APPLICATION OF LEAN SUPPLY CHAIN CONCEPTS TO A VERTICALLY-INTEGRATED COMPANY: A CASE STUDY

Nadia G. Akel[1], Iris D. Tommelein[2], J.C. Boyers[3]

ABSTRACT

This study applies lean supply chain concepts to a vertically-integrated pre-engineered metal building manufacturer, Butler Manufacturing. The paper shows how a flow perspective can be used to highlight non-value adding activities in business processes. Specifically, the study illustrates the application of value stream mapping tools to identify opportunities for reducing cycle time in the Butler order process. While value stream mapping tools have been used before in construction cases, this paper presents an analysis for a different context (that of a project order) as well as a different industry sector. In addition to the value stream analysis, the paper discusses specific supply chain metrics that are used in this case study to analyze order data that cover Butler's in-house supply chain from order taking to shipment. The overall aim of this research is to assist in determining to what extent vertical integration is appropriate for Butler to entrench itself in the pre-engineered metal building market.

KEY WORDS

Supply chain management, lean production, vertical integration, value stream mapping, pre-engineered metal building systems, change order.

[1] Ph.D. Student, P.E., Civil and Envir. Engrg. Department, 215 McLaughlin Hall, Univ. of California, Berkeley, CA 94720-1712, TEL/FAX 925/465-4655, nadia@astound.net

[2] Professor, Civil and Envir. Engrg. Department, 215-A McLaughlin Hall, Univ. of California, Berkeley, CA 94720-1712, 510/643-8678, FAX 510/643-8919, tommelein@ce.berkeley.edu

[3] Corporate Alliance Team Operations Manager, Butler Manufacturing Company, 700 Karnes Blvd. (64108) P.O. Box 419917, Kansas City, MO, 64141-0917, 816/968-3914, FAX: 816/968-4385, jcboyers@butlermfg.com

INTRODUCTION

This research investigates supply chain practices at Butler Manufacturing (henceforth, Butler). Butler engineers, designs, manufactures, and erects pre-engineered metal buildings and components both domestically and internationally. The Butler supply chain comprises supply in-house, reaching from one functional division (e.g., design) into another (e.g., fabrication). It also reaches outside of the organization, upstream to third-party suppliers and downstream to contractors. The company's vertically integrated nature creates a unique opportunity with regards to improving supply chain practices in the otherwise fragmented AEC industry. For instance, Butler is able to fabricate all primary and secondary structural steel components of a 100,000 ft^2 (9500 m^2) building in a 13-day time window after release of detail drawings.

Butler offers a variety of pre-engineered metal buildings, ranging from more standardized, modularized designs to 100% custom designs. Standardization and modularization provide a basis for efficient supply chain practices. The researchers, jointly with their sponsor, therefore decided to study these products, called A-cell buildings, which make up 60% of Butler's orders. A-cell buildings are based on a kind of parametric design that allows for customization while also considering efficiency and cost-effectiveness of fabrication. Butler uses Pronto, a proprietary computer program, to design its A-cell buildings. While this product takes advantage of the in-house design and fabrication capabilities, information and materials do not flow as smoothly as they could across internal organizational boundaries. As a result, the product lead time from order taking to materials delivery on site is larger than it could be, when considerations for continuous flow are taken into account.

The purpose of this case study is to explore potential benefits of applying lean production and supply chain management practices to Butler. The study focuses on A-cell buildings and investigates the possibility of achieving closer alignment between Butler's design/manufacturing arm and its construction arm. This entails identifying internal hand-offs and buffers, and then creating flow and implementing other lean practices in Butler and its subsidiaries. Alignment may be achieved by implementing lean production principles not only within but also across organizational boundaries.

BUTLER BACKGROUND

Butler designs buildings in-house because the required structural engineering knowledge in cold-formed and three-plate (rigid frame) steel design is neither widely taught nor readily available. In fact, the company has design offices in each of its six U.S. manufacturing facilities. In recent years, the pre-engineered metal building industry has moved from modular, standardized buildings to custom buildings. Butler has followed suit but many of its processes rely on parametric designs so that it can still take advantage of modularity in its processes.

Butler brings its building systems to market through various agreements with general contractors. It sells them predominantly through two distribution channels: (1) Butler Builders (henceforth, Builders), a network of local, independent general contractors authorized to sell and erect Butler Buildings, and (2) Butler Construction (BUCON), Butler's own construction arm. These two types of distributors serve different markets and generally do not compete with each other. Akel et al. (2001) further detail Butler's organization and distributor network, and Tommelein et al. (2003) elaborate on Butler's supply chain.

BUTLER ORDER DATA

While this case study focuses on Butler, a national corporation, most of the data was obtained in working with personnel at their plant in Visalia, CA. This choice was driven largely by the plant's relative proximity to U.C. Berkeley but also by the fact that Visalia personnel already had put significant effort in mapping their processes and implementing lean production practices.

The data for the value stream analysis are based on 21 Pronto orders handled by Visalia in 2001 to serve a single, larger-sized Builder. These 21 orders correspond to 18 projects. Only an exceptional project is broken down into multiple orders.

METRICS

Butler uses three main metrics at its production facilities: (1) value added time (VAT), (2) manufacturing cycle time, and (3) manufacturing lead time. These terms are defined below along with other supply chain metrics that are used in this case study to analyze order data that cover Butler's in-house supply chain from order taking to shipment. The definitions are based on Hopp and Spearman (2000), the Supply Chain Operations Reference Model Metrics (SCOR 2000), and the Lean Construction Institute (LCI 2004).

Cycle Time [unit of time]: The time for a product to go from the beginning to the end of a production process; i.e., the time the product spends as work-in-process. Cycle time includes three components: Value Added Time, Setup Time, and Wait Time. [Note that Butler refers to cycle time as the ***manufacturing lead time*** (***MLT***) and uses ***manufacturing cycle time*** (***MCT***) to denote VAT and Setup Time].

Cycle Time = VAT + Setup Time + Wait Time [= MLT = MCT + Wait Time]

Value Added Time (***VAT***) [unit of time]: The time necessary to actively work (design, engineer, fabricate, etc.) on an item (such as a project design, a beam, a clip, etc.). It is the time spent to perform a conversion task.

Setup Time [unit of time]: Time it takes to change over, clean up, or otherwise ready a machine or production unit to start the next task or operation.

Wait Time [unit of time] (also referred to as Queue Time). The time an item sits around waiting to be processed or handled as value added time.

Throughput (or ***Throughput Rate***) [unit of quantity/unit of time]**:** The average output rate of a production process (e.g., machine, workstation, line, plant) per unit time (e.g., parts per hour). The limit on throughput is capacity.

Capacity [unit of quantity/unit of time]: an upper limit on the throughput of a production process (Hopp and Spearman 2000 p. 216).

Schedule Plan Stability: The number of times the scheduled delivery date changed after it was 'fixed' once it appeared within the critical time fence. The critical time fence defines the moment after which changes become significantly more expensive to accommodate than they were, had they been made earlier (e.g., materials obtained and partially completed may become obsolete). It is the boundary between flexible and fixed capacity (SCOR 2000), sometimes referred to as the 'last responsible moment.'

Delivery Performance to Scheduled Commit Date: The percentage of orders that are fulfilled on or before the original scheduled or committed date (SCOR 2000).

ANALYSIS AND OBSERVATIONS

Koskela (2000) proposed six flow principles to reduce waste in organizations: (1) reduce the share of non-value adding activities (waste), (2) reduce lead time, (3) reduce variability, (4) simplify the number of steps, parts, and linkages, (5) increase flexibility, and (6) increase transparency. The following analysis adopts this flow perspective.

VALUE STREAM ANALYSIS: ORDER PROCESS AND CURRENT-STATE MAP

A value stream analysis of the Butler order process was performed in order to assess information and material flow, to identify the sources of waste, and to help visualize the entire order process. Per Rother and Shook (1998), Brunt (2000), Rother and Harris (2001), and Jones and Womack (2002), a value stream consists of all the actions (both value and non-value added) required to bring a product through the main flows essential to every product: (1) the production flow from raw material to customers, and (2) the design flow from concept to launch.

The value stream map we developed for the order process follows an order from the time it is placed by a Builder to the time it is shipped to the construction site. Figure 1 shows the value adding steps as rectangles, and the hand-offs with delays as triangles. Circled numbers correspond to process lead time descriptions in Table 1. Figure 1 shows activity durations (in total man-hours [mh] of work content) and lead time estimates provided by Butler personnel. The "average total actual time in system" is the estimated average lead time of a Butler order from the point the order is assigned to the actual ship date. In contrast to Figure 1, Figures 2 to 6 show planned and actual lead times calculated using order data. Table 1 summarizes statistical calculations for these figures. Note that original planned dates are the dates set prior to change orders, while revised planned dates correspond to planned dates that have been amended via change order.

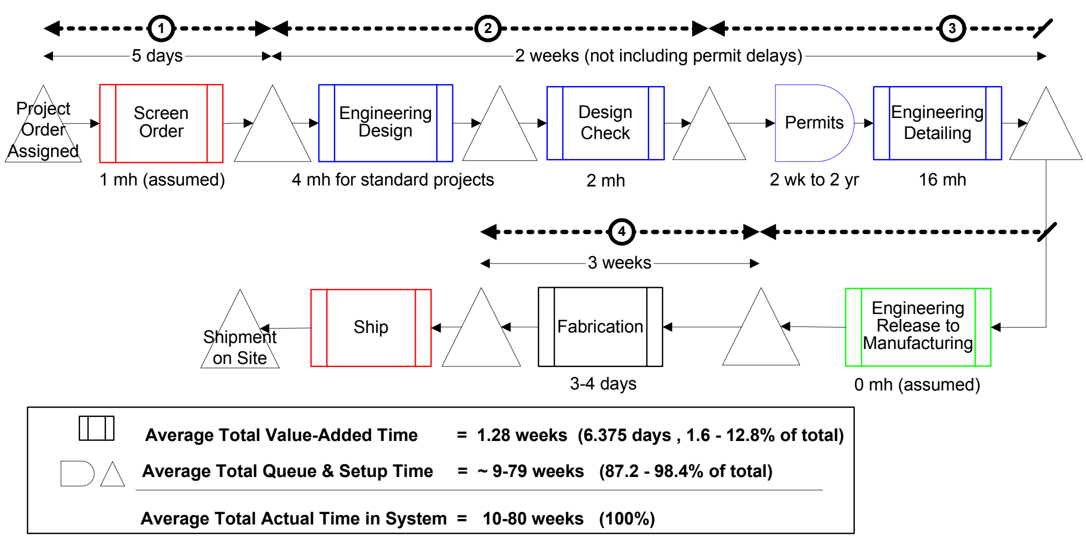

Figure 1: Value stream of Butler Visalia's order process

The estimates provided by Butler personnel (Figure 1) are relatively close to the mode (most likely) values calculated from the order data, which have skewed distributions (Figures 2 to 6). For example, the mode of the duration for the planned design activity is only 1 day, which is close to Visalia's estimate of 6 man-hours (4 hours for engineering design and 2 hours for design check). However, the average duration is much larger at 6.7 calendar days since it accounts for the outliers. Due to the skewed nature of these lead time distributions, Butler personnel properly used mode values as these do not account for the rare case of having an unusually long duration.

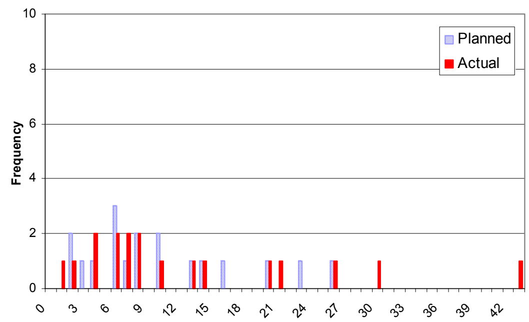

Figure 2: Frequency of Lead Time from Order Assigned to Design Start [days]

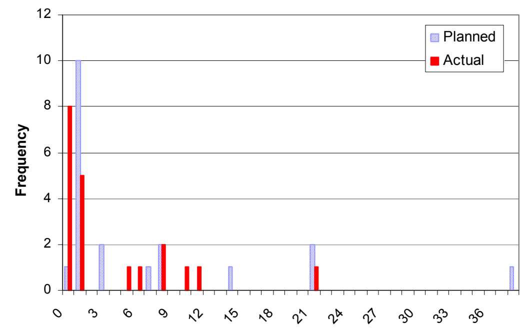

Figure 3: Frequency of Design Duration [days]

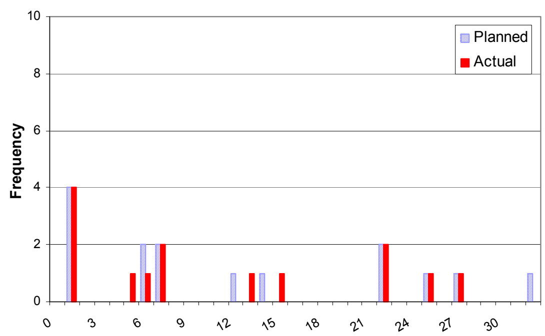

Figure 4: Frequency of Duration of Permit and Detail Engineering [weeks]

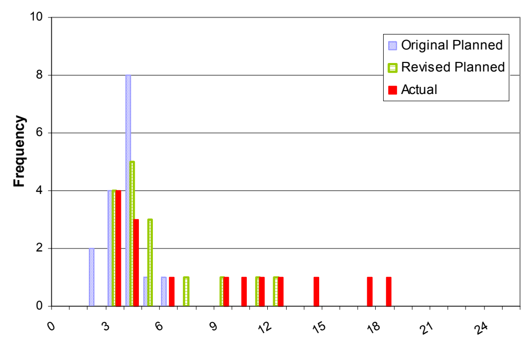

Figure 5: Frequency of Duration from Engineering Release to Ship Date [weeks]

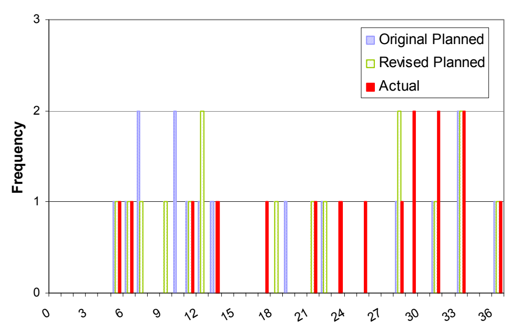

Figure 6: Frequency of Lead Time from Order Assigned to Ship Date [weeks]

The time required to obtain permits depends on the location of application and the number of projects that that city is processing—hence, the 2-week to 2-year range (Figure 1). For example, in Los Angeles permits take roughly 9 months to procure, whereas in a small municipality such as Visalia they take about 3 weeks. The order data analyzed had a mode of 1 week and an average of 12 weeks.

Table 1: Statistical calculations for Butler's order process

	Process Lead Time Description	Average	Standard Deviation	Mode	Figure
1	Order Assigned to Planned Design Start (days)	10.2	7.1	6	2
	Order Assigned to Actual Design Start (days)	12.8	11.2	6	
2	Planned Design Duration (days)	6.7	9.8	1	3
	Actual Design Duration (days)	3.7	5.5	<1	
3	Planned Permit & Engineering Detail Duration (weeks)	12.0	10.6	1	4
	Actual Permit & Engineering Detail Duration (weeks)	12.0	10.7	1	
4	Planned ERD to Original Planned Ship Date (weeks)	3.3	0.9	3.4	5
	Planned ERD to Revised Planned Ship Date (weeks)	5.0	2.8	5.0	
	Actual ERD to Actual Planned Ship Date (weeks)	8.8	6.7	2.6	
	Order Assigned to Original Planned Ship Date (weeks)	17.3	11.1	9.7	6
	Order Assigned to Revised Planned Ship Date (weeks)	19.0	11.0	11.3	
	Order Assigned to Actual Planned Ship Date (weeks)	22.8	10.0	28.1	

Circled numbers to the left of the table correspond to those shown in Figure 1.

By comparing estimated data to actual order data, performance metrics can be assessed. The total VAT (Figure 1) was roughly 1.28 weeks. This is 1.6 to 12.8% of the total estimated lead time (LT). According to actual order data, the VAT/LT is roughly 5.6% (Table 2). Compare this to other supply chains in the construction industry: Arbulu and Tommelein (2002) showed that VAT/LT is on the order of 3.5 to 4% for pipe supports used in power plants. Similarly, Elfving et al. (2002) and Elfving (2003) indicated that VAT is less than 10% of total LT for power distribution equipment. Hopp and Spearman (2000 p. 327) noted that "In most production systems, actual process and move times are a small fraction (5-10 %) of total cycle time." Anecdotal evidence based on lean construction studies suggests that VAT/LT is on the order of 1/20 (5%) for design and 1/10 to 3/10 (10-30%) for fabrication (Ballard 2003).

Table 2: Percentage of VAT for overall order process (after Tommelein et al. 2003)

Lead Time [weeks]		**VAT / LT**
from	**to**	
Order Assigned	Original Planned Ship Date	7.4%
Order Assigned	Revised Planned Ship Date	6.7%
Order Assigned	Actual Ship Date	5.6%

An opportunity appears to exist to streamline Butler's value stream since its VAT/LT ratio is on the low end at 5.6%, especially when considering that this number is for their standard parametric designs. Improvements may include reducing wait and setup times in the system. Increasing VAT up to 20% or more of LT has shown to be feasible in manufacturing and we suggest this as a target for the AEC industry.

Table 2 shows VAT/LT ratios computed using actual plant data. These include three sets of values, corresponding to (1) original plan, (2) revised plan, and (3) actual execution. Not surprisingly, the VAT/LT ratio is higher when considering planned as opposed to actual times because planners are optimistic and eventually schedules do slip.

CYCLE TIMES

Figure 7 illustrates the cycle times for various components fabricated at the Visalia plant. Note that the bars are not drawn to scale. The VAT/LT ratio varies greatly for different components. Primaries have an average ratio of 0.5% while wall roof panels have a ratio of 0.02%! In contrast, secondaries are more efficiently produced with a ratio of 25-50%. As was the case in the previous analysis, VAT is a very small percentage of the total cycle time for all components, with exception of the secondaries.

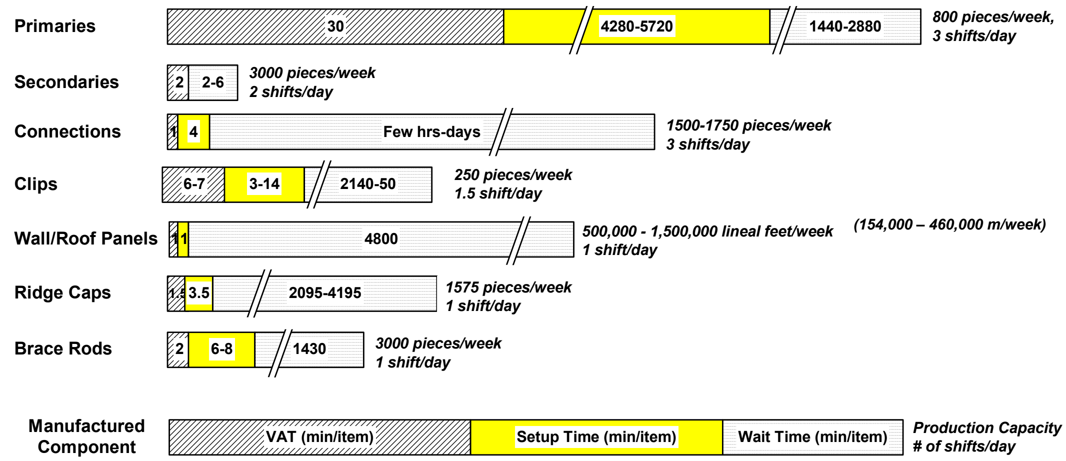

Figure 7: Cycle times for material fabricated at Butler Visalia

Figure 7 also shows the weekly plant production capacity for each component. For example, the Visalia plant can fabricate 800 primary components weekly in three 8-hour shifts. To appreciate the production capacity of the various components, Figure 8 shows a small pre-engineered building (Stuart 2002) that we have annotated with take-off data from a Butler building with footprint 60’ by 100’ (18.5 m x 31 m). For reference, most Butler Builder buildings are on the order of 50,000 to 100,000 square feet (4,750 to 9,500 m^2) (Akel et al. 2001).

The basic components of a pre-engineered metal building system are primary rigid frames, secondary members (wall girts and roof purlins), and cladding and bracing (Shoemaker 1999). The primary frames are designed using welded plate members instead of hot-rolled sections used in conventional steel design. This practice permits the use of tapered beam sections. By varying the web depth and flange size over the length of a member, pre-engineered metal manufacturers can produce designs that are more cost effective than their conventional steel counterparts. The secondary members are usually cold-formed into C and Z shapes.

The Visalia plant processes 25-30 orders per week more or less, depending on customer demand. Typically, there are 8-9 jobs ongoing at any one time. The Visalia plant itself has capacity to manufacture 700-800 frames pieces per week. For reference, a 100,000 square-foot building consists of approximately 200 frame pieces.

To understand the plant’s production capabilities, assume that the 6,000 sq.ft. (570 m^2) building in Figure 8 constitutes an average order, and assume that the ratio of the various component quantities is similar for all orders. Correspondingly, Table 3 shows the number of orders per week that can be processed for each component. The production of primaries governs overall production capacity since the maximum number of primary orders that can be fabricated per week is 21. It is even more of a bottleneck in light of the fact that the 800 pieces/week capacity is based on three 8-hour daily shifts. The plant's processing of 25-30 orders/week suggests that the primaries and secondaries run near 100% capacity utilization.

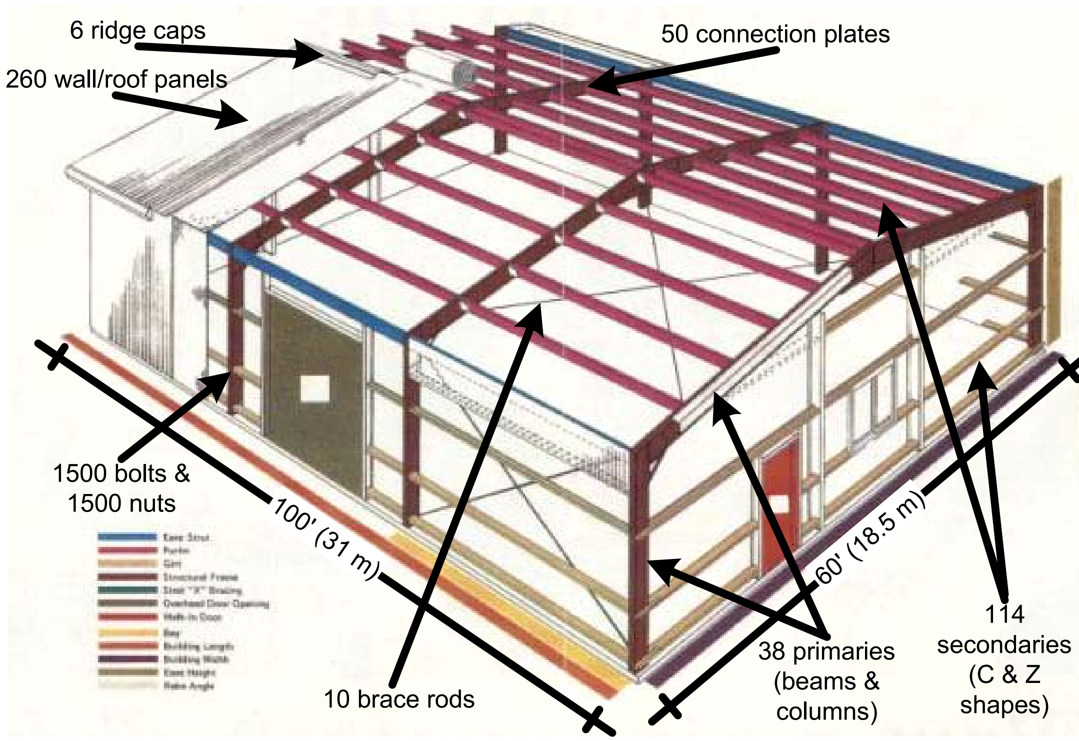

Figure 8: Small pre-engineered building (Stuart 2002) annotated with take-off data from Butler building with footprint 60' by 100' (18.5 m x 31 m)

Table 3: Plant order capacities for various materials in a 6,000 sq.ft. (570 m^2) building

	Primaries	Secondaries	Connections	Ridge Caps	Brace Rods
Production capacity [pieces/week]	800	3000	1750	1575	3000
Number of pieces for one 6000 sq.ft. building order [pieces/order]	38	114	50	6	10
Maximum number of orders/week	21	26	35	263	300

BATCHING

The hand-off from design to fabrication—governed by Pronto—is traditional and batch-oriented. Opportunities for process improvement are to be investigated in this area.

Figure 9 reveals batching rules that govern the hand-offs for a particular Pronto project. First, unless a project has completely regular plan and elevation views—i.e., a rectangular-shaped building with no mezzanine—it is broken down into multiple 'regular-shaped' orders for Pronto design purposes. Second, a Butler order is broken down into manifests—one for each fabrication location or outside suppliers. Third, an internal Butler manifest is broken into phases for production scheduling purposes. Finally, once the fabrication is completed and Butler receives the supplies from its suppliers, the order is reassembled and again broken down into transportation manifests. Such batch-oriented hand-offs cause matching problems (Tommelein 1998), thereby rendering the order process less efficient.

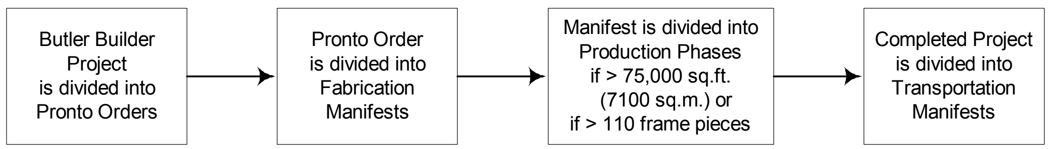

Figure 9: Batch-oriented hand-offs for Butler Builder projects

CHANGE ORDER ANALYSIS: SCHEDULE PLAN STABILITY

Of the 21 orders analyzed, 11 (52%) had change orders. The number of change orders per order ranged from 0 to 6, with an average of 1.19. All change orders, except for one, were to postpone planned ship dates and/or engineering release dates. Changes related to planned ship dates are common in the construction industry. Assuming all planned ship date changes were made within the critical time fence, the Schedule Plan Stability for the orders analyzed was 1.14. Schedule Plan Stability is less than the number of change orders per Butler order because some change orders did not occur within the time fence.

Figure 10 compares and contrasts the total delivery time of orders that did not have change orders ('A') with those that did ('B'). The dotted bars show the duration of permitting and detail engineering. Note that our observations about the data are speculative and are based on a small number of data points (21).

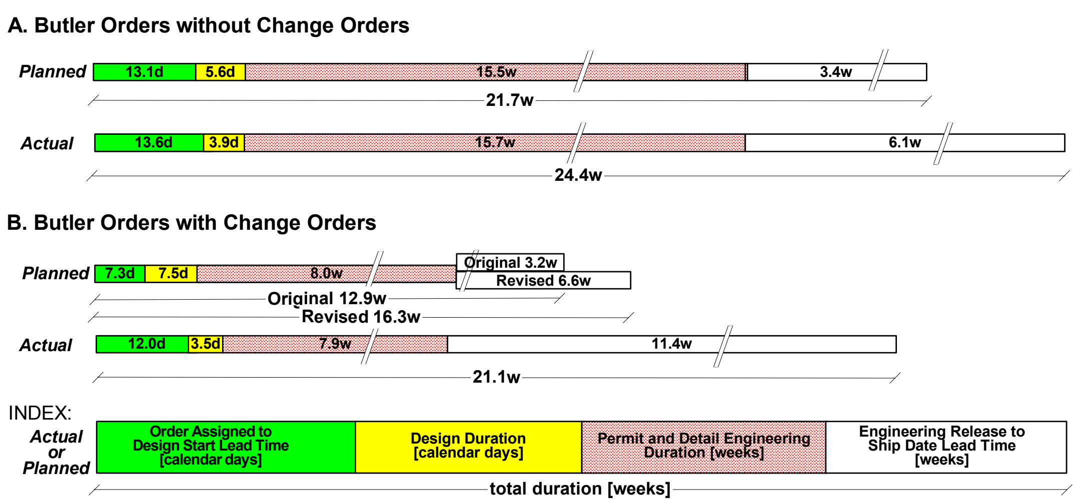

Figure 10: Butler orders with and without change orders

Permitting is a bottleneck: Since detail engineering has a VAT of 16 mh while the bars are on the order of 8-15 weeks, we infer that the bars primarily represent permitting delays. Permitting has a long lead time. Most striking is the large variation in its duration, in particular because the projects analyzed are all built in the same geographic area. The planned time required to get a permit is about 15.5 weeks for orders without changes, and slightly over half of that, 8 weeks, for orders with changes. Barring regional and design differences, we speculate that orders with changes are 'on the fast track' and require permit expediting, which may be done either for a fee, by active expediting, or the like.

Figure 10 may give the impression that permitting drives the start of engineering detailing and of fabrication further downstream, but the drawing does not show other supply chains feeding into this one. A reduction in time for permitting and thus between design and fabrication, may constrain the time available for other material procurement, mobilization, and stocking. Performance improvements for those tasks are then needed in order to make it possible for fabrication to start earlier.

Jump-starting the delivery process is difficult: While the planned Order Assigned to Design Start time for 'B' orders shaves 5 days off from what it is for 'A' orders, in practice, that lead time is close to what it is for 'A' orders anyway. Some of that lost time in 'B' orders ('lost' meaning the difference between planned and actual) appears to be made up by less time spent on design: the planned value of these two combined is 7.3 d + 7.5 d = 14.8 d and the actual value 12.0 d + 3.5 d = 15.5 d. These values are a few days less than their counterparts for 'A' orders, 18.7 d and 17.5 d respectively.

Note that for both 'A' and 'B' orders, the actual design time is less than the planned design time. It is the only task shown in Figure 10 for which this is the case. We speculate that the resources required to perform design are underloaded sufficiently so that they can accommodate 'urgent' demands without much difficulty. Underloading means that a resource is not scheduled to work at 100% capacity at all times, but instead at 80% or 90% depending on the variability in work flow. It is a management technique for creating reliability in work flow and throughput in systems that are subject to variability. Underloading should make it feasible to estimate durations and adhere to them, but the practice of padding schedules is deeply engrained.

Fast-track jobs create turbulence downstream: Orders with changes saw an escalation of Engineering-Release to Ship-Date, with actual values being nearly double that of planned values. Moreover, these 'B' orders had an actual value significantly larger than 'A' orders. Provided that it is correct to assume that orders with changes are on the fast track, a question then is how to manage changes while not jeopardizing fabrication?

Normal delivery is more reliable; fast-track delivery is plagued by uncertainty: For 'A' orders, the planned overall total duration is closer to the actual than for 'B' orders. This discrepancy is due to the fact that orders with changes have a much longer actual average engineering release to ship date lead time (11.4 weeks) than orders without (6.1 weeks). Changes appear to adversely affect fabrication scheduling, thereby hampering its ability to deliver the product in a predictable manner.

Schedules always slip: Actual ship dates always exceeded original and revised planned dates by several weeks, about 3 weeks for 'A' orders and about 5 for 'B' orders. This suggests that fabrication scheduling may be improved so that planned dates are less optimistic and closer to actual dates.

DELIVERY PERFORMANCE TO SCHEDULED COMMIT DATE

Only 17 out of 21 orders had information related to actual ship dates. Among these, only 4 were fulfilled (actual delivery) on or before the original planned ship date. Therefore, the Delivery Performance to Scheduled Commit Date ratio is a mere 4/17 or 23.5%. The actual ship date of these 4 orders coincided with the original planned ship date: none shipped early.

The percentage of orders that were fulfilled within one week and three weeks from the original planned ship date is 41.2% (7/17) and 47.1% (8/17), respectively. The poor estimation of original planned ship dates may be investigated by compiling reasons for failure and conducting a root cause analysis.

LESSONS LEARNED

Several lessons are learned from analyzing the Butler case:

- **Elasticity in production capacities:** Since frame production is usually the fabrication constraint at the Visalia plant, Butler runs frame production (primary steel fabrication and its associated connections) at this plant 3 shifts per day, 5 days per week. The other component fabrication lines typically do not run at capacity but on 1 or 2 shifts per day, depending on the component produced and demand for it. This elasticity in production capacity (by controlling the number of shifts/day) to accommodate market variability has helped Butler maintain competitive delivery schedules while mitigating costs of non-critical production activities.
- **Modularization and its impact on the production process (supply chain):** By categorizing designs according to degree of project customization, Butler was able to improve the efficiency of its design function and fine-tune it to take advantage of its fabrication capabilities.
- **Serving customer needs – supplier design for constructability or mistake-proofing (poka-yoke):** Butler spends considerable time and effort learning from its Builders and BUCON what the degree of constructability is of their products. The company invests heavily in research and development in order to make its products more appreciated by building erectors as well as owner-operators. For example, Butler worked with an upstream supplier to engineer a new kind of sealant (a putty-like material with tiny cubes in it) that a worker cannot compress too much during installation (doing so would squeeze the material out from the joint and thereby prevent sealing action). This putty material comes in rolls with layers separated using easily removable, non-tear plastic strips, and one side of the strip is precut lengthwise to allow for easy positioning of a screw through it.
- **Gaining insight into product demand:** Butler's Corporate Alliance group courts large owners, users of large Butler buildings. Because these owners have facilities around the country, sometimes even around the world, no Builder is in a position to serve them consistently. Butler's Alliance group was formed exactly for that reason. In developing a close relationship with owners, Butler also is gaining insight into upcoming demands for their products, which is valuable for their own production planning.
- **Standardization:** Butler has been able to provide a short made-to-order delivery time by standardizing products, automating large parts of the design process, maintaining approximately 3-month worth of inventories, and distributing production capabilities around the country so as to be close to delivery locations.

CONCLUSIONS AND RECOMMENDATIONS

Butler is proactively improving its processes, but its application of lean production today resides primarily at the plant level. By applying lean production principles across its internal functional divisions, Butler can realize additional improvements, in areas such as:

- **Batching:** The batching process from order-to-manifest could be improved to facilitate flow. Permitting demands a huge batch, but as far as production is concerned, design information may not be needed all at once (as Pronto demands now). The primaries could be designed first and released into production while the design of secondaries is under way. By releasing the time-critical production of the primaries, the overall design and fabrication duration of the entire project may be reduced. Furthermore, primaries are the members needed first in construction so this re-sequencing of work may also benefit further downstream operations. Butler should reconsider how projects are broken up in pieces (batches) that define the various units for design, document generation, fabrication, and shipping, and then streamline that process with work flow and the final unit of handoff to the contractor in mind.

- **Transparency:** Butler can improve information transparency across its internal functions and across its supply chain in order to tighten the rules-of-thumb that are used to replenish inventories. For example, Butler can be clearer about what is needed when, so that when deadlines are missed, the impact on production is better understood. Butler can also make its production process more transparent to its construction customers without necessarily giving away competitive advantage. A possibility is to penalize its customers for late changes.
- **Synchronization, One-Piece Flow, and Pull:** Butler could further study the time employees spend on soliciting and rectifying customer order data. This process presently appears to be time consuming and subject to variability so that it takes away from Butler's design and fabrication efficiency. A suggestion is to decouple order taking from design. Similarly, the permitting process appears to be time consuming and subject to variability. This process could also be decoupled from design (upstream) and fabrication (downstream). Some large owners of campus facilities, for example, do so by procuring permits by geographic area instead of project –by project. Butler could then aim for continuous flow in each of these four de-coupled production phases.
- **Production Balancing:** Butler's design and fabrication processes were mapped using symbols that represent value adding work as well as 'holding' positions (also known as transfer points, queues, inventories, waiting lines, etc.) Each process step was defined in terms of its VAT, setup time, and wait time. It appears as though the various production steps all progress at their own pace with relatively little consideration for the pace of other processes that are part of the same sequence or whose outputs merge at a later time. The production system as a whole, across design through fabrication, has not been balanced. This lack of balancing has many reasons, which have to do with variability and risk.
- **Alliances:** Butler currently has longer-term procurement agreements in place for structural steel. These were not investigated in the study, but they may be worth looking into to further improve SC performance.
- **Horizontal Integration:** Butler has bought other supplier firms (e.g., door and window suppliers) but it is not clear to what extent these products or processes have been streamlined to integrate with Butler's core products and processes.
- **Process Maps:** Butler could further detail the process maps that have been created in the course of this research to identify additional opportunities for SC improvement from a total systems perspective.
- **Array of Products Produced:** Butler could reconsider what it is producing at each of its 6 fabrication plants. Presently, all plants can make all primary and secondary components, albeit in a limited set of colors (some plants offer a wider selection than others), but some cannot make trim components such as eaves, gutters, etc. Butler must therefore ship such components between plants. It is quite possible that the cost to invest in tools and equipment to make these components in small quantities is not prohibitive, and would offset the cost of inter-plant transportation. (The decision to ship between

plants may be driven by Butler's past investment in fully automated but expensive production facilities, whose costs must be offset by high volumes of production.)

ACKNOWLEDGMENTS

The authors are deeply indebted to J.C. Boyers, Operations Manager in Butler's Corporate Alliance Team, for the wealth of information he has provided related to Butler's organization and operations, and data he obtained for this case study. This research project would not have been possible without J.C.'s continued assistance.

Thanks are due to all people interviewed, for the time they spent and knowledge they shared with us. To name a few specifically: Greg Stolze, Alice Brown, and Mark Nore, generously shared their experience in managing the design, operations, and demands of Butler's Visalia plant, and Ellis Daniels at Valley Steel Construction in Fresno shared his knowledge and experience in delivering pre-engineered metal buildings.

This research was funded in part by a grant from the Construction Industry Institute for Project Team 172 "Improving Construction Supply Chain Performance" whose support is gratefully acknowledged. The opinions as presented are those of the authors and do not necessarily reflect those of Project Team members or the Construction Industry Institute.

REFERENCES

Akel, N.G., Boyers, J.C., Tommelein, I.D., Walsh, K.D., and Hershauer, J.C. (2001). "Considerations for Streamlining a Vertically Integrated Company: A Case Study." *Proc. 9th Ann. Conf. of the Intl. Group for Lean Construction*, 6-8 August, Singapore.

Arbulu, R.J. and Tommelein, I.D. (2002). "Value Stream Analysis of Construction Supply Chains: Case Study on Pipe Supports Used in Power Plants." *Proc. 10th Annual Conf. of the Intl. Group for Lean Construction*, Brazil.

Ballard, G. (2003) Personal communication to Iris Tommelein, November.

Brunt, D. (2000). "From Current State to Future State: Mapping the Steel to Component Supply Chain." *The Intl. J. of Logistics: Research and Applications,* 3 (3) 259-271.

Elfving, J.A., Tommelein, I.D., and Ballard, G. (2003). "An International Comparison of the Delivery Process of Power Distribution Equipment." *Proc. 11th Annual Conf. of the Intl. Group for Lean Construction*, 22-24 July, Virginia.

Elfving, J.A., Tommelein, I.D., and Ballard, G. (2002). "Reducing Lead Time for Electrical Switchgear." *Proc. 10th Ann. Conf. of the Intl. Group for Lean Construction.*, 6-8 Aug., Brazil.

Hopp, W.J. and Spearman, M.L. (2000). *Factory Physics: Foundations of Manufacturing Management*. Irwin/McGraw-Hill, Boston.

Koskela, L. (2000). "An Exploration Towards a Production Theory and its Application to Construction." *Ph.D. Dissertation, VTT Publication 408*, Espoo, Finland, 296 pp.

Jones, D. and Womack, J. (2002). *Seeing the Whole – Mapping the Extended Value Stream*. March, The Lean Enterprise Institute, Brookline, MA, 97 pages.

LCI (2004). Lean Construction Institute Glossary. http://www.leanconstruction.org. Visited May 31.

Rother, M. and Harris, R. (2001). *Creating Continuous Flow – An Action Guide for Managers, Engineering, and Production Associates.* V. 1.0, June, The Lean Enterprise Institute, Brookline, MA, 104 pages.

Rother, M. and Shook, J. (1998). *Learning to See: Value Stream Mapping to Add Value and Eliminate Muda*. V. 1.1, Oct., The Lean Enterprise Inst., Brookline, MA, 106 pp.

SCOR (2000). *Supply Chain Operations Reference (SCOR) Model*, Supply Chain Council, Inc., Pittsburg, PA, Version 3.1, March. www.supply-chain.org

Shoemaker, W.L. (1999). "Metal Building Systems: A New Look." *Civil Engineering*, June, 69 (6) 56-59.

Stuart, M. (2002). *Metal Building Systems.* Figure in course outline downloaded on 9/6/02 from http://www.pdhcenter.com/.

Tommelein, I.D. (1998). "Pull-driven Scheduling for Pipe-Spool Installation: Simulation of Lean Construction Technique." ASCE, *J. of Constr. Engrg. and Mgmt*., 124 (4) 279-288.

Tommelein, I.D., Walsh, K.D., and Hershauer, J.C. (2003). "Improving Capital Projects Supply Chain Performance." *Research Report 172-11*, Construction Industry Institute, University of Texas at Austin, 241 pages.