國立屏東科技大學

參加 2012 年(第 20 屆)國際精實營建年會報告

考慮需求變異於預鑄廠生產排程

服務機關：國立屏東科技大學土木工程系
姓名職稱：柯千禾副教授
派赴國家：美國加州
出國期間：101/7/12-101/7/25
報告日期：101/12/13

目錄

一、行程目的：

此行程之主要目的為至美國加州「2012 年(第二十屆)國際精實營建年會」發表國立屏東科技大學於精實營建之研究成果，發表論文中文名稱：考慮需求變異於預鑄廠生產排程，論文英文名稱：Arranging Precast Production Schedules Using Demand Variability，參與本會議之研究成果約於 10 個月前開始準備，此會議有兩階段審稿制度，皆為雙盲審查(Double-Blind Review)，第一階段為摘要審查，約於 2011 年 12 月開始，2 月份通知是否接受，本次發表論文摘要於 2012 年 2 月份接受發表，全文提交於 2012 年 5 月送出，投稿後「2012 年(第二十屆)國際精實營建年會」籌備會同意以口頭發表(Oral Presentation)方式報告此論文。

國際精實營建年會為全球發表精實營建成果最重要之會議，該會議每年固定舉辦，我國亦於此年會中占有重要之地位，2009 年為國立屏東科技大學主辦，持續參與此會議因此更具重要性，此外，2012 年為此會議舉辦第二十周年，此年會議更具重要性，至該年會發表研究成果具指標意義，亦對提升我國於此研究領域之國際知名度有幫助。

加州聖地牙哥州立大學為聖地牙哥主要大學之一，歷史悠久，瞭解該校軟硬體設施與課程規劃，可作為國內大學軟硬體設施與課程規劃時之參考。

二、參加會議經過

- 7 月 12 日 搭機出國

  由桃園國際機場搭乘中華航空公司班機前往美國加州，飛機於加州洛杉磯國際機場降落。

- 7 月 13 日至 7 月 17 日　參訪加州聖地牙哥州立大學

  此段期間參訪加州聖地牙哥州立大學，瞭解該校軟硬體設施與課程規劃，參觀設施包含：教學大樓、會議中心、美式足球場、校史館、停車設施、圖書館等。

- 7 月 18 日至 7 月 20 日　參加 2012 年(第 20 屆)國際精實營建年會(IGLC 20)

精實營建國際研討會主要目的為透過學界與工業界之互動，創造、發展與發表精實營建知識。這三天的學術會議由業界及學術界人士以口頭發表或海報的方式進行，論文審查分為摘要與全文兩階段匿名審查。IGLC 20 研討會地點位於加州聖地牙哥州立大學(San Diego State University)，研討會三天議程如下：

	Opening and Welcome Wednesday 18th 8:30 - 9:00
ID	**Session 1 Wednesday 18th 9:00 - 10:30 -- Chair: Christine Pasquire**
67	Developing Production Theory: What Issues Need To Be Taken Into Consideration?
6	On The Categorization Of Production; The Organization – Product Matrix
170	The Eighth Flow - A Common Understanding
99	Decision-Making Theories: Implications For Lean Construction
122	Deciding A Sustainable Alternative By 'Choosing By Advantages' In The AEC Industry
19	Value Paradigm: Revealing Synergy Between Lean And Sustainability
120	Lean And Green: A Relationship Matrix
68	The Relation Between The Sustainable Maturity Of Construction Companies And The Philosophy Of Lean Construction
139	Subsidy Allocation Mechanism For Successful Implementation Of Green Contracting Strategies
111	Lean And Green Construction: Lessons Learned From Design And Construction Of A Modular LEED Gold Building
	Session 2 Wednesday 18th 11:00 - 12:30 -- Chair: Lauri Koskela
71	Whole-Building Measurement And Computing Science: BIM For Lean Programming And Performance
155	Extending The Interaction Of Building Information Modeling And Lean Construction
8	Root Causes Of Clashes In Building Information Models (BIM)
127	Pull Planning As A Mechanism To Deliver Constructible Design
1	Integration Framework Of BIM With The Last Planner System
16	BIM And Lean Interactions From The BIM Capability Maturity Model Perspective: A Case Study
130	Use Of Design Drivers, Process Mapping, & DSM To Improve Integration Within An Introductory BIM Course
62	Reducing Rework In Design By Comparing Structural Complexity Using A Multi Domain Matrix
123	12 Meeting Facilitation Techniques To Improve Healthcare Design Development
50	Using The Kano Model To Identify Customer Value
42	A Case Study On Benefits Realisation And Its Contributions For Achieving Project Outcomes
	Session 3 Wednesday 18th 13:30 - 15:00 -- Chair: Thais Alves
12	Leadership And Cultural Change: Necessary Components Of A Lean Transformation
75	Incentive Systems To Support Collaboration In Construction Projects
102	Meta-Organization: The Future For The Lean Organization
180	Path Dependency To Path Creation: Enabling Strategic Lean Implementation
186	Developing A "True North" Best Practice Lean Company With Navigational Compass
36	Behavioral Factors Influencing Lean Information Flow In Complex Projects
206	Application Of The Rapid Lean Construction-Quality Rating Model To Engineering Companies
40	How Integrated Governance Contributes To Value Generation – Insights From An IPD Case Study
110	Accelerating The Adoption Of Lean Thinking In The Construction Industry
44	The Adoption Of Lean Construction In The Final Stages Of A Construction Process, Why Does It Not Happen?
78	Literature Review On Trust And Current Construction Industry Trends
	Session 4 Wednesday 18th 15:30 - 17:00 -- Chair: Luis Alarcon
85	A Brief History Of The Concept Of Waste In Production
13	A Lean Management Approach For Power Plant Construction Projects: Wastes Identification And Assessment
2	A Green-Lean Approach For Assessing Environmental And Production Waste In Construction
142	Waste In Construction: A Systematic Literature Review On Empirical Studies
95	Exploring Value Through The IGLC Community: Nineteen Years Of Experience
90	Spread Of BIM: A Comparative Analysis Of Scientific Production In Brazil And Abroad
55	Ten Years Of Last Planner In Finland - Where Are We?
148	Management Of Preconstruction Using Lean: An Exploratory Study Of The Bidding Process
138	Application Of The Principles Of Lean Thinking In The Post Work Construction Department
132	Possibility Of Applying Lean In Post-Disaster Reconstruction- An Evaluation Study
20	How Do You Understand Lean?

IGLC 20：研討會第一天議程

	Session 5 Thursday 19th 08:30 - 10:00 -- Chair: Glenn Ballard **SESSION FORMAT:**This session will be a mixed presentation and poster format, with five papers selected for 4 minute presentations and the balance presented as posters. A 35 minute poster session will go first, then the 5 papers will be presented consecutively five minutes each, then 35 minutes devoted to collecting key points and answering questions. Authors presenting papers in this session are asked to contact the session chair, Glenn Ballard for instructions for participating in an N/3 process to select which papers will be presented in which format.
47	Making-Ready And Making-Do: Information, Uncertainty And Perceptions Of Readiness
177	Is Improvisation Compatible With Lookahead Planning? An Exploratory Study
25	Improving The Making Ready Process - Exploring The Preconditions To Work Tasks In Construction
187	Uncertainty And Contingency: Implications For Managing Projects
41	Little's Law For The Us House Building Industry
17	Using Production System Design And Takt Time To Improve Project Performance
147	Look-Ahead Planning: Reducing Variation To Work Flow On Projects Laden With Change
39	Production Control Using Location-Based Management System On A Hospital Construction Project
51	Assessement Of Kanban Use On Construction Sites
161	Using Design Science To Further Develop Visual Management Application In Construction
202	Exploring Crew Behavior Under Unexpected Events
	Session 6 Thursday 19th 10:30 - 12:00 -- Chair: Tariq Abdelhamid
153	Design Science Research In Lean Construction: An Analysis Of Research Processes And Outcomes
53	'Find-Think-Write-Publish' – Lean Thinking In Scientific Paper Writing
105	A Modeling Approach To Understand Performance Of Lean Project Delivery System
91	The Last Planner System As A Driver For Knowledge Creation
52	Transparency In Construction Sites
194	The Oops Game: How Much Planning Is Enough?
159	Production Control Game For Teaching Of Location-Based Management System's Controlling Methods
32	Technological Capability: Evidence From Building Companies In A Lean Learning Environment
166	Different Perspectives On Teaching Lean Construction
117	Can We Teach Lean Construction Methods In Schools Of Architecture?
89	Survey Instrument To Facilitate Continuous Improvement Of Lean Teaching Materials: A First Run Study
	Session 7 Thursday 19th 13:00 - 14:30 -- Chair: Iris Tommelein
101	What Is Seen As The Best Practice Of Site Management?
181	Assessing Reverse Logistics In South African Construction
93	Norwegian Project Managers And Foremen's Experiences Of Collaborative Planning
144	Evaluation Of The Presence Of The Principles Of Lean Construction In Companies Acting In The Market Of Building In The State Of Goiás
22	Utilization Of Extra Planning Activities By Construction Companies In Sergipe, Brazil
140	Analyzing Barriers To Productivity Improvement In The Dominican Republic
135	State Of Production Plan Reliability – A Case Study From India
28	A Critical Review Of The Potential For The Implementation Of Lean In The Nigerian Building Industry
204	Adapting Lean Construction Technique In Nigerian Construction Industry
97	Implementing A Performance Improvement Strategy For Reinforced Masonry Building Construction
112	Learning, Structural Masonry Technology And Lean Construction: A Case Study In A Small Building Site
	Session 8 Thursday 19th 15:00 - 16:30 -- Chair: Kristen Parrish
11	Should Project Budgets Be Based On Worth Or Cost?
5	Interorganizational Cost Management And Its Implications For Target Costing In Construction
76	Cost Comparison Of Collaborative And Ipd-Like Project Delivery Methods Versus Competitive Non-Collaborative Project Delivery Methods
133	"Lean Governance": A Paradigm Shift In Inter-Organizational Relationships (Iors) Governance
66	Further Work On Measuring Workflow In Construction Site Production
7	The Robust Schedule – A Link To Improved Workflow
106	A Review Of The Standardized Work Application In Construction
160	Öppen - Lean Thinking, Prefabrication, Assembly And Open Building Thinking - All Applied To Commercial Buildings'
109	Decreasing Complexity Of The On-Site Construction Process Using Prefabrication: A Case Study
23	Arranging Precast Production Schedules Using Demand Variability
9	Applying Lean In Construction – Cornerstones For Implementation
	Gala Dinner Aboard the Berkeley Museum Thursday 19th 18:30 - 21:30

IGLC 20：研討會第二天議程

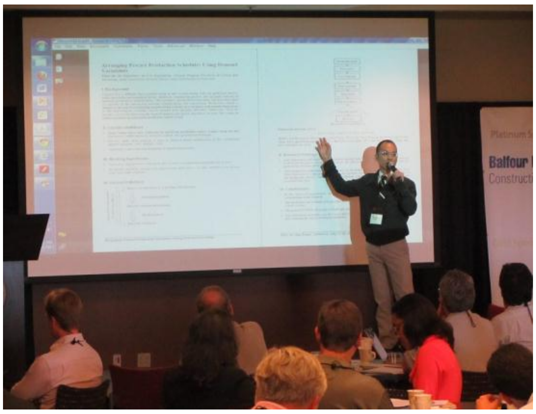
ID	**Session 9 Friday 20th 08:30 - 10:00 -- Chair: Greg Howell**
126	Causes Of Time Buffers In Construction Project Task Durations
3	Understanding The Relationship Between Productivity And Buffers In Construction: A Simulation-Based Case
190	Relationship Of Time Lag Buffer To Material Stockpile Buffer Levels
24	Reducing Material Management Costs Through Lateral Transshipment
70	On Improvement In Construction Supply Chain Management
152	Proof Of Financial Feasibility Of Projected Plaster By Mapping The Value Stream
168	Cost Performance Of Energy Efficiency Measures In Residential Retrofit Projects
72	Developing A Lean Model For Production Management Of Refurbishment Projects
136	Driving Continuous Improvement By Developing And Leveraging Lean Key Performance Indicators
88	Lean Monitoring And Evaluation In A Construction Site: A Proposal Of Lean Audits
172	Application of Just In Time to the Fabrication and Installation of Prefabricated Concrete Facades in Buildings
	Session 10 Friday 20th 10:30 - 12:00 – Chair: Carlos Formoso
115	Identifying The Bullwhip Effect Into The Last-Planner Process During The Construction Stage
129	The Social Dynamic Of Improvement When Using The Last Planner System: A Theoretical Approach
193	Construction Crew Design Guidelines: A Lean Approach
43	Characterizing Final Stages Of Construction Work
33	Implementing Lean Six Sigma: A Case Study In Concrete Panel Production
197	Production Practices For High Reliability In Concrete Construction
58	In Time At Last–Adoption Of Last Planner Tools For The Design Phase Of A Building Project
14	Product Development In Cathedral Hill Hospital (Chh) Project
184	Design Inadequacies Analysis In Low Income Housing Service Areas
57	An Overview Of The Customisation Strategies Developed By Four Organisations Of The House-Building Sector
21	The Level Of Stakeholder Integration – Sunnyvale Case
	Session 11 Friday 20th 13:00 - 14:30 – Chair: Rafael Sacks
198	Interaction Of Production Control And Safety Management System And Implications For Safety
173	Leading Indicators For Safety
183	Cue-Based Decision-Making In Construction: An Agent-Based Modeling Approach
182	Improving H&S By Limiting Transport Externalities In South Africa
56	An Examination Of Safety Meetings On Construction Sites
31	Use Of Five Whys In Preventing Construction Incident Recurrence
128	Forward Thinking Index
15	Trends And Challenges To The Development Of A Lean Culture Among UK Construction Organisations
82	Digital Allocation Of Production Factors In Earth Work Construction
121	Revisiting The Concept Of Flexibility
201	Identifying Lean Construction Categories Of Practices In The IGLC Proceedings
	Friday 20th 14:30 - 15:00 Chairs deliver session summaries (3 minutes each)
	Friday 20th 15:00 - 16:30 IGLC Business Meeting, All Authors Invited To Participate In The Decision Making

IGLC 20：研討會第三天議程

與會過程中以口頭(Oral)方式配合投影片發表論文，發表論文中文名稱：考慮需求變異於預鑄廠生產排程，論文英文名稱：Arranging Precast Production Schedules Using Demand Variability，報告時間約十分鐘，每場次安排有三位報告講者，三位講者全數報告完成後再一併問答，報告後有三位國際人士對本發表論文提出問題：分別為美國學者、以色列學者與非洲學者，國際與會人士一致對本發表論文予以肯定，亦透過討論過程交換意見，提升本國於精實營建此一領域之知名度與國際能見度。

參加研討會實況

發表論文實況 I



發表論文實況 II

討論實況

研討會場

研討會場

7 月 24 日　　搭機返國

由洛杉磯國際機場返國，抵達桃園國際機場。

三、與會心得

- 預鑄廠生產流程改善應從多方面著手，包含：物料管理、供應鍊、生產排程等。
- 當討論變異之影響時應將其範圍縮小一些，使研究主題更為明確。
- 精實的精神在於不斷改善與組職學習，唯有不斷改善、持續進步，方能保有企業競爭力。
- 精實營建著重於去除施工流程中之浪費，有學者將強迫施工者工作(“making-do”)視為是一種浪費。在研討會發表過程中有學者提出應先確認強迫施工者工作(“making-do”)之定義，如果沒有事先定義“making-do”，則無法改善“making-do”所造成之浪費。
- 本研究著重於預鑄生產原料之轉運，有學者認為完成後之預鑄構件或許亦可作為轉運物件之一。
- 精實營建強調於設計的過程中透過專案成員相互檢視與討論，將問題提前浮現，因為沒有一個人可以知道所有事情，因此，協同合作是很重要的。

四、建議事項

- 加州聖地牙哥為美國重要軍事港口，其於軍港外展示退役之航空母艦供遊客參觀，增加收入，可做為本國借鏡參考。
- 該研討會運用A3表格(A3為精實營建所使用的一種表格)呈現各篇內容的摘要，擺脫傳統以摘要方式提供讀者快速了解論文內容，A3方式可作為本國未來舉辦研討會之參考。
- 此研討會並未提供紙本會議論文集，改以A3表格取代，全文則以電子檔方式提供，可減少大量紙本、節能減碳，此方式可作為本國未來舉辦研討會之參考。
- 加州聖地牙哥州立大學位於州際公路旁，為減少行車噪音影響，該校於公路旁設置隔音板，此外，該學附近有多條道路穿越，穿越路段設置具設計感之天橋與架空走廊，除維護行人安全外亦可凸顯學校特色，值得借鏡。

附錄 發表論文

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, 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.,

---

[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

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). 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).

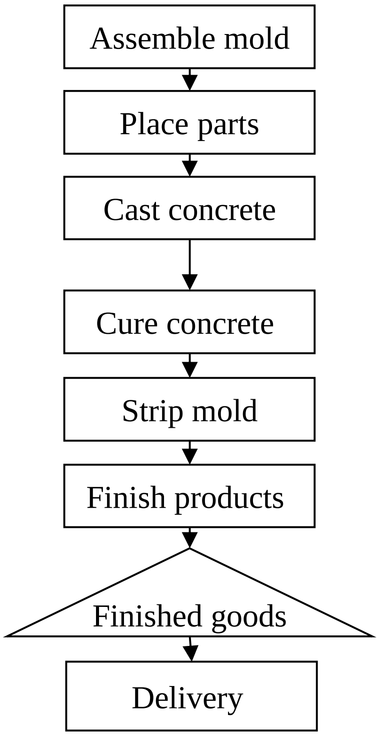


Figure 1: Precast production process

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.

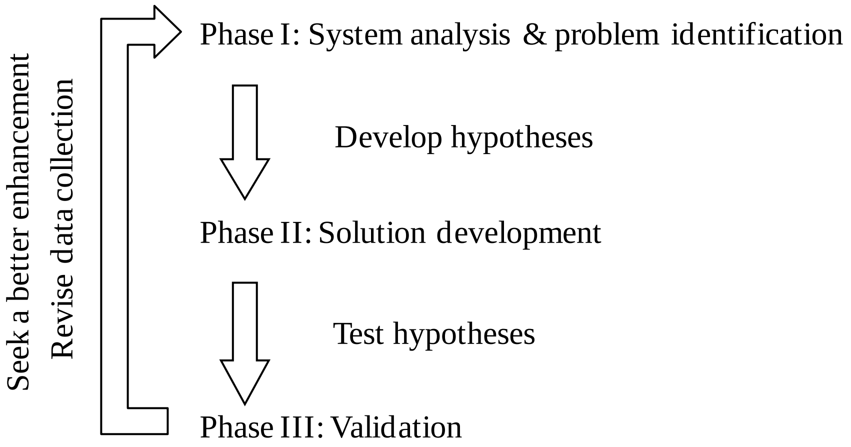


Figure 2: Improvement plan for production control in fabrication (Adopted from Ko, 2011)

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.

$$\mathrm{FLT} = \mathrm{WDT} + \mathrm{SDT} + \mathrm{PT} + \mathrm{FT} + \mathrm{AT} + \mathrm{DT} \tag{1}$$

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.

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

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

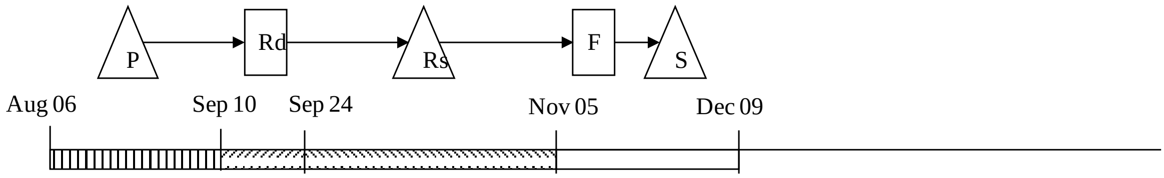
To derive a production schedule that considers the impact of demand variability, two principles are proposed to adjust the production schedule based on the estimated lead times: 1) start fabrication later relative to the required delivery dates and 2) shift production milestones back to the end of the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

APPLICATION

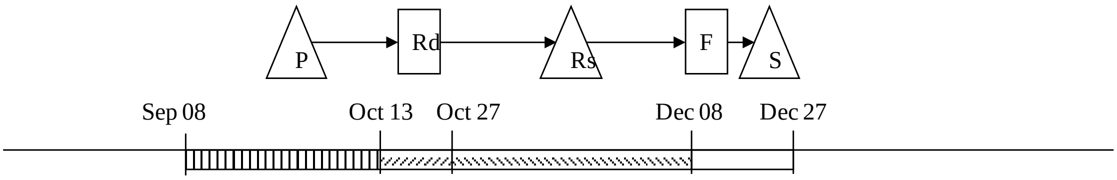
The proposed improvement plan was applied to a real precast concrete fabricator to validate its effectiveness. To understand the fabricator's practices, this research analyzed archived Job Status Reports. The precast fabricator collaborating in this research maintained a Job Status Report in the form 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.



(a) Original Schedule



(b) Adjusted Schedule

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.