# Considering Customer Variability in Precast Production Schedules

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## Abstract

Demand variability is the biggest headache for fabricators. The objective of this research is to develop an improvement plan that continuously enhances production control systems for precast fabrication. A Lead Time Estimation Model (LTEM) is established to reduce the impact of demand variability. Two principles are proposed to adjust the production schedule according to the estimated lead times. In the LTEM process, previous jobs awarded from specific customers are analyzed for customer behavior. Potential fabrication lead time is established for specific customers for forthcoming projects. The adjustment principles i.e. 1) start fabrication later relative to the required delivery dates and 2) shift production milestones backward to the end of the production process, are built based on reducing the impact of demand variability. These principles are applied to produce a robust production schedule that reduces the impact of demand variability. The effectiveness of the developed improvement plan, LTEM, and the adjustment principles are validated using a real precast fabricator.

**Keywords**: Demand variability, Lead times, Production control, Precast fabrication.

## Introduction

Construction is different from manufacturing in that manufacturing tasks are performed indoors with controllable environmental factors. However, construction projects rely on timely delivery of materials produced by manufacturers (Ballard and Arbulu, 2004). These products and the fabrication shops which produce them sit squarely at the intersection between manufacturing and construction (Walsh et al., 2004; Barriga et al., 2005). Production control is defined as the task of coordinating manufacturing activities in accordance with manufacturing plans so that preconceived schedules can be attained with

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optimum efficiency (Voris, 1956; Bertrand et al., 1990). Fabricators strive for business success by delivering the required quantity and quality of products on time. This cannot be achieved without an appropriate production control system (Hamez et al., 2008).

Production control systems have been proven effective in solving various kinds of managerial problems. For example, Iwata et al. (2003) established a planning methodology which takes into account the required cycle time and production cost levels with budget constraints. Toba et al. (2005) proposed a load balancing method that leveled all product processing operations among fabrication lines. A production control strategy developed using neural networks and the simulated annealing approach was proposed by Scholz-Reiter and Hamann (2008). Their system can react to changing conditions according to product selection and customer demand. In Schwartz and Rivera's (2010) research, supply chain management is concerned with the efficient movement of goods through a network of suppliers and retailers. A fluid analogy was used to develop a production control model for tactical inventory management problems in a production-inventory system. Many studies have been conducted on improving production control systems using the pull mechanism, buffer approach, inventory control, and optimization technique (Hopp and Spearman, 2000). These manufacturing theories show promise as ways to improve project performance in the construction industry (Koskela, 1992; Ballard, 2000). Variability is inevitable and ubiquitous in construction projects (Robinette and Williams, 2006). The objective of this research is to develop an improvement plan for continuously enhancing the fabricator production control system. A key production issue, demand variability, is discussed in this research.

## Improvement Plan

Continuous improvement is one of the keys to raise the performance of production systems (Womack and Jones, 2003). This study has developed a methodology to provide a guideline for continuous improvement. The improvement plan, shown in Fig. 1, consists of three phases, i.e. "System analysis & problem identification," "solution development," and "validation", forming a continuous improvement loop.
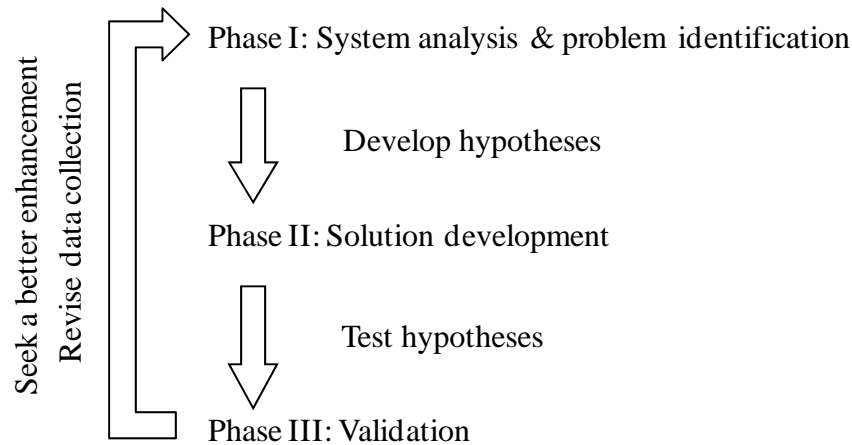
Seek a better enhancement

Revise data collection

Phase I: System analysis & problem identification

Develop hypotheses

Phase II: Solution development

Test hypotheses

Phase III: Validation

Figure 1. Improvement Plan

## Lead Time Estimation Model

Fabricators schedule production plans based on required delivery dates and expected durations (lead times). However, schedules may be disrupted by the late receipt of design information, design changes, or changes in delivery dates. This demand variability originates with the customer and causes fabricators to risk loss of capacity or increased inventory costs. Variability is an inevitable part of the production process and, to absorb variability, one possible approach for fabricators is to take variability into account when they make schedules (Ko and Ballard, 2004). An LTEM was developed to estimate the production lead time under the impact of variability. The LTEM consists of three steps, viz. represent fabrication lead times, analyze customer behavior, and calculate lead times.

### Represent Fabrication Lead Times

The first step in estimating lead times is to make the fabrication process explicit and visible. A process map is used to represent the production system. Fabrication lead times are defined as the period from order acceptance by the fabricator to the beginning of product deliveries to the customer (Chapman, 2005). By this definition, fabrication lead time can be regarded as the time fabricators require for completing an order.

Fabrication lead times (FLT) can be represented using Eq. (1). The equation is a general formula for engineered-to-order products that can be modified for other product types (e.g., made-to-stock, made-to-order and fabricated-to-order) to represent the required fabrication lead times.

$$FLT = WDT + SDT + PT + FT + AT + DT \qquad (1)$$

where WDT is the Waiting for Design information Time, SDT is the Shop Drawing production and review Time, PT is the Procurement Time, FT is the Fabrication Time, AT is the pre-Assembly Time, and DT is the Delivery Time.

**Analyze Customer Behavior**

Fabricators formulate production schedules according to the time for required production processes and the customer's required delivery date. However, customers may impact production schedules in several ways. For engineered-to-order products, fabricators cannot start preparing shop drawings until the design information is received (WDT). Once the shop drawings are complete, the manufacturer has to wait for a review from the general contractor, architect, and/or engineer (SDT). Patterns of customer managerial behavior can be tracked from historical data on previous projects (Scholz-Reiter and Hamann, 2008). A statistical analysis of previous jobs can therefore be used to represent an individual customer's behavior in terms of the frequency and magnitude of milestone changes.

**Calculate Lead Times**

The impact of variability on fabrication lead times is represented in Eq. (2) where $WDT_v$, $SDT_v$, $PT_v$, $FT_v$, $AT_v$, and $DT_v$ can be positive or negative, positive denoting the duration is extended from the original milestone while negative denotes it is shortened.

$$FLT_v = WDT + WDT_v + SDT + SDT_v + PT + PT_v + FT + FT_v + AT + AT_v + DT + DT_v \quad (2)$$

where $FLT_v$ is a lead time impacted by demand variability, $WDT_v$, $SDT_v$, $PT_v$, $FT_v$, $AT_v$, and $DT_v$ are the derivative times of WDT, SDT, PT, FT, AT, and DT respectively induced by the demand variability.

## Production Schedule Adjustment

To derive a production schedule that considers the impact of demand variability, two principles are proposed to adjust the production schedule based on the estimated lead times: 1) start fabrication later relative to the required delivery dates and 2) shift production milestones back to the end of the production process. The first principle identifies a proper time to start fabrication whereas the second one designates the remaining time points.
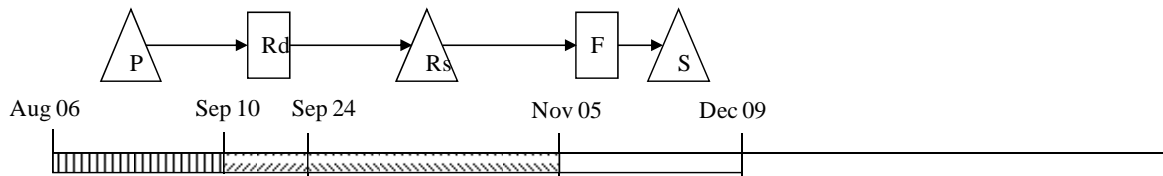
## Application

The proposed improvement plan was applied to a real precast concrete fabricator to validate its effectiveness. To understand the fabricator's practices, this research analyzed archived Job Status Reports. The precast fabricator collaborating in this research maintained a Job Status Report in the form of a spreadsheet. In the archive, each job was recorded as a row with 58 columns, composed of three parts providing basic information, a sequence of milestones and actual dates, and element dimensions. The frequency of milestone changes was aggregated from the archived data. Justifying these is part of customer behavior. Jobs are grouped by contractors, and eight customers which had worked with the fabricator on four or more jobs were selected for analysis. Most customers made either slight or no changes to the final approval milestone. The production release milestone is rarely changed because the fabricator can fabricate the products within a few days, and thus has a greater degree of control over this milestone, which is also true for start production milestones. Changes in delivery dates are subject to change for all customers. This implies that demand variability is inevitable and the fabricator should take it into account in the production schedule. The production schedule should take demand variability into account to reduce its impact. Two adjustment principles proposed in this study were applied to tune the production schedule.
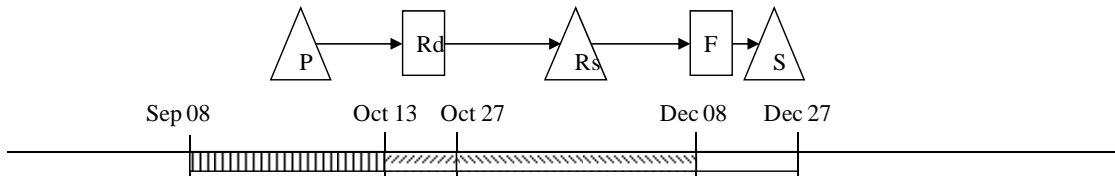
1. Start fabrication later relative to the required delivery dates: The fabricator needs only one day to fabricate the precast elements. As a result, the start production milestone can be set one day prior to the customer ready day.

2. Shift production milestones back to the end of the production process: Set a relatively later fabrication time as a bench-mark, and pull the durations the fabricator needs back to the end of the production process. The end of the production schedule is the original date adding the estimated lead time.

In the test job, the originally planned lead time was 125 days, and the actual lead time was 182 days. The estimated lead time, 143 days, which considered the impact of demand variability, provided a better result for approaching the actual lead time. The originally planned schedule, actual dates, and adjusted schedule are displayed in Fig. 2. Comparing figures 2(a) and (b), the first adjustment principle set the fabrication time relatively late to the estimated delivery day, reducing the amount of time that the products were kept in storage.

(a) Original Schedule



(b) Adjusted Schedule



Legend:

| P | Rd | Rs | F | S |
|---|---|---|---|---|
| Proved drawings | Make work ready | Released works | Fabricate | Stored products |

Figure 2. Production Schedules

## Conclusions

This study presents a plan to improve fabricator production control systems. A Lead Time Estimation Model (LTEM) was developed to approximate fabrication lead times according to historical data from the customer's previous jobs. Two adjustment principles were then used to tune the production schedule to protect fabricators from the impact of demand variability. The effectiveness of the proposed plan, model, and adjustment principles were validated using a real precast fabricator in the initiative improvement iteration.

In the course of improvement, the enhancement plan can be strengthened if fabricators are collaborating in the research. The developed improvement plan provides a road map for fabricators to review their production control systems. Following the improvement phases helps fabricators develop an awareness of the urgent need to enhance their production systems. It then guides them through actively participating in improvement activities and eventually supporting the improvement solutions. The presented case study showed that the proposed improvement plan systematically analyzed the production system and identified problems. The proposed LTEM can produce a lead time relatively close to the actual results. Two adjustment principles can also assist fabricators in making a proper production schedule, thus reducing the impact of demand variability. The proposed improvement plan, LTEM, and adjustment principles contain a few simple steps that can easily be applied in industrial contexts.

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## Acknowledgements

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