ARRANGING PRECAST PRODUCTION SCHEDULES USING DEMAND VARIABILITY

Chien-Ho Ko[1]

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 planning, 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 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 levelled all product processing operations among fabrication lines. A production

[1] Associate Professor, Department of Civil Engineering, National Pingtung University of Science and Technology, 1, Shuefu Rd., Neipu, Pingtung 912, Taiwan, phone: +886-8-7703202, fax: +886-8-7740122, e-mail: ko@mail.npust.edu.tw; Research Director, Lean Construction Institute-Taiwan; Executive Director, Lean Construction Institute-Asia

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). However, previous work focused on investigating process and flow variability, ignoring crucial demand variability incurred from customers. This research assumes that understanding the demand variability would be beneficial in allowing managers to arrange reasonable schedules. 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.

PRECAST PRODUCTION PROCESS

Precast fabrication can be divided into six steps, i.e. mold assembly, placement of reinforcement and all embedded parts, concrete casting, curing, mold stripping, and product finishing (Ko 2010), as shown in Figure 1. Different with production systems, precast elements are produced stationary instead of conveying by belts due to their huge volume and heavy weights. Therefore, fabrication works are completed by mobile crews. The mold assembly activity requires a specific dimension. In general, precast fabricators use steel molds for the purpose of reuse. Precast element primarily contains two kinds of materials, namely, concrete and steel bars. Reinforcements and embedded parts are put in their positions after the mold is formed. Embedded parts are used to connect and fix with other components or with the structure when the precast elements are erected. The concrete is cast when the embedded parts are in their positions. To enhance the chemistry solidifying concrete, steam curing is carried out. Otherwise, the concrete requires weeks to reach legal strength. Moving or erecting elements before reaching the legal strength could cause damage. The molds cannot be stripped until the concrete solidifies. Due to the cost of developing steel molds, fabricators reuse molds once they are stripped. Finally, production elements are finished. Defects such as scratches, peel-offs, and uneven surfaces are treated in this step. Afterwards, precast elements are shipped to the storage yard awaiting delivery to construction site (Ko 2010).

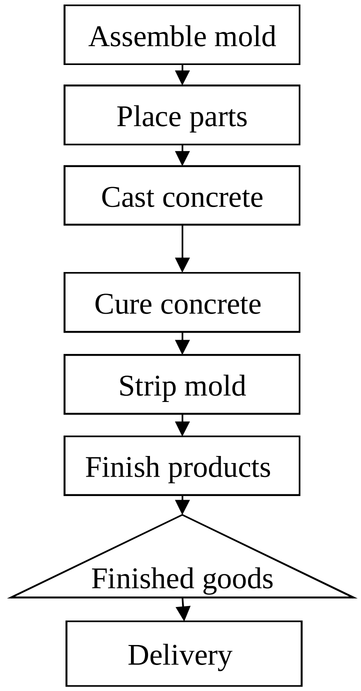

Figure 1: Precast production process

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 Figure 2, consists of three phases, i.e. “System analysis & problem identification,” “solution development,” and “validation”, forming a continuous improvement loop.

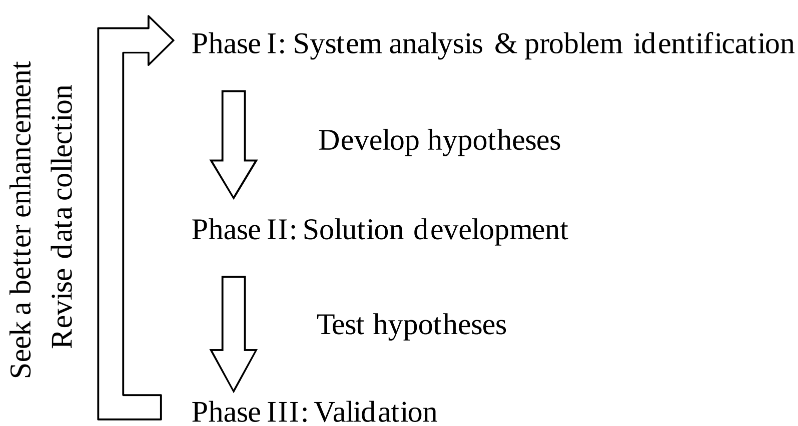

Figure 2: Improvement plan for production control in fabrication (Adopted from Ko 2011)

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.

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

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.

- 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.
- 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 Figure 3. Comparing figures 3(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.

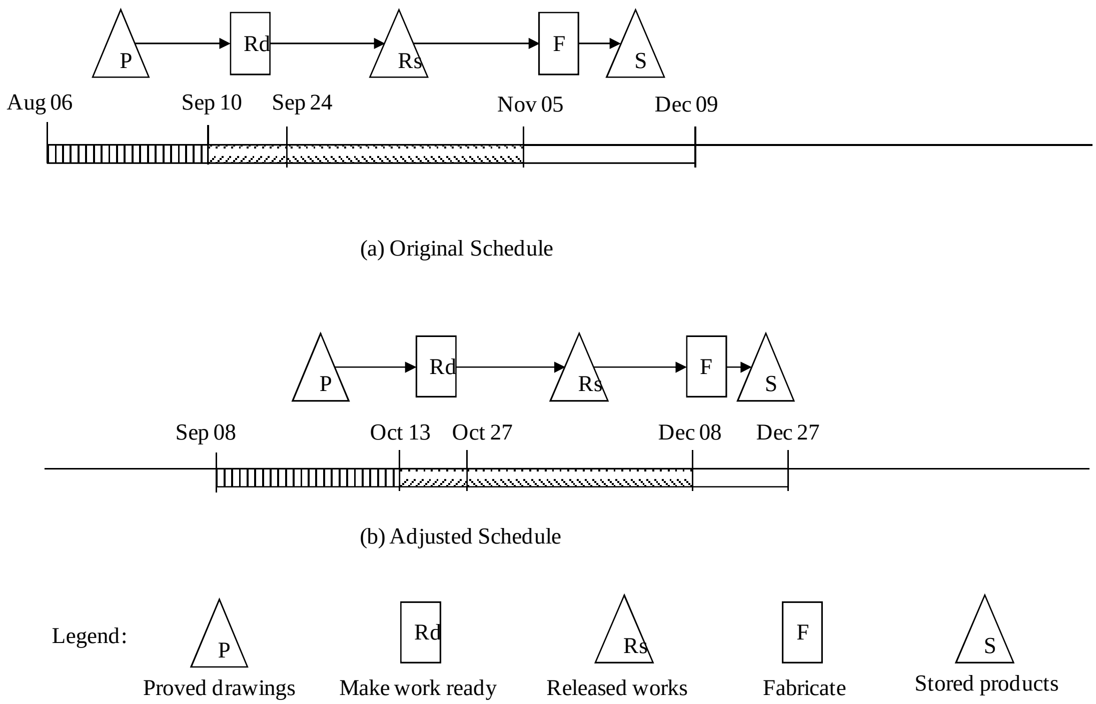

Figure 3: Production Schedules

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. Future study could further integrate the proposed method with the enterprise resources planning system to enhance the precast production system.

ACKNOWLEDGEMENTS

This research was funded by grants NSC 96-2221-E-212-020 and NSC 97-2221-E-020-036-MY2 from the National Science Council (Taiwan), whose support is gratefully acknowledged. Any opinions, findings, conclusions, or recommendations expressed in the paper are those of the author and do not reflect the views of the National Science Council. The author would like to thank the investigated precast fabricator for supporting this study. Special thanks are due to Professor Glenn Ballard, of the University of California at Berkeley, for his intellectual contributions and input to this research.

REFERENCES

Ballard, G. (2000). “The Last Planner System of Production Control.” PhD thesis, University of Birmingham, Birmingham, U.K.

Ballard, G. and Arbulu, R. (2004). “Taking Prefabrication Lean.” *Proceedings of the 12th Annual Conference of the International Group for Lean Construction*, Elsinore, Denmark.

Barriga, E.M., Jeong, J.G., and Hastak, M. (2005). “Material Control System for the Manufactured Housing Industry.” ASCE, *Journal of Management in Engineering*, 21 (2) 91-98.

Bertrand, J.W.M., Wortmann, J.C., and Wijngaard J. (1990). *Production Control: A Structural and Design Oriented Approach*. Elsevier, New York.

Chapman, S. N. (2005). *Fundamentals of Production Planning and Control*. Prentice Hall, New York.

Hamez, F.R., Ballard, G., and Tommelein, I.D. (2008). “Improving construction work flow – The connective role of look ahead planning.” *Proceedings of the 16th Annual Conference of the International Group for Lean Construction*, Manchester, UK.

Hopp, W.J., and Spearman M.L. (2000). *Factory Physics: Foundations of Manufacturing Management*. 2nd edition. McGraw-Hill, NY, NY.

Iwata, Y., Taji, K., and Tamura, H. (2003). “Multi-objective capacity planning for agile semiconductor manufacturing.” Production Planning & Control, 14 (3) 244-254.

Ko, C.H. and Ballard, G. (2004). “Demand Variability and Fabrication Lead Time: Descriptive Research, Phase I.” Technical Report, Construction Engineering and Management Program, Civil and Environmental Engineering Department, University of California, Berkeley, CA.

Ko, C. H. (2010). “An integrated framework for reducing precast fabrication inventory.” Journal of Civil Engineering and Management, 16(3) 418-427.

Ko, C. H. (2011). “Production control in precast fabrication: considering demand variability in production schedules.” *Canadian Journal of Civil Engineering*, 38 (2), 191-199.

Koskela, L. (1992). “Application of the new philosophy to construction.” CIFE Technical report # 72, Stanford University, Stanford, CA.

Robinette, C.J. and Williams, R. C. (2006). "The effects of construction variability on the superpave simple performance test." *Journal of ASTM International*, 3(8) 1-12.

Scholz-Reiter, B. and Hamann, T. (2008). "The behaviour of learning production control." *CIRP Annals - Manufacturing Technology*, 57 459–462.

Schwartz, J.D., Rivera, D. (2010). "A process control approach to tactical inventory management in production-inventory systems." *International Journal of Production Economics*, 125 (1) 111–124.

Toba, H., Izumi, H., Hatada, H., Chikushima, T. (2005). "Dynamic load balancing among multiple fabrication lines through estimation of minimum inter-operation time." *IEEE Transactions on Semiconductor Manufacturing*, 18(1) 202-213.

Voris, W. (1956). *Production Control: Text and Cases*. R. D. Irwin, Homewood, Illinois.

Walsh, K.D., Hershauer, J.C., Tommelein, I.D., and Walsh, T.A. (2004). Strategic Positioning of Inventory to Match Demand in a Capital Projects Supply Chain. ASCE, *Journal of Construction Engineering and Management*, 130 (6) 818-826.

Womack, J.P. and Jones, D.T. (2003). *Lean Thinking: Banish Waste and Create Wealth in Your Corporation*. Revised and Updated, Free Press, New York.