

Present management methods used in the construction industry focus primarily on project level management at the expense of production level management. Even the best developed plans usually change over the course of a project due to unexpected events and uncertainty. The focus on project control leads to a state of perpetual troubleshooting and the deployment of corrective action (cure) plans that seldom work due to the endemic sluggish response in the AEC industry. Conversely, Lean Construction advocates the use of both project and production management, wherein project planning sets the project strategic direction and production planning sets the tactical direction. At the operational level, production control, not project control, is used to orchestrate operations and to craft course-staying (prevention) plans that avoid missing interim and incremental milestones, which are traditionally tracked by project control metrics such as schedule and cost variances.

According to Koskela (2000), a production planning and control system should follow three principles: "The first principle is that the assignments should be sound regarding the prerequisites… The second principle is that the realization of assignments is measured and monitored… The third principle dictates that causes for non-realization is investigated and those causes are removed. Thus, in fact, continuous, in-process improvement is realized."

The Last Planner System (LPS®) initially proposed in (Ballard 2000) is a system of production planning and control in which any assignment has to be well defined, sequenced in such a way that it is constructible, should be sound, and should be "sized to the productive capability of the crew". A reading in the Lean Construction research literature indicates that the Last Planner System is a lean-based tool that has been successfully applied to control workflow unreliability on simple and complex construction projects [Ballard and Howell 1994a, Ballard and Howell 1994b, Ballard 1997, Ballard 2000, Mohammed 2005]. 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.

Application of the LPS typically results in unearthing numerous problems with the production planning process and procedures that a contractor utilizes. With limited time and budgets, the construction manager needs a method to prioritize the process improvement initiatives to undertake. This paper explores the use of six-sigma based metrics and techniques to better reveal the efficacy of the production planning process as well as identify the common-cause and special-cause deviations in the production planning process. The paper will report on the adaptation of six-sigma metrics and techniques to data collected from an actual construction project. Data was collected from a construction project and a set of analysis tools was used to analyze the data and find areas of improvement. The paper will report on the adaptation of control charts to the PPC data as well as case-study results. The six-sigma metric developed also provides a better basis for the normalization of the PPC metric such that intra-company and inter-company production processes can be compared for benchmarking and process improvement purposes.

## SIX SIGMA

Motorola developed Six Sigma in the late '80s as a system that would help them achieve near-perfect products (Breyfogle et al. 2001). This system focuses on detecting and removing process performance variability and uses various statistical methods and tools to achieve a 'closest to zero-defect' product. Linderman et al. (2003) defines Six Sigma as "…an organized and systematic method for strategic process improvement and new product development that relies on statistical methods and scientific method to make dramatic reduction in customer defined defect rates." The methodology used to achieve Six Sigma goals is known as DMAIC (Define, Measure, Analyze, Improve, and Control).

The six sigma metric measures defects in a *product* or *process*. Sigma (s) is the symbol for standard deviation in statistics. Thus a six sigma level means having all the products produced within six standard deviations of the mean (average). Stated differently, a process having a six sigma yield level will have 99.99966% of its products produced without defect. The aim of a company adopting Six Sigma is to bring its entire defect rate to as low as 3.4 defects per million opportunities, which translates to a 6s measure.

## LEAN CONSTRUCTION AND SIX SIGMA

The potential of Six Sigma tools in conjunction with Lean Construction tools to improve production processes should be tapped and used in all sectors of the construction industry. Abdelhamid (2003) reviewed Six Sigma, its methods and metrics and suggested its use as an enabler of Lean Construction. The paper presented an example extending the Six Sigma metrics to the Percent Plan Complete (PPC) of the Last Planner System. Using the Six Sigma metrics provided a more thorough understanding of the process and reflected a true picture of its performance. According to Abdelhamid (2003) the advantage of finding the sigma quality level is not only limited to assessing the capability of the process to produce perfect products but also in assessing the efficacy of the production planning process in terms of its ability to maintain a reliable workflow between production processes.

### PERCENT PLAN COMPLETE (PPC) VS. ROLLED THROUGHPUT YIELD (YRT)

In six-sigma literature, rolled throughput yield (YRT) is defined as the probability that a single unit can pass through a series of process steps free of defects. The main advantage of using this metric is that it explicitly considers rework. Abdelhamid (2003) proposed the use of the concept of rolled throughput yield (YRT) metric as the performance measure in the Last Planner System. An example of using the concept of the YRT metric instead of PPC was illustrated for a manufactured housing application. For detailed discussion on rolled throughput yield refer to Abdelhamid (2003).

Mohammed and Abdelhamid (2005) suggested using *rolled* PPC similar to the rolled throughput yield. Using the *rolled* PPC metric has the potential to expose the *hidden factory* (rework performed to rectify defects during sub-processes). The *rolled* PPC metric gives better insights into the magnitude of the process performance failure. Rolled PPC metric essentially is the product of individual PPCs over a period of time. It can be represented as follows:

$$\textit{rolled}\ \mathrm{PPC} = \prod_{i=1}^{m} \mathrm{PPC}_i \qquad (1)$$

where $\mathrm{PPC}_i$ is the PPC for day 'i' calculated as 'number of assignments completed / number of assignments made', 'm' represents the total number of days over which PPC was calculated, and $\prod_{i=1}^{m}$ is the product symbol, which derives from the capital letter Δ (Pi), and represents the product (multiplication) operation.

This research used the *rolled* PPC metric as a measurement tool for assessing the performance of production planning. In contrast to calculation of PPC, the *rolled* PPC will give a better order of magnitude of the deficiencies of the planning process, and, thus it is more realistic tool for performance measurement. For more detailed discussions please refer to Abdelhamid (2003).

For this research, the rolled PPC data was normalized by converting it to the corresponding sigma level. This is performed using the following set of equations (see Breyfogle (2003) for more discussion):

$$PPC_{norm} = \sqrt[m]{PPC_R} \tag{2}$$[3]

where $PPC_R$ is *rolled PPC* calculated using Eq (1) and 'm' represents the number of days (or any other time unit) over which PPC was tracked,

$$MAPP_{norm} = -\ln(PPC_{norm}) \tag{3}$$

where MAPP stands for *missed assignments per plan*, and ln( ) is the natural logarithm operation. To determine the sigma quality level, also called $Z_{benchmark}$, for the processes under consideration, the following equation is used:

$$Z_{benchmark} = Z_{MAPP_{norm}} + 1.5 \tag{4}$$

where $Z_{MAPPnorm}$ is the standard normal value corresponding to the $MAPP_{norm}$ found using Equation 3. This sigma value is normalized and thus can be used for comparison of different processes and can also be extended to compare one company to another and even one industry to another. It's a very good benchmarking metric for continuous process improvement.

### Run Chart or Time Series Plot

In general, measured or collected data can be analyzed statistically in various ways to determine areas of improvement. This is necessary so that management can identify the aspects that need immediate attention and assign priority levels to the tasks that need to be undertaken to improve the overall production planning process and thus improve crew performance and crew-to-crew handoffs (workflow). Determination of high priority actions can be achieved by performing statistical analysis on the data.

Variation is inherent in any process and it leads to unreliability in the process. One of the aims of Lean Construction is to eliminate or reduce the variations to the extent possible. The variations could be attributed to either common causes or special causes (Abdelhamid 2003). Common causes are those causes that are built into the process and cannot be eliminated

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[3] This equation is essentially the geometric mean of a set of data.

unless the process is reengineered. Whereas, special causes are those that create sudden variations in the established process and should be targeted for elimination. A run chart or time series plot is a popular method to determine the special causes and it is used here to statistically determine such causes and find means to eliminate the cause.

There are various types of run charts. The *p-chart* with variable sample size is the most suitable for this research. In a *p-chart*, a statistical range (upper and lower limits) is set for the data and the data is plotted. The range can be set by defining an upper control limit (UCL) and a lower control limit (LCL). These limits can either be set by the company or can be mathematically calculated. Any data that is outside the limit is an indicator of an out-of-control process. This may be due to a special cause and it can be detected and avoided.

To create a p-chart, the metric 'PPC' should be modified to focus on the incomplete assignments by introducing the Percentage Plan Incomplete (PPIC) metric. PPIC is the ratio of total number of tasks incomplete to the total number of tasks planned to be completed.

For a given set of PPIC data, a *p-chart* can be plotted to determine special causes that lead to incomplete tasks. The p-chart is constructed using the following equations:

- $$Std\_dev = \sqrt{\frac{PPICavg(1 - PPICavg)}{Tasks\_assigned}} \quad (5),$$

where, $PPICavg = \dfrac{\sum Tasks\_incomplete}{\sum Tasks\_assigned}$ and *Std_dev* is the standard deviation of the process. With $PPIC_{avg}$ and *Std_dev* the following is calculated:

- $$UCL = PPICavg + Std\_dev \quad (6)$$
- $$CL = PPICavg \quad (7)$$
- $$LCL = PPICavg - Std\_dev \quad (8),$$

where UCL is the upper control limit, CL is the average control limit, LCL is the lower control limit.

## DATA COLLECTION AND ANALYSIS

### ROLLED PPC

To demonstrate the application of the *rolled* PPC assessment metric as well as how to prioritize process improvement initiatives using LPS, data was collected by visiting two apartment buildings (Building I and II) on a daily basis for a period of eleven weeks. On each day, the site superintendent provided details of the activities planned for the next day. A site tour was also completed to verify the status of activities in the two buildings. Any activity that was not performed or partially completed was recorded as incomplete as well as reasons for non-completion were also collected. The reason for incompletion of any activity was recorded using the following reason codes: Productivity, Engineering, Non-Conformance, Owner Decision, Weather, Pre-Requisite, No-Show, Trade, Supplier, Space, and Other.

A sample of the data collected for the tasks planned and completed for week 7 is shown in Table 1. The PPC values for both building I and II for all weeks are graphically illustrated in Figure 1 and Figure 2.

Table 1 shows an average PPC for week 7 of 64% and this is calculated by taking an average of all the daily PPC values. Turning attention to these daily PPC values indicates that on day 1, one out of two activities were completed giving a PPC value of 50%. Similarly, on day 2, two out of three activities were completed giving a PPC value of 66.66%. The incomplete activity on day 2 was due to the extra work performed to complete the previous day's work. Thus, on day 2 only 50 % of the work expected to be passed from day 1 was actually completed and passed on. In other words, the PPC value for day 2 hides the extra work done owing to incomplete work on the previous day.

*Table 1: Sample data for week 7 – Building I*

| | 26-Apr | 27-Apr | 28-Apr | 29-Apr | 30-Apr | Weekly PPC | *rolled* PPC |
|---|---|---|---|---|---|---|---|
| **Tasks Planned** | 2 | 3 | 3 | 3 | 3 | | |
| **Tasks Completed** | 1 | 2 | 2 | 2 | 2 | | |
| **PPC (%)** | 50 | 66.66 | 66.66 | 66.66 | 66.66 | 64 | 10 |

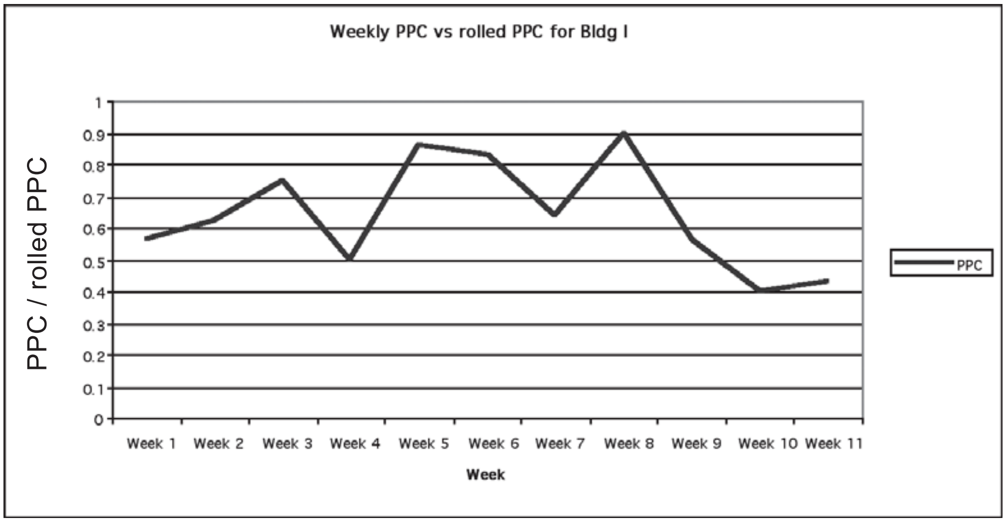

*Figure 1. Graph of PPC for Building I*

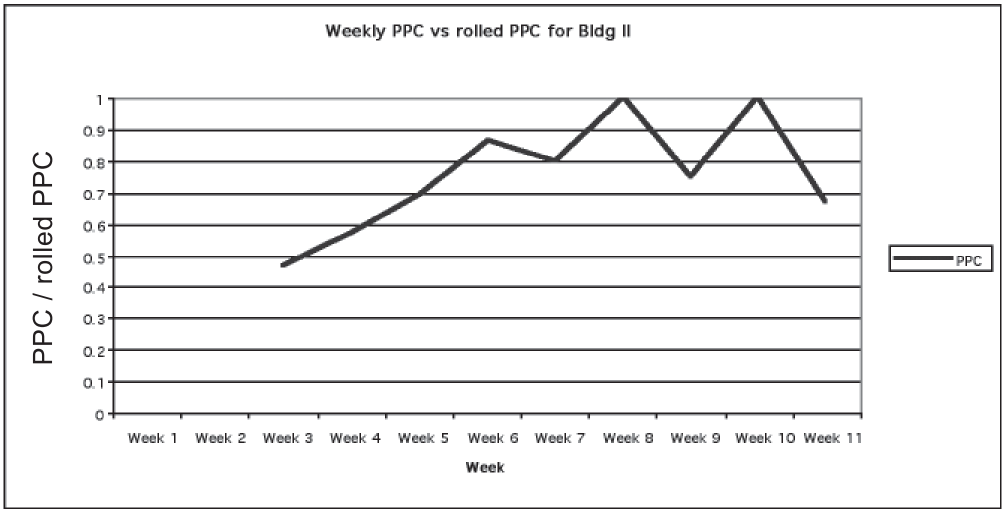

*Figure 2. Graph of PPC and* rolled *PPC for Building II*

So, in reality, on day 2, only 66.66% of the work passed on was completed. Multiplying PPC for day 1 with the PPC for day 2 can accurately reflect this. Hence, at the end of day 2 the PPC should be 33.33% (50% * 66.66%). Similarly for day 3 the work passed on was only 33.33% completed as planned, and, hence, the output for day 3 will reduce due to the fact that earlier work had to be completed. This can be shown by multiplying daily PPC for day3 with the previous days PPC and so on.

The weekly '*rolled* PPC' is a value obtained by multiplying the daily PPCs for the week. The weekly *rolled* PPC for the sample data in Table 1 is 10% (50%*66.66%*66.66%*66.66%*66.66%). As mentioned earlier, the *rolled* PPC metric gives a more accurate value for measuring the performance of the process without hiding the rework because of incomplete tasks on the previous day(s).

Figures 3 and 4 show graphs plotted for PPC and *rolled* PPC for Building I and Building II.

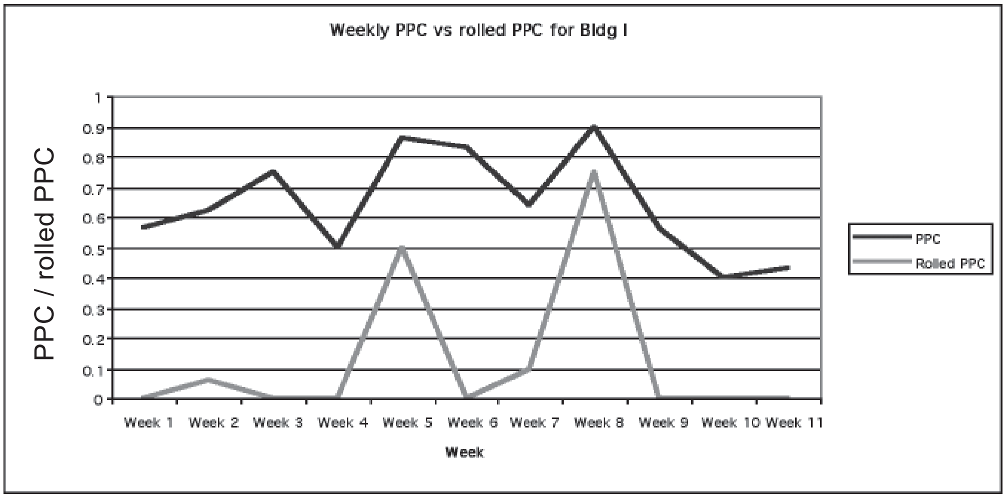

*Figure 3. Graph of PPC and rolled PPC for Building I*

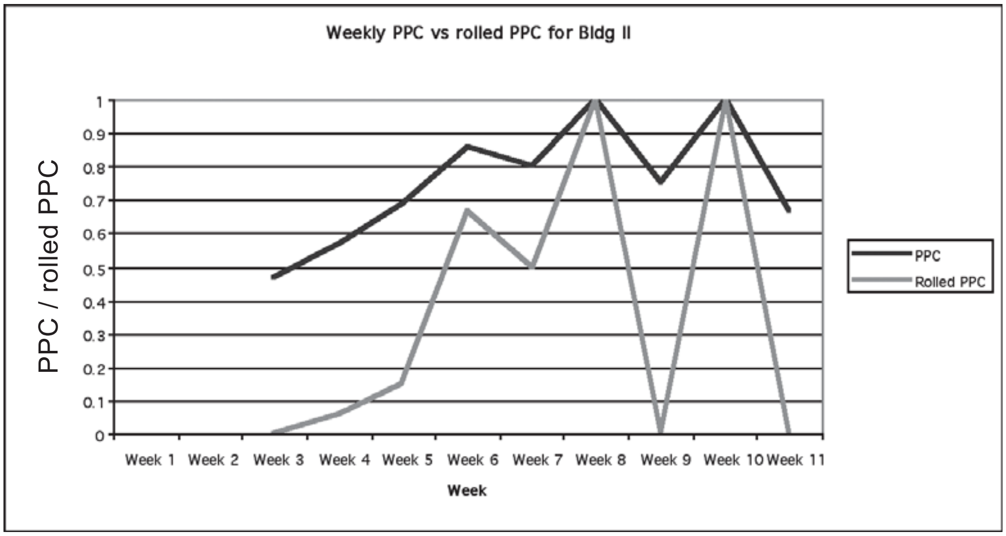

*Figure 4. Graph of PPC and* rolled *PPC for Building II*

It can be seen from the graphs in Figures 3 and 4 that the *rolled* PPC is much lower than the PPC for each week. A value of zero for *rolled* PPC indicates that the week had at least one day with a PPC of zero, and a value of hundred for *rolled* PPC indicates that the week had 100% PPC on all days of the week. This clearly shows the efficacy of the *rolled* PPC metric in being able to measure the performance of the production planning process in both the best and the worst cases.

### NORMALIZED PPC AND ROLLED PPC

The sigma value for the production planning process in each building was calculated based on the average PPC value and then using the rolled PPC value. The values were as follows:

Sigma Level for Building I: By Average PPC, Sigma Yield Value = **3.24**

By rolled PPC, Sigma Yield Value = **2.39**

Sigma Level for Building II: By Average PPC, Sigma Yield Value = **3.44**

By rolled PPC, Sigma Yield Value = **2.85**

The difference in the sigma yield value for the same building is due to the different yield metric used to calculate the sigma level. The rolled PPC, as suggested in this paper, gives a lower value for the sigma level at which the production planning process is being executed, and is perhaps more reflective compared to the sigma level based on the average PPC.

We believe that this is due to the fact that the rolled PPC metric captures the extra work done to complete previously incomplete and/or rework activities. It is also worth noting that the difference between the sigma values in the two buildings is likely due to the learning effect achieved in Building II activities, which always followed activities in Building I.

As mentioned earlier, these sigma values are normalized and thus can be used for comparison of different size and scope production processes and can also be extended to compare one company to another and even one industry to another.

### P-CHARTS AND PPC DATA

For the PPIC data, derived from the PPC data collected as mentioned earlier, a *p-chart* was plotted for both buildings in the study to determine special causes that lead to incomplete tasks. Figure 5 shows a *p-chart* plotted using data of incomplete tasks for Building I.

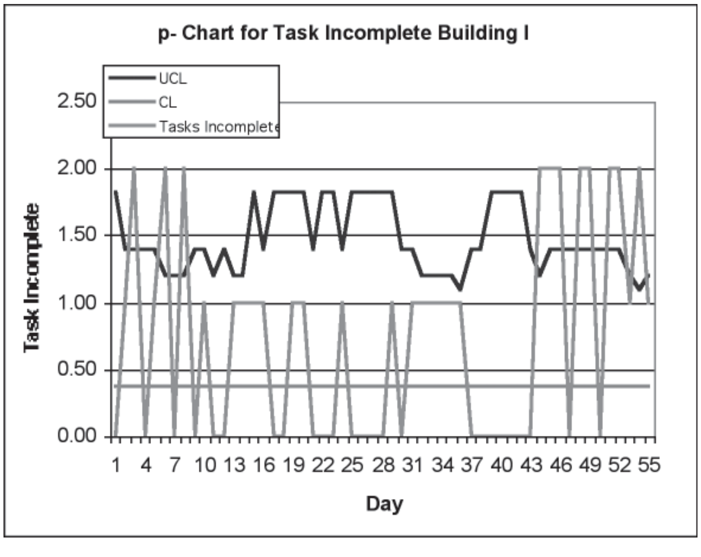

*Figure 5 P-Chart for Task Incomplete in Building I*

In Figure 5, the LCL limit is zero in this case, i.e., we would like to see no incomplete tasks. The UCL value for each day is varying because the number of tasks assigned for each day is varying. On any given day, the tasks incomplete should not be more than the UCL value.

Figure 5 clearly illustrates that on some days, the incomplete tasks were more than the UCL. This is an indication of special cause variation. The particular days can be identified and reasons for incomplete tasks can be evaluated and reduced, or if possible eliminated, such that similar conditions do not recur. In this case, the special cause variation was determined to be a result of the "Inspection" process, which could either mean that the inspector did not show up, or the inspection could not be passed most of the times. The company should look further into this particular area and improve on the process. This process is underway and will be reported on in future publicaitons.

If this process is repeated on a weekly basis or any fixed period of time, the past causes for high number of incomplete tasks can be determined and measures can be taken to avoid such instances in the future. This is the main aim of monitoring and controlling using statistical analysis.

## CONCLUSIONS

The Last Planner System (LPS®) and the metric PPC is a very effective tool for production management. Use of the *rolled* PPC metric and its normalized six sigma level value, and p-charts in conjunction with the LPS® would help reveal the efficacy of the production planning process. This study illustrated how applying the power of both lean construction and six-sigma tools to the production management process could further leverage the PPC data in identifying targeted process improvements. The widespread adoption of the metrics suggested in this paper will yield useful information in both refining the metrics as well as in establishing their efficacy in improving production management on construction projects.

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