Lean Evaluation of an Engineering Process: A Case Study in Furniture Industry

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Abstract

Currently, an efficient engineering process is very important for the furniture manufacturers. For example, drawings or production documents are controlled merely by the release date and not by a systematic method to measure each internal process and how it affects internal cost and customer satisfaction. This research was conducted through a case study in a furniture plant located in China, manufacturing American-style furniture products. The objective was to investigate the company's current engineering process, identify nonvalue-added activities, and analyze the engineering performance based on certain key performance indicators (KPIs) such as lead time, document error rate, and engineering throughput. A survey was sent out to the engineering group to determine each engineer's understanding of the current engineering efficiency. Results show that "product complexity" and "engineer competency" are the two most influential factors that impact the engineering process lead time. Most engineers spend 10% to 20% of their daily working time issuing engineering change orders. Different engineering groups showed a difference in engineering throughput, customer diversity, and production document error rate. From this research, it is concluded that engineering change order (ECO) is a significant driver of engineering lead time. Also, the current processes include a significant amount of nonvalue-adding activities, interfering with the engineers' ability to prepare production documents for downstream jobs and affecting the overall manufacturing process.

Keywords: Lean thinking, lean manufacturing, furniture production, key performance indicators, KPIs, engineering change order, ECO, Toyota Production System, TPS, product life cycle.

Introduction

The goal of lean thinking is to use the least amount of resources and time to deliver desired customer value through a continuous flowing value stream (Womack and Jones 1996). In the furniture industry, lean strategies have been widely used in the production area (Cumbo, Kline, and Bumgardner 2006). Schuler and Buehlmann (2003) indicated that lean manufacturing is an essential element for strategic renewal of the business model in the U.S. furniture industry. Moreover, through a survey of 145 wood products companies in the U.S., Cumbo, Kline, and Bumgardner (2006) found that a majority (55%) of these companies had been implementing lean manufacturing at the time of the study. Within the subsectors, 56% of cabinet makers, 71% of upholstered, and 53% of nonupholstered furniture manufacturers indicated they were doing lean implementations. Quesada-Pineda and Gazo (2007) illustrated that lean manufacturing practices, like pull system scheduling, are positively related to the performance of furniture manufacturing companies. Motsenbocker et al. (2005) conducted a case study to investigate the effectiveness of using flow-line technology to increase productivity in the furniture industry. The benefits of this technology were reflected in reduced lead time and inventory, more production space, labor savings, and increased productivity. In another case study, Czabke (2007) investigated lean implementation in two U.S. wood products companies and two German wood products companies. He found the following:

- The implementation of lean results in a more efficient and cost-effective manufacturing performance.

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- Lean is suitable for nonproduction areas in the secondary wood products industry.
- Communication is a big challenge to implement lean.

Hunter (2008) proposed to incorporate the Toyota Production System (TPS) in the furniture industry by the implementation of a cellular manufacturing subsystem in upholstery furniture production. According to the author, the benefits of the proposed TPS double D-shaped manufacturing cell include increased productivity, decreased labor cost, improved quality, relaxed line balancing problem, improved worker ergonomics, and continuous process improvement.

The application of lean thinking in nonproduction areas, especially the engineering process, has been given extra attention in other industries during the last decade (Donald Reinertsen 2005; Middleton, Flaxel, and Cookson 2005; Browning 2003; Haque 2003; Freire and Alarcón 2002). However, research on lean thinking has not been conducted in the furniture industry. In the wood furniture industry, engineering also plays an important role in the product life cycle. Engineering not only helps materialize design concepts but also facilitates mass production and mass customization (Da Silveira, Borenstein, and Fogliatto 2001). Therefore, there is a need in the furniture industry for an efficient engineering process. This research aims to analyze the current engineering performance and key performance indicators through a survey questionnaire given to the case study company's engineering group.

Theoretical Background

The lean thinking concepts were introduced in 1990 by Womack, Jones, and Roos (1990) in their study that compared the manufacturing performance of the automobile industry between Western and Japanese car makers. The goal of lean thinking is to use the least amount of resources and time to deliver customer value through a continuously flowing value stream (Womack and Jones 1996). It encompasses five basic principles to eliminate "waste" (waste in this context is understood as any activity that does not add value from the customer's point of view):

- Specify value
- Identify the value stream
- Implement flow
- Implement pull
- Pursue perfection

The first principle means to "specify the value" from the customer perspective, not from the engineers' point of view (or any other people within an organization). "Identify the value stream" signifies figuring out all the processes to deliver a product or service to customers. "Flow" indicates generating continuous value-creating steps, making them flow, and reducing batch sizes for a single-task process. "Pull" represents developing customer value from a pull system instead of push. Every process along the value stream should be aligned with the customer's needs and satisfy these needs in a timely manner. "Pursue perfection" signifies to endlessly strive for perfection, avoiding waste and errors, and keep implementing continuous improvements (Womack and Jones 1996). The same authors indicated that lean principles also fit in areas outside manufacturing operations. Baines et al. (2006) pointed out that lean principles have great potential benefits when applied to knowledge-based activities such as new product development (NPD) and engineering. Karlsson and Ahlstrom (1996) classified engineering as one of the interrelated techniques in lean product development. Morgan and Liker (2006) described the engineering process as that in which "raw materials consist of information – customer needs, past product characteristics, competitive product data, engineering principles and other inputs that are transformed through the product development process into the complete engineering of a product that will be built by manufacturing."

Engineering plays an important role in determining the production costs. Prasad (1996) depicted the cost associated with fixing a mistake in the product life cycle and indicated that fixing a problem at the early stages in the product life cycle costs less than detecting and fixing the problem during later stages. He also stated that this allows more opportunities for making improvements. Moreover, Anderson (1990) in his book "Design for Manufacturability" mentioned that "by the time a product has been designed, only about 8% of the total product budget has been spent. But by that point, the design has determined 80% of the cost of the product." Similarly, Boothroyd, Dewhurst, and Knight (2001) stated that more than 70% of production costs are determined in the product design stage. Ehrlenspiel et al. (2007) also discussed how significant the decisions made in the product development stage are for the product life cycle. However, in traditional sequential engineering processes, manufacturing engineers lack an effective communication channel with the product engineers, and thus the best opportunity to use engineering guidelines to control cost and achieve manufacturability is missed at an early stage of product life cycle (Eppinger et al. 1994).

Considering the previous findings, this research aims to conduct a current-state analysis of the engineering process for a typical manufacturer of American-style furniture through a questionnaire study, and to try to find the influential factors controlling the engineering lead time, error rate, job completion, and accuracy.

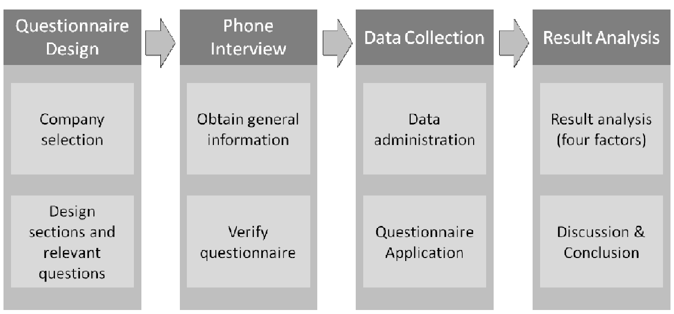
Methods

Case study methods were used to evaluate the current state of the engineering process, including questionnaires, personal interviews, analysis of plant documents, and direct observations – all of which helped to increase the reliability of the data collection process (Bonoma 1985). Considering the travel cost as well as the scattered locations of each interviewing group during the case study, a questionnaire was utilized as the major case study method (Moser and Kalton 1972, Hochstim and Athanasopoulos 1970). Another consideration for using the questionnaire method was the time availability of the respondents in the engineering groups; thus by using a questionnaire, the respondents were more flexible to allocate their time to complete the questions without interrupting their work (Hoyle, Harris, and Judd 2002). The questionnaire was structured in five parts:

- Engineering experience and awareness of lean concepts and problem-solving methods
- Engineering process metrics
- Factors affecting engineering lead time
- Factors affecting job completion and accuracy
- Engineering changes

To obtain the most comprehensive results for the research, the researcher also combined the quantitative data from the questionnaire with the qualitative data from phone interviews and observations to generate results (Bourgeois III and Eisenhardt 1988). The phone interviews with supervisors helped to validate answers from engineers. The questionnaire was administered in four stages.

Figure 1. Four stages of questionnaire method: questionnaire design, phone interview, data collection, and result analysis.



Questionnaire Design

Company selection

The selection of the case study company was based on two criteria – company size and product type (Robb and Xie 2003, McNamara 1972). The company currently has 10 manufacturing plants employing almost 3,000 employees. The annual sales turnover was around $90 million in 2009. It has been producing case goods and upholstery products for top-tier U.S. furniture brands for many years. The company runs four business units. Three of the business units produce solid wood products and one produces upholstery products. The product lines of this company are concentrated on American-style furniture but diversified on product architectures (the way to construct the furniture). These two conditions (a. American-style furniture; b. diversified on product architecture) were also the major reasons the researcher chose to select this company as the candidate for the case study.

Design sections and relevant questions

The questionnaire was designed into four sections – engineering metrics, lead time, job completion/accuracy, and engineering error.

Process metrics

In determining which metrics were viable to assess the current engineering performance, a phone interview was conducted with several supervisors and product engineers to assess different metrics. Upon consensus, 11 metrics were selected that can reflect the quality of the current engineering performance. The description of each metric is shown in **Table 1.** These metrics were also widely used to assess and communicate process improvement results for nonproduction value streams. (Keyte and Locher 2004; Barzizza, Caridi, and Cigolini 2001).

Table 1. Assessment and results metrics.

Metrics	Description
Process time	The accurate time spent on making engineering documents
Value-added time	The total sum of each major process time
Nonvalue-added time	The time not spent on making engineering documents
Engineering error rate	The total number of errors made during a period of time divided by the total number of engineering documents made within the same period
Lead time	The sum of process time and nonvalue-added time
Number of people	The total number of engineers in the engineering group
Overtime	The extra time spent doing work after the regular work time
Changeover time	The time required to prepare an engineering task to change from making good results of the last engineering task to making the first good result of the new engineering task
Percent of completion	The percentage of production documents that delivered on time
Inventory	Unfinished engineering orders from customers
System reliability	The percentage of time that a specific hardware or software does work

Engineering lead time

Many industries had focused on development lead time as a measure of competitive performance in product development (Keyte and Locher 2004, Clark and Fujimoto 1989a). This section focused on analyzing different factors affecting the engineering lead time. The questions designed for this construct included engineering lead time influential factors: engineering process time, development tool, and competency of engineers (Clark and Fujimoto 1989b, Keyte and Locher 2004).

Job completion and accuracy

Keyte and Locher (2004) indicated that job completion and accuracy make up an important indicator used to measure the quality of engineering design. The question designed for this section included the average number of production documents and production document completion rate.

Engineering change (EC)

Engineering change is a significant driver of product development costs and lead time (Loch and Terwiesch 1999). Engineering changes (ECs) refers to making design changes to an existing product (Barzizza, Caridi, and Cigolini 2001). It includes changes for improving production efficiency as well as the changes for assuring product quality and performance (Balakrishnan and Chakravarty 1996). The questions designed for this section included engineering error rate, and the percentage of time of issuing engineering change orders (ECOs).

Phone Interview

Verify questionnaire

To develop a comprehensive questionnaire, a phone interview was conducted after completing the first draft of the questionnaire. One purpose of the phone interview is to verify the questions developed for the questionnaire. The questionnaire was sent to the engineering supervisor in advance, and then through the phone interview the supervisor helped to review each section of the questionnaire and gave feedback. Thus, the viability of each section of the questionnaire was assessed using the phone interview (Coon, Pena, and Illich 1998).

Obtain information

Another purpose for this interview was to collect relevant information on engineering experience and the respondents' perception of lean concepts and problem-solving methods. Then questions were developed covering these aspects that complement the four sections defined above (Burke and Miller 2001).

Data Collection

Data administration

The case study was conducted within a limited timeframe and on-site cost. The researcher administered questionnaires on site with the help of the group supervisors. The sample size is limited to the number of engineers each engineering group had at the time of the research. Therefore, the sample size of the solid wood group was 32 respondents, and the sample size of the upholstery group was 15 respondents. The survey was given to the supervisors of each engineering group so that person could forward the survey to the engineers within each group (Robb and Xie 2003, Frey and Oishi 1995).

Besides, the researcher had also presented a workshop on lean manufacturing after conducting the questionnaire. A total number of 30 people, including engineering management, product engineers, and production supervisors, had attended the workshop. The workshop was intended to explain the lean concepts and problem-solving methods within the questionnaire to help the associates be aware of the power of lean and find potential areas to start lean projects in their work environment.

Questionnaire application

The survey questionnaire was sent out to the supervisors in each of the engineering groups. Interviews with these supervisors were also conducted to assist in assessing validity and methods variance (Robb and Xie 2003). Before each respondent completed the survey, questions were explained carefully as concerns arose from respondents. Then the supervisor in each engineering group collected the completed questionnaires. The valid rate of respondents in the solid wood group was 100%, and the valid rate in the upholstery group was 86.7%.

Questionnaire analysis

Because descriptive statistics is an especially common tool implemented in most statistics studies, it was used to analyze and describe the data in the study (Sprinthall 2003). Bar and pie charts were used to show the response rate, distribution, and variance of data. In addition, the radar chart helped show the response frequency, and the box plot chart was used to show the average, median, and quartiles distribution of the survey data (Ott and Longnecker 2008). Inferential analysis – the Unequal Variance Two-Sample t-Test (Ruxton 2006) – was used to compare the familiarity of lean knowledge and problem-solving methods between different engineering groups.

Results and Discussion

The results section is organized in five major parts. The first part displays the results of engineer experience and knowledge of lean concepts and problem-solving methods. The second part is the process metric section that indicates the important metrics to reflect the engineering performance. The third part reveals the factors that could influence the engineering lead time. The fourth part illustrates the job completion and accuracy of the current engineering process. In the last part, the most frequently occurring errors in the engineering documents are presented, as well as the analysis of the impact of issuing engineering change orders on engineering lead time.

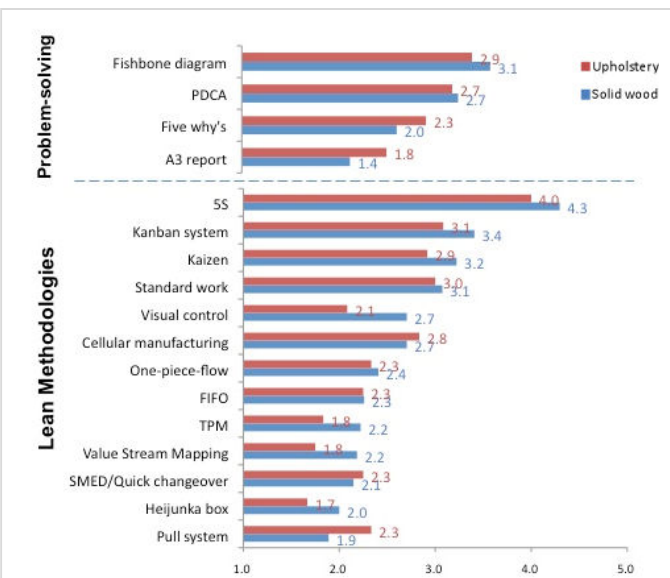
Engineering experience and awareness of lean concepts and problem-solving methods

In this case study company, the nonupholstery (solid wood) and upholstery engineers exhibited different experiences in product engineering. The investigation showed that 38% of the upholstery engineers had more than six years of experience. By contrast, the majority of solid wood engineers (40%) had three–five years of work experience. However, the junior engineers (less than two years) in the upholstery engineering group account for 39% of the overall engineering crew, whereas in the solid wood group, they account for 30% of the crew. Furthermore, there are 31% entry-level engineers (less than one year) in the upholstery engineering group, compared to just 6% of entry-level engineers in the solid wood engineering group. Overall, the number of engineers above the junior level in the solid wood engineering group is larger than the upholstery group.

The reason the upholstery engineering group lacked experienced engineers was that, at the time of the study, this group was preparing and training junior-level engineers for a new upholstery plant. So the number of entry-level engineers in this group looks relatively high. Another reason was that some experienced upholstery engineers left the company for various reasons. On the other hand, the engineers in the solid wood plant were relatively stable, and few entry-level engineers were recruited in recent time. The current engineering capacity can also be reflected in the lead time of production documents. The solid wood products group had a lead time 17% faster than that of upholstery products.

Also for the interest of this study, a question was aimed at learning how much each engineer knows about lean. So the engineers were asked, based on a 1–to–5 scale, their familiarity on 13 frequently used lean concepts and four common problem-solving methods.

Figure 2. Knowledge of lean methodologies and problem-solving methods.



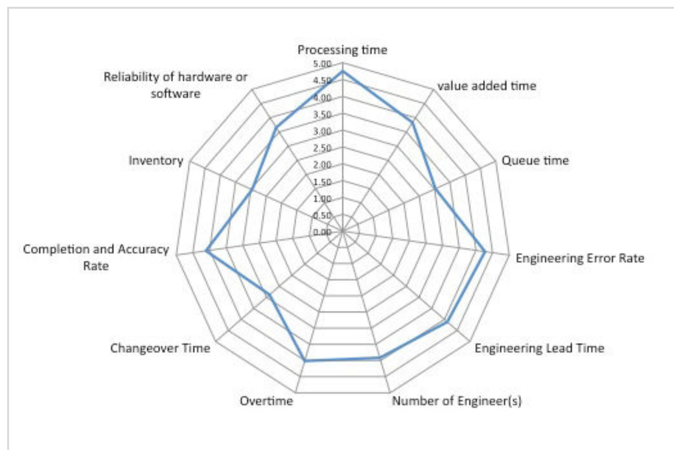
Level of understanding: 1=No idea, 5=Very familiar

According to the result, 5S turned out the most acknowledged lean method. The company has been implementing lean principles in the production area since 2003, and like most furniture companies in China, they started with the "5S" initiative (Feld 2000). This is the reason why 5S was the most acknowledged lean method known by all the engineering groups. On the other hand, some lean concepts like "kanban system," "kaizen," and "standard work" (Van Goubergen and Van Landeghem 2002; Rahn 2001; Feld 2000, Henderson, Larco, and Martin 2000; Rother and Shook 1998) had been implemented by the company but were not as effective as "5S." Thus, the rating on some of these methods, in **Figure 2**, was not as high as 5S. The on-site lean manufacturing workshop not only let the associates have an in-depth understanding of the lean principles they had implemented but also familiarized them with other useful lean methods and problem-solving methods.

Engineering process metrics

The result shows **(Figure 3)** that among the 11 metrics defined in the questionnaire, "Processing Time," "Engineering Error Rate," "Engineering Lead Time," and "Completion and Accuracy Rate" were the top-rated ones. The result included the response from both solid wood and upholstery engineering groups. The result also was coincidently consistent with the predefined questionnaire structure, which includes the following investigation on lead time, job completion/accuracy, and engineering error.

Figure 3. Identified engineering performance metrics.

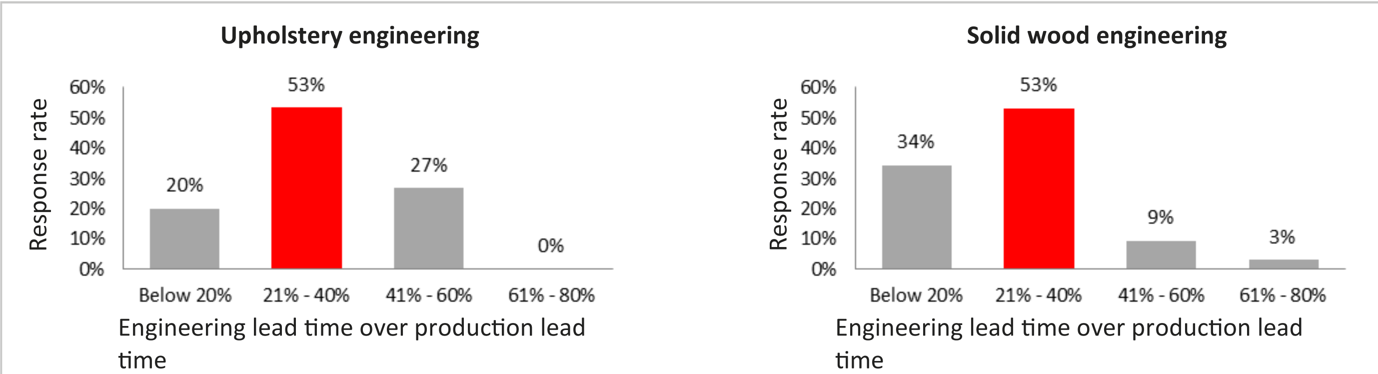


Response rate on a scale of 1 to 5,
1 is "unimportant," 5 is "very important"

Factors affecting engineering lead time

The engineering lead time refers to the total amount of time each engineer spent on making preproduction documents and mass production documents in the design and engineering phase within the production lead time. The production lead time means the total lead time of each product life cycle toward delivering customer desired products, which encompasses the processes of selling and marketing, design, engineering, manufacturing, packaging, and all other necessary steps. Thus the engineering lead time is a portion of the production lead time. So the engineering lead time positively impacts the on-time delivery of products to the customer. In this context, it is necessary to know the percentage of time the engineering process takes toward the overall production lead time. Generally, the shorter the engineering lead time, the more it will be reserved for the other necessary manufacturing processes. **Figure 4** shows that more than half of the engineers perceive the current engineering lead time accounted for 21% to 40% of the overall production lead time. Some prod-

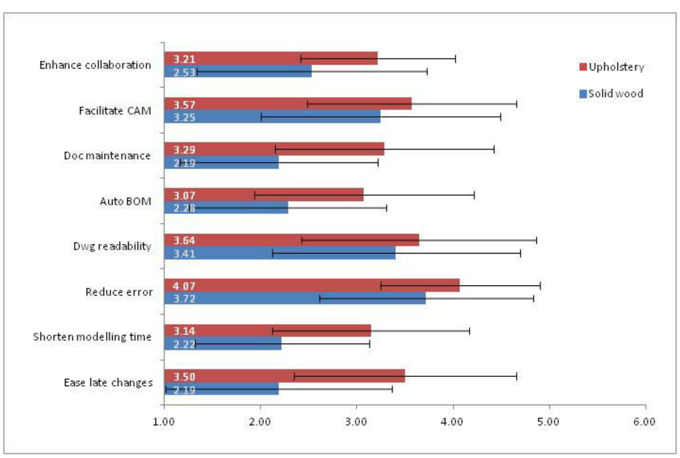
Figure 4. Engineering lead time versus production lead time in two engineering groups.



ucts may even take up to 61% to 80% of production lead time on engineering. These products are usually custom furniture with a high price, even in a small batch of orders.

To further explore which factors are the major contributors of longer lead times, 10 factors were included in the questionnaire for evaluation purposes. The results showed, from both solid wood and upholstery engineers, that "Engineers experience/competency" and "Product architecture complexity" were the top two factors that could influence the engineering lead time. The results were concluded from the responses of 32 solid wood engineers and 15 upholstery engineers. Also, "Tool" was considered the least influential factor that could impact the engineering lead time. However, the company had been using two engineering design tool kits at the same time – SolidWorks and AutoCAD. These tools exhibited different impacts on engineering jobs (other than lead time) in terms of the capability to enhance collaboration, facilitate computer-aided manufacturing, maintenance engineering documents, and automation generation of bills of material. **Figure 5** explains that these two engineering solutions are supposed to have different impacts on the engineering lead time. SolidWorks had been mainly applied in the upholstery engineering process in this company.

Figure 5. Performance difference using SolidWorks as the primary engineering design tool.



From direct observation, it was seen that the upholstery products usually needed to create the 3D model for product frames, and SolidWorks explicitly presented its advantage on creating complex frame models, generating bill of materials, reducing design errors, and creating reader-friendly drawings.

To help illustrate how product complexity has an impact on engineering lead time, a question was designed to select the corresponding lead time for developing each product within a standard product set. In this question, two standard sets of products for solid wood product lines and upholstery product lines were separately defined. Engineers indicated the time spent on completing each engineering task within a certain standard product set. In **Figure 6**, the x axis shows the response rate of different product engineering lead times, and the y axis shows different types of products to form the standard product sets. The products within the standard solid wood products set included mirror, nightstand, drawer chest, armoire base, armoire hutch, dresser, and bed. The products within the standard upholstery product set included ottoman, chair, sofa chair, loveseat, tufted chair, sleeper sofa, and sofa.

Following the standard product sets in the nonupholstery group, **Figure 6** shows that the bed, armoire hutch, and dresser are the top three products that need longer engineering time, for which most engineers need "5 to 6 days" to finish these products. From the upholstery group results, it could be observed that more upholstery products require "5 to 6 days" of engineering lead time, compared to solid wood products. These upholstery products include sofa chair, sleeper sofa, tufted chair, love seat, and sofa. In fact, the reason more upholstery products take a longer lead time is that the upholstery products usually include more engineering steps, compared to the solid wood products. For example, upholstery products usually need a certain amount of time to wait for the fabric suppliers to deliver the samples for making the mock-ups; every piece of fabric needs to be measured on a special device to digitalize the contour and dimension of the fabric; and every product needs a fabric specification in addition to the manufacturing specification to facilitate the mass production process. All these tasks need extra engineering lead time for upholstery products.

Figure 6. Average lead time distribution of each product.

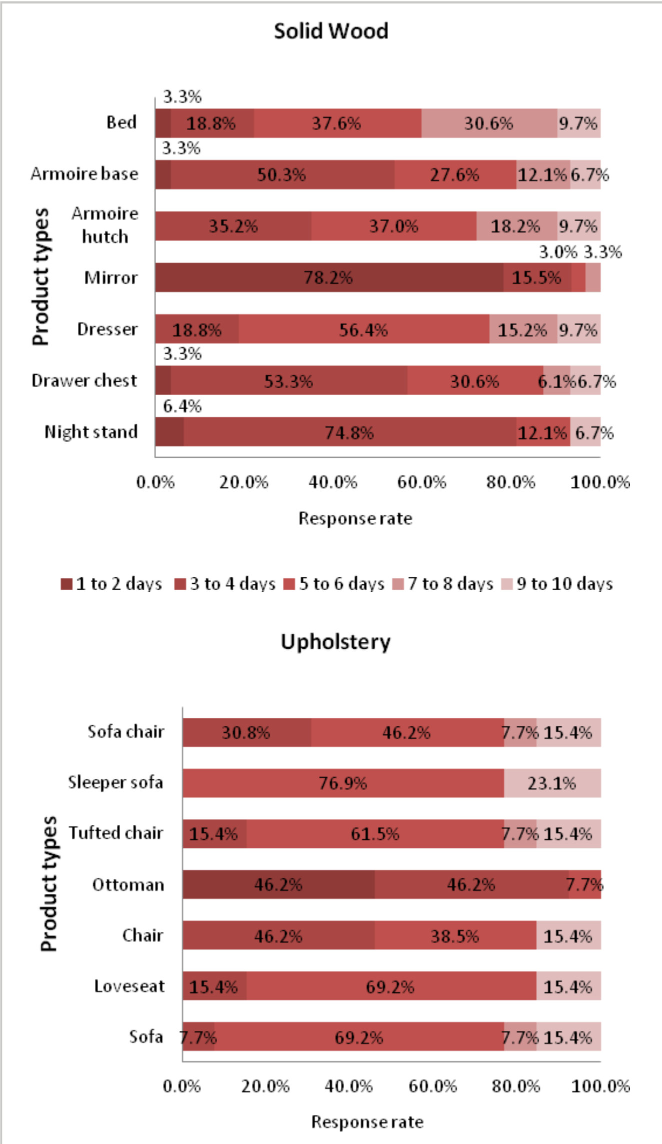
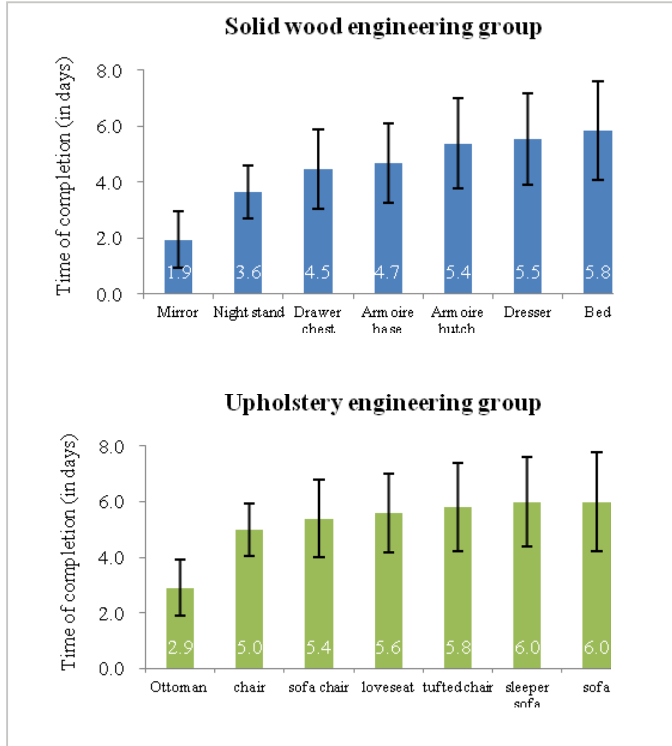


Figure 7. Average engineering lead time for each product.



ducted to learn how many customers each engineer had served during the last six months. Although the overall T-test, in **Figure 8,** shows there are no significant differences between solid wood engineering and upholstery engineering in the average number of customers that were served, it is still easy to notice that upholstery engineers on average had dealt with "1 to 2" customers in the last six months, while most solid wood engineers had served "3 to 4" customers within the same time period.

Figure 8. Average customer number.

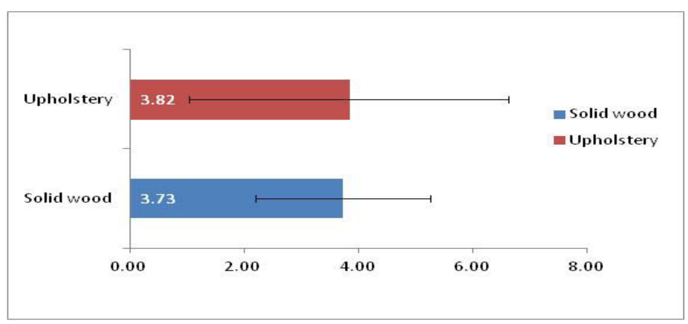


Figure 7 presents a summary of the average lead time to complete each type of product within a standard set of product line. The variation of lead time to finish each type of product illustrates product architecture complexity has a positive relation to the engineering lead time. For example, in a solid wood product set, beds (which usually have the most difficult product structure) take the longest engineering lead time, which is about 5.8 days, whereas the nightstand (which usually has the easiest product structure) takes about 1.9 days of engineering lead time.

Factors affecting job completion and accuracy

Customer demand

To find whether the fluctuation of customer demands impacts engineering performance, an investigation was con-

Engineering throughput

To understand the current engineering throughput, each engineer was asked the number of engineering documents he/she could generate per month. The engineering documents include both preproduction documents and mass production documents. From their answer, **Figure 9** shows that most engineers were likely to complete "3 to 4" engineering documents per month for the job shops. It could also be observed that, in the upholstery engineering group, there is no difference in the quantity of preproduction and mass production documents released per month. **Figure 10** shows there is a difference in the number of production documents generated in the solid wood engineering group and the upholstery engineering group.

Figure 9. Respondent distribution on engineering throughput.

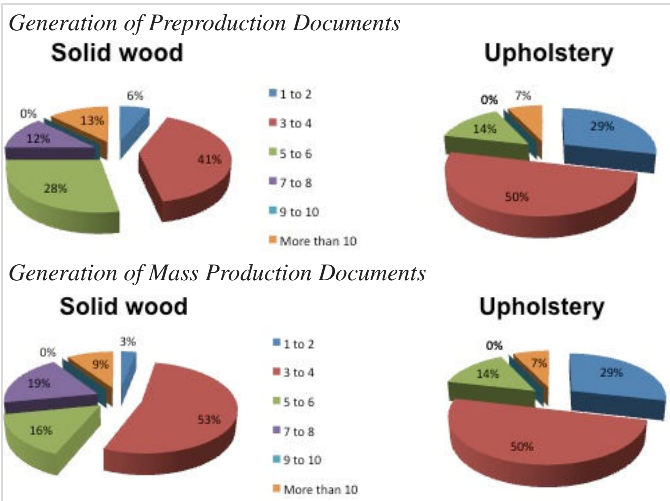
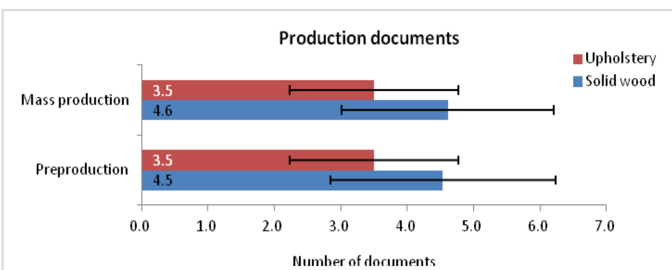


Figure 10. Average number of preproduction and mass production documents generated per month in each engineering group.



Engineering Change

Error rates

Error rate is an important factor that influences the overall performance of the engineering process. Consequently, the amount of errors on average each engineer made in their engineering documents was measured. **Table 2** shows that the majority of engineers in both groups had "1 to 2 errors" for each type of engineering error. From this observation, it was found that each type of error would inevitably happen but differed on how many times it had occurred. There were just a few countermeasures used to prevent errors from happening. Through personal interviews with engineering supervisors, it was discovered that checking errors manually is probably the only way to prevent them. Although SolidWorks software could help to detect some drawing errors, it still cannot detect errors in the bill of materials (BOMs) because most BOMs jobs still rely on manual entry instead of automated generation of BOMs.

Comparing individual errors, **Table 2** also shows that "drawing errors" and "part dimension errors" are the most frequently occurring errors in both engineering groups. Furthermore, it could also be observed that for almost each type of error except "dimension missing," the average number of errors for the solid wood group is higher than for the upholstery group. A reason for this might be that the solid wood group made more engineering documents than the upholstery group, so it has a relatively higher possibility of generating more errors.

Engineering Change

Because engineering change is a significant driver of product development cost and lead time (Loch and Terwiesch 1999), a question was designed to ask what percentage of time each engineer spends daily on issuing engineering change orders (ECOs). Thirty-two solid wood engineers and 15 upholstery engineers provided valid responses. **Figure 11** and

Table 2. Comparison of error rate in each engineering group.

	Occurred errors in **Solid Wood** group			Occurred errors in **Upholstery** group		
Types of errors	**None**	**1 to 2**	**3 to 4**	**None**	**1 to 2**	**3 to 4**
Drawing errors	3.3%	66.7%	20.0%	16.7%	58.3%	8.3%
Missing essential drawings	40.0%	53.3%	6.7%	58.3%	25.0%	16.7%
Wrong architecture applied	56.7%	36.7%	6.7%	58.3%	41.7%	NA
Wrong material applied	60.0%	33.3%	6.7%	75.0%	16.7%	NA
Wrong hardware receiving department	30.0%	60.0%	10.0%	50.0%	41.7%	NA
Hardware missing	23.3%	70.0%	6.7%	41.7%	58.3%	NA
Wrong amounts of hardware	6.7%	76.7%	16.7%	33.3%	50.0%	16.7%
Wrong hardware applied	20.0%	66.7%	10.0%	50.0%	41.7%	8.3%
Dimension missing	30.0%	63.3%	6.7%	25.0%	66.7%	8.3%
Parts counting error	10.0%	83.3%	6.7%	33.3%	58.3%	8.3%
Part dimension error	13.3%	73.3%	13.3%	16.7%	66.7%	16.7%

Figure 12 show that most of the engineers spent less than 20% of their daily engineering time on issuing the ECOs. Engineers were also asked to give a specific time period. Twenty-three percent of upholstery engineers gave “5%–15%” of their daily work time and 46% of engineers provided the answer of “10%–20%” of their daily work time. On the other hand, in the solid wood section, 18% of engineers answered that issuing ECOs seized “5%–15%” of their daily work time, 45% of engineers spent “10%–20%” of their daily time on issuing the ECOs, and 3% of engineers answered “1%–10%” of their daily engineering time. The current state implies that most engineers spent 10%–20% of their daily working time on the rework. That accounted for almost 50 minutes to nearly 2 hours in a day (8-hour work days) doing nonvalue-added work. In the current engineering process, usually right after releasing the mass production documents, there is a severe increase of engineering changes needing ECOs. Sometimes the engineers were required to spend the whole day working on the ECO without doing any other engineering tasks.

Figure 11. Response rate on ECO percentage.

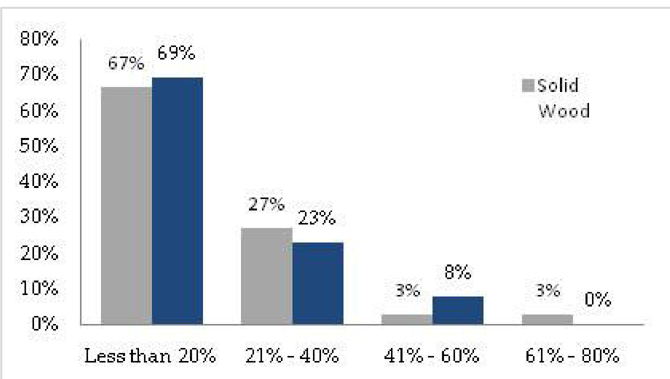
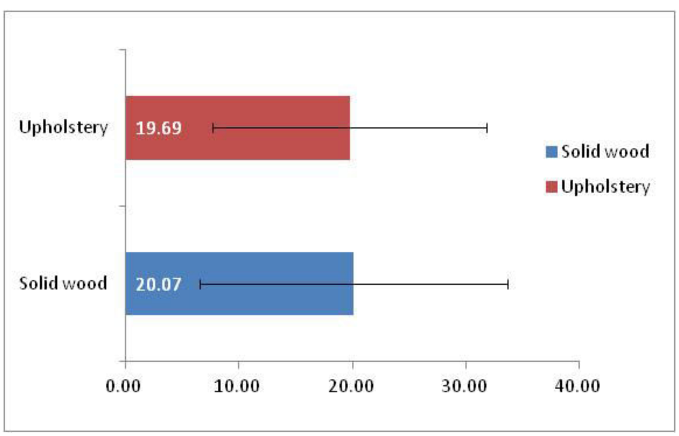


Figure 12. Time spent on ECO.



Conclusions

The current engineering process in this particular case study exhibits unnecessary engineering tasks regarded as waste. These wasteful processes might interfere with the engineers’ ability to effectively and efficiently prepare production documents for downstream jobs. “Generate production documents” is the top responsibility for furniture product engineers. But currently, most engineers were distracted by many nonvalue-added tasks. For instance, 10%–20% of engineering time was spent on releasing engineering change orders (ECOs). To leave more engineering time for addressing value-added activities, for example, the company might consider assigning some responsibilities to specific people in production to help engineers issue a portion of ECOs, such as adding screws for strengthening certain product structures. This type of modification does not need big changes of product design or architecture. In this sense, it not only helps balance the workload and provides more flexibility for the product engineers, but it also solves the dilemma where product engineers do not have time to issue ECOs for an urgent production change and industrial engineers in production cannot work on this change until they receive the relevant ECOs from engineering.

Processing time is one of the most important lean metrics used to measure engineering performance and it varies depending on the type of customer and products. Although the average number of customers serviced in upholstery engineering and solid wood engineering shows no statistically significant difference, the average number of production documents generated by each engineering group is different. The difference indicates that the engineering capacity (in terms of completed customer orders) of the solid wood group appears to be larger than the capacity of the upholstery group.

From the case study, the following was learned:

- Lean concepts and problem-solving methods are still deficient in the current engineering group.
- “Processing Time,” “Engineering Error Rate,” “Completion and Accuracy Rate,” and “Engineering Lead Time” are four of the most important factors to impact engineering performance in the case study company.
- Engineering lead time accounts for a large portion (21% to 40%) of the overall production lead time.
- Product complexity and engineer competency are two of the most significant influential factors that impact the engineering lead time.
- Upholstered products usually have longer lead times than solid wood products.
- Currently, the average throughput (in terms of the average number of production documents) of the solid wood engineering group is higher than that of the upholstery group.
- The frequency of each type of error is similar between the solid wood engineering group and upholstery engineering group.
- Engineering change orders (10% to 20%) account for a big portion of engineers’ daily work time.

- 3D engineering design solution is having positive impacts on household furniture engineering tasks in terms of enhanced collaboration, facilitated computer-aided-manufacturing, easy document maintenance, automatic BOM generation, readable drawings, reduced engineering errors, shortened modeling time, and easy-to-make late engineering changes.

This research presents some limitations. First, the time period of this case study was short. Second, only the engineering groups from this single case study company were included in the survey. The research did not include more companies to make a broad conclusion on the whole industry. Third, the numbers of engineers involved in the survey were not equally distributed between the upholstery engineering group and the solid wood engineering group. It was not easy to generate better statistic results.

- Based on this study, future research should focus on the following:
- Using lean principles to further identify waste in furniture engineering processes through value stream mapping.
- Developing specific methods to further eliminate waste and improve engineering efficiency, with emphasis on
  - Shortening process times and overall engineering completion lead time
  - Reduce engineering job batch sizes
  - Countermeasures to prevent engineering errors
  - Increase customer satisfaction
- Finding opportunities to promote other companies involved in this type of research that focuses on finding lean opportunities in the nonproduction area.

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