# Using Value Stream Mapping to Analyze an Upholstery Furniture Engineering Process

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**Abstract**

This study presents a systematic approach of streamlining an upholstery furniture engineering process based on a case study in one of the largest export-oriented furniture manufacturers in China. The approach encompasses an analysis of the current state of the engineering process and the proposal of a lean future state value stream map (VSM). The current state analysis includes the definition of the product family, analysis of current customer demands, and the definition of the process metrics of the engineering process. Data were collected during a half-month visit to the furniture plant in China. Results from the current state VSM show that the value-added ratio of the current engineering process is 26.0 percent. Many engineering steps present deficiencies, such as the processes of creating drawings, compiling mass production documents, checking and signing off on engineering documents, creating CNC programs, and generating packaging files. After the current state VSM, it is found that unpredictable process cycle time and expediting engineering change orders are two major problems in the current engineering process. Based on current state VSM, the research focuses on countermeasures to solve the root causes of the major problems and proposes the best practices for the future VSM.

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 (Hoppmann 2009). Different types of lean methods have been implemented industry-wide. Some methods include pull system, cellular manufacturing, one-piece flow, standard work, visual control, Kaizen, quick changeover, 5S, value stream mapping (VSM), and kanban event (Rother and Shook 1998, Feld 2000, Henderson et al. 2000, Van Goubergen and Van Landeghem 2002). Among these methods, VSM appears as an important tool to facilitate the lean transformation. It maps both the information flow and the materials flow, identifies various types of wastes, and streamlines the value stream toward the future state (Womack and Jones 1996b).

VSM has demonstrated its effectiveness on the manufacturing processes to maximize customer value (Womack and Jones 1996b, Rother and Shook 1998). However, nonproduction activities, such as design and engineering, appear to have a significant influence on production cost and lead time (Anderson 1990, Prasad 1996, Boothroyd et al. 2001, Tapping and Shuker 2003, Ehrlenspiel et al. 2007), so a lot of industrial participants are trying to engage in applying lean principles in nonproduction activities. Nonproduction activities involve many knowledge-based areas, such as design, new product introduction, engineering, and product development (Baines et al. 2006). Other applications of VSM in nonmanufacturing industries could be found in sales process, health care, admission inquiry process, and information management (Kim et al. 2006, Tischler 2006, Barber and Tietje 2008).

In the secondary wood products industry, lean principles and techniques have demonstrated effectiveness, especially in enhancing the productivity of the furniture manufacturing process (Hunter et al. 2004, Motsenbocker et al. 2005, Hunter 2008). VSM also showed its power in streamlining the manufacturing process for the wood

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industry (Czabke 2007, Quesada-Pineda et al. 2009, Espinoza et al. 2010). However, lean principles could also create benefits to nonproduction processes in the secondary wood products industry such as the engineering process (Czabke 2007). The impact of the engineering process in the production cost is extremely important (Baines et al. 2006); however, there has been no research emphasis on the application of lean principles to the engineering process in the furniture manufacturing industry. This study exhibits a case study to evaluate current state VSM of a furniture engineering processes to identify both value-added and non–value-added engineering activities toward fulfilling customer requirements. In the meantime, future state will be generated based on process efficiency investigation. Then countermeasures will be proposed as to how valid and useful implementations would improve the process.

## Literature Review

### Lean engineering

Lean thinking principles have been applied mostly to manufacturing activities. However, practitioners and researchers have given so much attention to the implementation of lean principles and the mapping of manufacturing processes that they overlooked the importance of other nonmanufacturing processes, such as design and engineering, that directly affect the cost in the product life cycle (Baines et al. 2006). Womack and Jones (1996a) indicated that lean principles are also a fit for areas outside manufacturing processes, and these principles have great potential and benefits if applied to knowledge-based activities, such as design, new product development, engineering, and product development (Freire and Alarcón 2002, Browning 2003, Haque 2003, Middleton et al. 2005, Reinertsen 2005). Some examples of lean applications in engineering processes can be found in the aerospace, automotive, software, and construction industries (Baines et al. 2006). For example, Freire and Alarcón (2002) developed a lean design process for a construction project based on lean manufacturing concepts and methods. They proposed four stages to carry out effective methods in the design process for improvements:

- Diagnosis and evaluation
- Changes implementation
- Control
- Standardization

Following the above methodology, Freire and Alarcón (2002) applied seven lean tools on five potential areas of a product development process in the construction industry. The applied lean tools resulted in an effective engineering performance that led to increased value-added activities, reduced product unit errors, largely decreased waiting time, and reduced cycle time.

Furthermore, Haque (2003) conducted research of lean engineering in the aerospace industry. He restated five-step lean principles applied to a manufacturing process (Womack and Jones 1996a, Rother and Shook 1998) and further redefined each principle in a lean engineering manner. He then applied three different lean applications (Kaizen on a design process, single-piece flow in new product introduction, and offline development to speed time to market) at three different levels—process hierarchy, detailed design, and project management—on three case study companies. He also mentioned the importance of modular design as a lean tool to facilitate the product engineering on easing future modification or evolution of products and the reuse of design elements. In the case of an ''offline development of products'' illustration, modular design showed its effectiveness on reducing lead time by 25 to 50 percent. Other research by Browning (2003) concluded that applying lean to the product development processes was not all about minimizing cost, shortening cycle time, and reducing waste, but its application can also maximize customer value. Furthermore, Reinertsen (2005) incorporated lean manufacturing methods to deal with the inherent variability in the product development process. Five key methods were applied to streamline the product development process: queue management, batch size reduction, cadence, rapid local adjustments, and waste elimination. Table 1 shows a summary of literature on lean product development and engineering.

The above examples show the similarities of specific methods used for streamlining the engineering process that were inherited from the lean production methods.

*Table 1.—Literature on lean product development and engineering.*

| Author | Title | Outcomes |
|---|---|---|
| Freire and Alarcón (2002) | Achieving Lean Design Process: Improvement Methodology | Proposed a methodology to achieve a lean design process for the construction industry by applying seven tools for improvement based on five areas: client, administration, project, resources, and information |
| Haque (2003) | Lean Engineering in the Aerospace Industry | Proposed applying lean principles to three different levels of engineering processes:<br>• Detailed design level<br>• Project management level<br>• Design strategy level |
| Browning (2003) | On Customer Value and Improvement in Product Development Processes | Demonstrated the effectiveness of ''maximizing value'' as a preferred way to incorporate ''lean'' in the product development process architecture compared with the effectiveness of ''minimizing cost and time'' |
| Reinertsen (2005) | Let It Flow | Proposed to apply five key methods of lean manufacturing to address the inherent high variability of product development; the methods encompassed queue management, batch size reduction, cadence, rapid local adjustments, and waste elimination |
| Middleton et al. (2005) | Lean Software Management Case Study: Timberline Inc. | Demonstrated the effective application of lean principles in software engineering |

## VSM in the wood products industry

In the wood products industry, previous research has used VSM methodology. Czabke (2007) conducted a survey in the secondary wood products industry and listed VSM as an important just-in-time production practice in the lean manufacturing process. Espinoza et al. (2010) used VSM to portray the flow of information and materials to identify specific quality control activities in the wood products supply chain. Also, based on a case study of three companies located in Honduras, Costa Rica, and Guatemala, Quesada-Pineda et al. (2009) used VSM to conduct quantified research analyzing the value-added times for wood products manufacturing companies in Central America. Key findings in the research included the following:

- Raw material inventory accounts for most of the waste in the three case study companies.
- Value-added time ranged from 8.8 to 12.3 percent of total process lead time.

Furthermore, Norman (2008) proposed a pull-based manufacturing system for secondary wood product manufacturers to achieve product lead time reduction and on-time delivery to the final customer. VSM was used to evaluate a case study company's current state production performance. By implementing pull production and supermarket methodology, the results showed that the proposed future state can achieve a reduction of lead time from 15.1 to 7.5 hours.

Also, Leonard (2005) used VSM to evaluate the current state and design future state of a southern yellow pine lumber production system. By more closely synchronizing and planning operations with sawmill output, the lead time reduced from 35.3 days to a range of 10.8 to 14.9 days; future state capital inventory requirements were less than 50 percent of the current state inventory requirement.

## Methodology

As shown in Figure 1, the research followed the structure of defining process boundaries, identifying main processes, analyzing customer needs, selecting and measuring process metrics, calculating system metrics, and analyzing current state VSM and generating future state VSM (Keyte and Locher 2004). Seventeen days were spent in the case study company's upholstery product engineering department collecting relevant process information. The methods used for collecting the process data included data entry sheet, direct observation, and engineering archives. Then the current state VSM was generated based on the investigation. Furthermore, through root cause analysis, several improvement opportunities and countermeasures were proposed, and the future state VSM was applied.

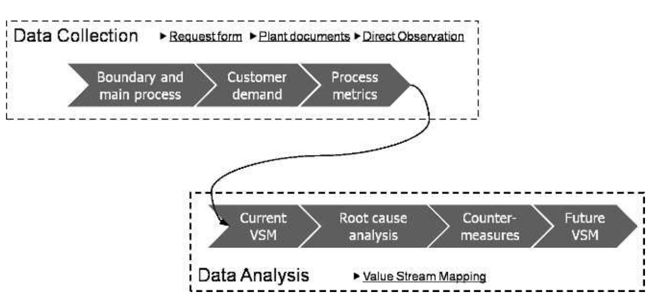


*Figure 1.—Methodology for the present study.*

During the case study, survey questionnaires and interviews were also conducted with multiple supervisors and product engineers. Therefore, multiple information concerning process sequence and performance was obtained, such as key performance indicators, main processes, product family, and customer demand.

The survey questionnaire was composed of four sections that included process metrics, lead time, job completion, and engineering error. The survey results provided a basis to compare with the real process metrics during the investigation. For instance, lead time results from the survey questionnaire were used to measure the gap between the real engineering lead time and the standard time that was set by the management.

The target group for the questionnaire study was composed of all the product engineers in the company. In total, 33 solid wood engineers and 15 upholstery engineers participated in the survey questionnaire study. The valid rate of respondents in the solid wood group was 100 percent. The valid rate of respondents in the upholstery group was 86.7 percent.

Phone interviews were conducted before using the questionnaire. Mainly engineering supervisors were interviewed for two purposes: (1) to verify the questions developed for the questionnaire so that the viability of each section of the questionnaire was assessed and (2) to obtain information that would complement the investigation and help to develop new questions.

### Description of the case study company

Because of a limited budget and time frame for an overseas case study, this investigation focused on only one company. The selection of the case study company was based on several aspects, such as company size, product type, customer, location, and turnover (McNamara 1972, Robb and Xie 2003). Some measurements used to determine the company size include the number of manufacturing plants, number of employees, and turnover. The selected company for the case study produced diversified product types that would help generate sound and practical results for this research.

Based on the above criteria, the case study company that was chosen owns 10 manufacturing plants employing more than 10,000 workers making both solid wood and upholstery products for different American and European customers. The annual sales turnover was around US$90 million in 2009. The company has been making furniture products for more than 20 years and is located in China. Currently, the company has been cooperating with many established US customers; most of the customers have been involved in the furniture business for a long time, and their businesses account for a large portion of the household furniture market share in the United States. Because of the wide customer base, the company carries a wide range of products and has a large engineering group. The engineering group consists of four individual engineering departments associated with different business units. The whole engineering group consists of more than 40 product engineers and more than 20 industrial engineers.

### Data collection

*Determination of product family and customer demand.*—Product family refers to a set of products that share a common platform but have individual features and functionality, satisfying a variety of customer needs (Meyer and Utterback 1993). Focusing on the product family and analyzing a process with similar product architecture helps to save engineering time, improve product quality, and reduce manufacturing costs during the new product development process. Furthermore, by analyzing customer demand, the products that require more effort and engineering resources can be determined. In this study, the product family is defined based on two considerations: (1) engineering procedures and (2) historical customer demand (frequency of orders). If a collection of products possessed a similar structure and similar manufacturing methods, it was considered a product family. On the other hand, if a collection of products with similar structure and engineering procedure has been ordered frequently by customers, it is reasonable to build a product family for these product groups to ease engineering and manufacturing efforts.

A few indicators were used to analyze customer demand in the primary and secondary engineering processes based on the data from the engineering archives in the 6 months prior to the study. These indicators include average orders per month, total number of current monthly orders, and orders per day. Based on these indicators, two important measurements were calculated (work-in-progress [WIP] inventory and takt time) for analyzing the process efficiency. The WIP inventory is the basis for calculating the total lead time for delivering the finished products or service in the value stream (Keyte and Locher 2004). The takt time synchronizes the pace of completing each work unit to the pace of customer demands (Rother and Shook 1998). In this study, the customer was identified as the internal customer, which is the production. By accessing recent customer's orders, indicators such as average orders per day and takt time were determined (Table 2). These indicators are the basis for further process analysis and VSM.

*Process metrics*.—Process metrics were used to analyze each engineering process. The metrics helped identify and quantify both value-added and non–value-added functions. The metrics included process cycle time, engineering error rate, and rework time. Data for each metric were collected in two ways: existing process statistics provided by the company and personal data collection by the researcher. For instance, cycle time was collected through the data request form, and then the actual values were determined from the average. However, by the time of the study, each upholstery engineer had different progress on their current projects. It was difficult to track the process time of each engineer. So under the recommendation of the engineering supervisor, three engineers were selected from the engineering group that could represent the most accurate process cycle time an engineer typically takes to complete each engineering process. Also, these engineers were available to start new projects to coordinate with the investigation. All the participants were ideal respondents with several years of work experience and some basic knowledge of lean. An evaluation form was used to collect results from these engineers such as inventory data (in terms of unfinished orders).

*Process cycle time and lead time*.—The results of process cycle time (value-added time) and process lead time (non–value-added time) were collected by using the following methods. First, a day was defined as the checkpoint to count the unfinished orders for different processes. Second, an evaluation form was sent out to each engineer under investigation. On the form, the engineers indicated which step they had completed, the time required to complete an order, and the number of orders not yet completed (inventory) before beginning the next engineering step.

## Data analysis

*Identify the value stream*.—This part of the investigation fell into two parts. The first part was to use a context diagram to identify the supplier and customer of the engineering process. A context diagram (supplier/customer) is used for system engineering analysis to reflect the interaction between a system and its outside interfaces (Kossiakoff and Sweet 2003). In this case, it was used to analyze the requirements from the customer end and also the engineering requirements for the supplier end. The second part was to identify individual engineering processes. Each main engineering process and its sequence were defined through personal interviews with the supervisors and managers.

*Value stream mapping*.—For creating the current-state VSM, data collected from the on-site visit were converted, calculated, adjusted, and summarized. A process hierarchy was conducted first in order to combine similar or unnecessary small processes into more generalized main processes. Next, the value of each metric, such as process cycle time, number of operators, error rate, and rework time, were identified for each process. After creating the current state VSM, different types of waste and the bottleneck processes were identified. Root causes analysis of these symptoms was further conducted by using Ishikawa diagram (fishbone diagram) methodology. Then countermeasures were proposed and incorporated into the future state VSM.

# Results

Before proceeding to VSM, several analyses were conducted concerning process metrics. First, customer

*Table 2.—Accessing the customer demand (data from the most recent 6-month period).*

| Data samples | Data collection method |
|---|---|
| (1) Average number of orders per month (in the last 6 mo) | Content analysis of plant document |
| (2) Number of orders for the current month | Content analysis of plant document |
| (3) Available days of work time (during a month) | Personal interview |
| (4) Average products per day | = (1)/(3) |
| (5) Daily available work time | Content analysis of plant document |
| (6) Takt time | = (5)/(4) |
| (7) Total process cycle time | Current state VSM |
| (8) Engineers needed | = (7)/(6) |

demand was calculated on a daily basis. Then the product family was defined for further planning for the VSM. Next, the process analysis section was composed of process boundary analysis and main process analysis. The boundary analysis used the context diagram to analyze the interaction between the engineering system and its external factors. The main process analysis identified and categorized each main process. Further, the process metrics data were generated for the current state VSM. The next step was to discover the waste and unnecessary steps in the current state mapping. Several proposals and countermeasures were given to streamline the process, and then the future state VSM was developed.

## Product family analysis

After researching customer orders for all collections of upholstery products incurred in the previous 6 months (Keyte and Locher 2004), it was observed that five types of products accounted for 86.4 percent of orders (Fig. 2). These products included sofa, chair, ottoman, sofa chair, and loveseat. Three of these products (sofa, chair, and loveseat) shared the same product architecture because of their similarities in terms of processes of engineering, manufacturing, planning, and packaging. From the order perspective, these three types of products represented 60 percent of customer orders during the previous 6 months. Therefore, the product family was identified as sofa, loveseat, and chair products.

## Customer demand analysis

The total number of orders within the product family for the last 6 months was 159 product orders. The information shown in Table 3 was summarized for the primary engineering process. The orders per day is essential for further calculating the days used to consume the inventory (in terms of engineering orders) within different processes. This information allows calculations for the elements of VSM.

## Process analysis

*Process boundary analysis*.—A context diagram was used to show the interaction between a system and its important external factors (Kossiakoff and Sweet 2003). As can be seen in Figure 3, two suppliers were identified in the current engineering design system: product development and production. Product development provided engineering processes with new product drawings and customer specifications. The production department delivered the

*Table 3.—Indicators for primary engineering process.*

| Indicators | Value |
|---|---|
| Average no. of orders per month | 26.50 |
| Total no. of current monthly orders | 43.00 |
| Available monthly work time (d) | 24.50 |
| No. of orders per day | 1.76 |
| Daily available work time (min) | 480.00 |
| Takt time (h) | 4.50 |

updated production plan to the engineering department on a timely basis. This plan was the foundation for creating the engineering plan. The production plan was developed based on customer orders, so the production time was calculated backward from the shipping date on the order. Because engineering usually took a significant portion of production lead time, an accurate engineering plan could ensure the on-time delivery of products. According to the survey questionnaire results, engineering accounted for 21 to 40 percent of production lead time.

From the customers' perspective, engineering provided services (mainly drawings, bills of material [BOM], specifications, and programs) for a number of fabrication processes. These manufacturing processes were the downstream customers of the engineering process, which included rough mill, production quality control, procurement, mock-up process, packaging process, carving process, machining process, and thermoforming process.

*Main process analysis*.—Andersen (1999, p. 3) defined a process as ''a logic series of related transactions that converts input to results or output.'' The engineering process is an important component of a business process since it is ''a chain of logical connected, repetitive activities that utilizes the enterprise's resources to refine an object (physical or mental) for the purpose of achieving specified and measurable results/products for internal or external customers'' (Rolstadås and Andersen 2000, p. 139).

After having identified the product family in the case study company, the main processes of engineering used to make the family of products were identified as well. Fifteen major engineering processes were identified for the upholstered products, including research product architecture, create drawings and BOM, create fabric cutting drawings, apply new material SKU#, create law tag, fill out material purchasing form, create sofa specifications, create 2.5-axis CNC programs, check/sign off/distribute preproduction documents, follow up preproduction mock-up process, compile mass production document, check/sign off/ distribute mass production documents, create fabric manu-

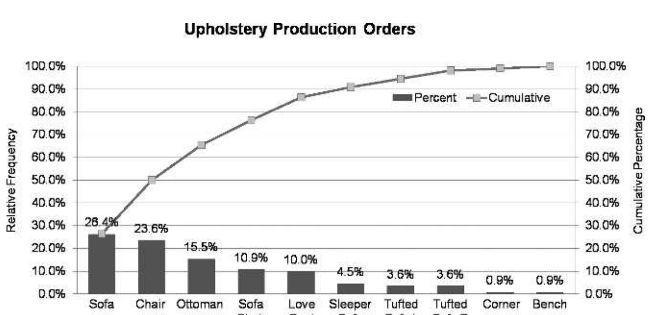


*Figure 2.—Customer demand of upholstery products in the last 6 months.*

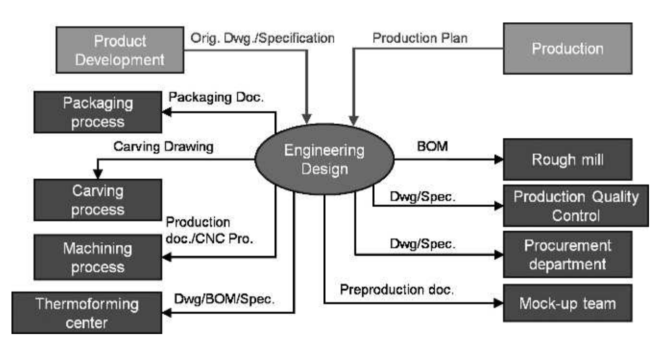


*Figure 3.—Engineering design context diagram.*

facturing specification, create packaging document, and create five-axis CNC program.

*Process metrics and unit*.—Lean metrics could help people understand the impact of their efforts toward continuous improvement and waste elimination (Tapping and Shuker 2003). In order to determine the appropriate process metrics, a selection process based on 11 metrics was conducted by the engineers through the applied survey questionnaire. The engineers rated each metric on a scale of 1 to 5. The final process metrics were determined from the top four highest-ranked metrics: processing time, queue time, lead time, and completion and accuracy rate. These metrics were the basis for selecting the metrics for the VSM. After discussion with the engineering supervisor, the selected metrics for this research were determined as process cycle time, error rate, and rework time.

*Process cycle time and lead time*.—The average process cycle time for completing each engineering process is shown in Table 4. As shown in the table, the value-added time for the sum of each individual process cycle time was 8.8 days. Then the value-added time of the whole process can be presented in the current state VSM. The total lead time was calculated by summing up all the value-added time and non–value-added time. Therefore, the lead time of the main engineering process was 133.9 days.

## VSM: Current state

Before generating the current-state VSM, some single steps in the main engineering processes listed in Table 4 needed to be grouped together to form major processes in the current state VSM. In this case, the processes of create frame and fabric drawings and dimension table, apply new material code, create law tag, and fill out material purchasing form were combined as create drawings and instructions. Similarly, create fabric cutting drawings and hardware table and create sofa manufacturing specification were combined as create BOMs and specifications. Therefore, 12 steps were reduced to 8 steps. The reason for separating the processes create drawings and instructions and create BOMs and specifications during the investigation was that it was much easier to track the process cycle time of each smaller activity instead of tracking the whole activity, which usually took a longer period of time in a discontinuous basis.

*Current state overview*.—As all the elements in the value stream had already been identified, a current state VSM was generated to have an overall picture of the current engineering process (Fig. 4). In the current state VSM, both supplier and customer are internal. The internal customer is production. Production informed engineering of the production schedule 4 weeks prior to the anticipated need. Based on the production schedule, engineering developed a schedule for developing new products. The engineering supervisor oversaw the monthly schedule and triggered each individual engineering activity. An engineering requirement planning system was used to develop and manage this schedule.

The supplier is the internal product development department. Product development oversaw communication with external customers, collecting all the customer requirements, compiling the information into specification files, and delivering original drawings and customer specifications to engineering. New product requirements were handed over to engineering through group discussion meetings where product development presented important new product design details and engineering specifics to the engineering group. This meeting was organized twice a month, meaning that engineering requested customer specifications for new product development every 2 weeks.

In the main engineering process, there were eight individual engineering activities. The process cycle time varied from 120 minutes (research product architecture) to 1,080 minutes (check preproduction document). The WIP orders between each engineering activity varied from 1.3 to 25 days. The engineering lead time was about 133.9 days, whereas the value-added time was just 34.8 days. The value-added ratio was 26.0 percent, which is represented by using the value-added time divided by the non–value-added time.

*Problems in current state*.—From current state VSM, two major contributors to the overall lead time, shown in Figure 4, are excessive WIP orders and unbalanced process cycle time. Recall the questionnaire survey study where the unpredictable and unbalanced process time had been distracting engineers' value-adding capability. These distractions make it difficult to level workloads and lead to expedited engineering change orders (ECOs). The following discussion will focus on finding the root causes of these problems. By identifying root causes to these problems, a future state VSM can be developed to present the countermeasures.

Figure 5 shows that only three processes could barely keep pace with customer demands. Several processes

*Table 4.—Value-added time versus non–value-added time.*

| Value-added time (process cycle time) | Minutes | Non–value-added time | Days |
|---|---|---|---|
| Research product architecture | 120 | Prior research product architecture | 1.3 |
| Create frame and fabric drawings and dimension table | 714 | Prior create frame and fabric drawings and dimension table | 2.1 |
| Create fabric cutting drawings and hardware table | 274 | Prior create fabric cutting drawings and hardware table | 2.2 |
| Apply new material code | 15 | Prior apply new material code | 2.2 |
| Create law tag | 20 | Prior create law tag | 2.2 |
| Fill out material purchasing form | 15 | Prior create material purchasing form | 2.2 |
| Create sofa manufacturing specification | 20 | Prior create sofa frame description | 2.2 |
| Create 2.5-axis and five-axis CNC programs | 375 | Prior create template and CNC programs | 10.2 |
| Check/sign off/distribute preproduction documentation | 1,080 | Prior check/sign off/distribute preproduction documentation | 19.3 |
| Create packaging documents | 310 | Prior packaging documents | 18.0 |
| Compile mass production documentation | 605 | Prior compile mass production documentation | 25.0 |
| Check/sign off/distribute mass production documentation | 696 | Prior check/sign off/distribute mass production documentation | 12.2 |
| Total process cycle time (d) | 8.8 | Total lead time (d) | 133.9 |

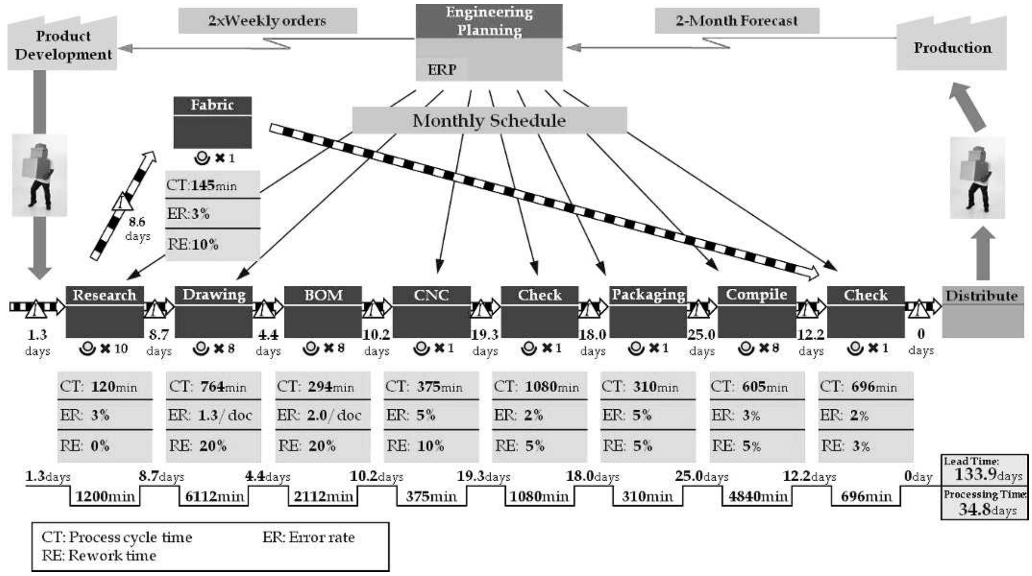


*Figure 4.—Current state value stream map. ERP = engineering requirement planning; BOM = bills of material.*

exhibited very high cycle times. For instance, engineering could not work on compiling mass production documents for a couple of days before they received all the production feedbacks from the mock-up process. Furthermore, engineering supervisors and managers could not guarantee they would have time to check engineering documents during their regular work day because they were frequently interrupted. Therefore, costly overtime must be used, or the process would get behind schedule. From observations, many interruptions led to unpredictable and unbalanced process cycle time as well as excessive engineering change orders (ECOs). This translates into excessively long cycle times to complete an engineering activity.

## Root cause analysis

The root causes of the two major problems found in the previous section are unpredictable and unbalanced process cycle time and expediting engineering change orders (ECOs). In Figure 6, each root cause is shown and explained in the following discussion.

*Lack of standardization.*—In the current process, many parts and assembly models did not have standard drawings. The engineers used their own designs of commonly used parts and assembly, and this lack of standardization led to parts proliferation and large inventory in the manufacturing process. Also, the lack of standardization increased the possibility of errors in the engineering design. Product engineers took a large portion of time issuing ECOs. From the survey questionnaire study, 67 to 69 percent of the engineers answered that it took 10 to 20 percent of their daily work time to address ECOs, which were considered as reworks and did not create value to customers.

*Inefficient communication.*—Inefficient communication includes the communication with external and internal customers. External customers are the real customers who purchased the products. Sometimes, a design change needed to be confirmed with the external customers, which took several weeks. This made the engineering lead time unpredictable. From the survey questionnaire, engineering lead time accounted for 21 to 40 percent of the overall

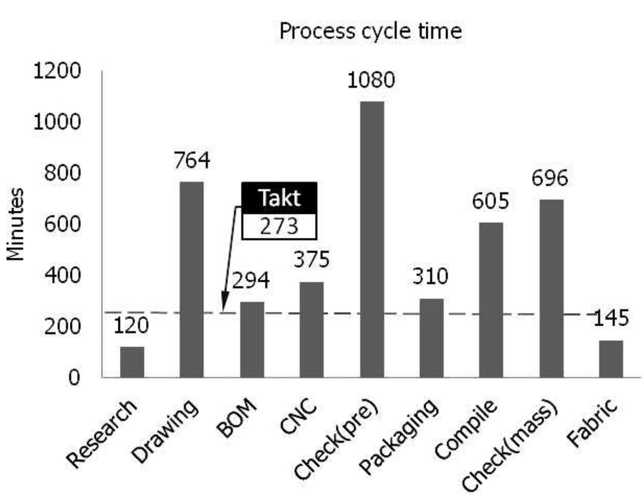


*Figure 5.—Takt time versus process cycle time. BOM = bills of material.*

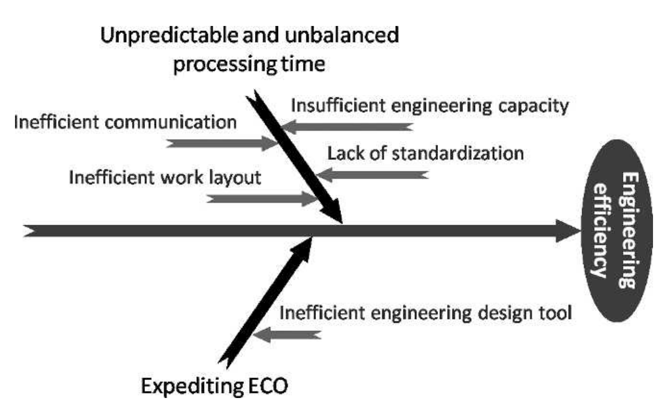


*Figure 6.—Root causes of two major problems. ECO = engineering change order.*

production lead time. On the other hand, communication with internal customers (production) was also not efficient. In Figure 4, the compile process used a lot of overtime to keep pace with customer demand. A major cause for overtime was because engineering normally had to wait a couple of days to collect the mock-up feedback before they worked on compiling the mass production document. This waiting time created unpredictability in the compiling process cycle time, and it also contributed significantly to the overall engineering lead time.

*Insufficient engineering capacity*.—Lack of people on certain tasks also resulted in unbalanced process cycle time and inevitably increased overtime. For example, there was one supervisor in charge of checking all the engineering documents. The available working time of an engineering supervisor was 480 minutes a day, and the takt time was 273 minutes. This meant the supervisor needed to check, sign off, and have someone distribute the engineering document at least once a day, but the supervisors were too busy to check the production document on a timely basis.

*Inefficient work layout*.—In the current office environment, the engineering department shared the office equipment with other departments. For example, the printer was placed in a spot where it took 25 to 30 seconds on average for an engineer to travel and pick up the printed paperwork from the printer. Even worse, the printer was packed with printouts from several departments, and it took awhile for the engineers to search for their documents and collect all the drawings needed.

*Inefficient engineering design tool*.—Based on the questionnaire survey study, drawing errors and part dimension errors were the two most frequent errors in the engineering documents. Also from the survey study, the results showed that the three-dimensional (3D) engineering design solution has more potential to improve engineering performance compared with the 2D engineering design tool that the department had been using.

Next, future state VSM will be utilized to solve these root causes in the engineering process. Although the future state is not the ideal state, it is the picture of the lean transformation process for this specific value stream.

## Future state analysis

*Countermeasures for lack of standardization*.—In the current engineering process, standardization is supposed to focus on two aspects. One is the standardization for managing the workload, and the other is the standardization for the quality engineering design. The necessity of workload management is because of the large process cycle times required for steps such as drawing, compile, and check. The engineers are responsible for managing and leveling out their workload. Without a standardized procedure, none of the engineers were efficient in managing their workloads.

In addition, the lack of quality design can be found in that there are no standard engineering design elements in existence for the ease of developing new parts. This lack of standardization results in inefficient downstream processes. Engineers develop individual designs and architecture, leading to excessive engineering errors and parts proliferation in the manufacturing process. Also, there is no standard drawing format for engineering documents, which causes difficulty in finding useful information on the drawings when needed.

A potential countermeasure for solving the work management problem is to balance and level engineer workload through process combination and automation. An implementation is to combine drawing, BOM, check (preproduction document), and compile (mass production document) into one process, DWG/BOM, and then focus on changing the way of creating drawings and automating generation of BOM based on the existing design. Previously, each engineer created drawings from beginning to end for a product. This led to large process cycle times because no method existed to manage the workload. However, workload balance could be better managed if parts drawings were separated into smaller job pieces. For instance, the supervisor could assign one person to create drawings for a sofa arm frame, another person to create a back frame, and so on; in the end, a new engineering document will be compiled by putting together the drawings from each engineer. Furthermore, by using the 3D engineering design package, the engineering team could also generate BOM based on an established 3D model. The process cycle time for creating BOM could then be zeroed out. In this way, the workload would be managed at a smaller scale, and the processing time could be predicted more accurately.

*Countermeasures for inefficient communication*.—The inadequate communication between engineering and external customers led to the situation where the customer can make changes anytime during an engineering design cycle. This inevitably resulted in a lot of rework and an unpredictable process cycle time. Therefore, it was necessary to establish a frozen zone to control the number of customer changes. The frozen zone set an end point where customers could not make further changes in a product life cycle.

On the other hand, it can be observed from Figure 4, that the process cycle time of the compile mass production document process is much longer than the takt time. This is because engineering could not start compiling the mass production document until they received the summary report of changes from the mock-up process. Although the processing time of compile is not long based on the investigation, the process cycle time shows a longer time period that averaged 10 days. During this waiting, engineers usually started working on other projects to offset their time loss. In this case, the countermeasure was to create a mock-up progress log that recorded the feedback from mock-up processes on a daily basis so that engineers could work on the engineering changes immediately instead of waiting for the final report. The processes of check preproduction document and compile mass production document could be eliminated because all the changes were completed on time and conducted in a steady pace parallel with the mock-up process instead of on a sequential basis, which involved a lot of waiting. Also, the same work log solution could be applied to the processes of CNC and packaging, which could reduce process cycle times by 30 percent (from 375 to 263 minutes) and 20 percent (from 310 to 248 minutes), respectively.

*Countermeasures for insufficient engineering capacity*.—According to the current state VSM, the check process runs out of capacity, and it is hard to catch up with customer demand. Therefore, appropriate check methods and capacity planning are needed to deal with the bottleneck. The proper check method helps to shorten the process cycle time. Usually, after completing the engineering documents, the engineer printed out all the drawings, BOM, and specifications for the engineering supervisor or manager to review. These files were then returned to engineers to make changes and print again for final approval and distribution. This process involved waste and extended the engineering process cycle time. By contrast, the online checking does not need to print every drawing or file, and each engineer can work on corrections immediately as long as they receive the electronic review from supervisors or manager.

Furthermore, as indicated in Figure 4, the check process has one operator (which was one of the two engineering supervisors). Because not enough operators are involved in this process, it cannot keep pace with customer demand and therefore causes significant overtime. In order to meet the takt time, in the future state, the check process would involve all the engineering management, which includes two engineering supervisors and one manager. Also, there will be just one check process in the future state VSM. So the process cycle time of checking engineering documents can be reduced from 1,776 minutes on average to 296 minutes. In addition, the online review could reduce the process cycle time another 10 percent, that is, to 266 minutes. In this way, the process cycle time of the check process is getting closer to the takt time.

*Countermeasures for inefficient work layout*.—Currently, the engineering work layout is not well organized. Some engineers had to walk around to deliver material to the supervisor on the other side of the work area. The printer and plotter were far away, forcing the engineers to spend a portion of their work time traveling back and forth to print out drawings. It is necessary to propose a work cell layout to enhance productivity so that supervisors and engineers can physically work together and the office supplies are easy to reach.

*Countermeasures for inefficient engineering design tool*.—The appropriate design tool can help prevent drawing errors and part dimension errors identified in the previous study. Although the 3D engineering design solution cannot guarantee improvement on the speed of engineering design, it can help improve the quality of engineering design with fewer errors and design flaws. The design features in the 3D engineering solution are helpful in solving excessive ECO problems. For instance, some 3D engineering solutions can check the existing 3D model and find any interference (overlapped area of components in the product assembly model) in the current design to prevent potential design flaws in the drawing so that potential manufacturing cost can be avoided. This proactive solution can help reduce design changes. Additionally, the 3D engineering solution can also automate BOM, for which manual entry was needed before.

Table 5 is a summary of all the root causes, countermeasures, and kaizen events. According to the countermeasures, the future state VSM is generated, suggesting target improvement areas and the potential improvement outcomes that could be achieved.

In the future state VSM (Figure 7), engineering planning sends work instruction to the first process step at the beginning of the value stream. The overall process is flowing on a first-in, first-out (FIFO) basis. The starting point of the process is to send new orders to research from product development. The FIFO lane will keep the order inventory to 1 day maximum. Then researched orders will pass to the DWG/BOM process for creating drawings and BOM on a 2-day FIFO maximum. Specific kaizen events aim to balance certain processes and improve engineering performance. For instance, the kaizen events proposed for the DWG/BOM process include standardization, BOM automation, new design tool, frozen zone, and work layout planning. The downstream processes, like fabric, CNC, and packaging, will also receive jobs on a FIFO basis. Finally, all the work will be sent to the check process for final approval. The total lead time of future state VSM is 15.0 days, or an 88.8 percent reduction from the current state VSM. The processing time of future state VSM is 9.0 days, or a 74.1 percent reduction from the current-state VSM.

Table 6 is a summary of what could be implemented and improved in the future state VSM compared with the current state VSM. From Table 6, it can be observed that the proposed countermeasures will help to balance and level the process cycle time and also reduce the error rate. For example, the combination of processes—creating, drawing, and BOM—as well as specific kaizen events would have benefits toward reducing process cycle time. The time to create BOM was eliminated in the future state because the BOM can be automatically generated with the 3D

*Table 5.—Summary of countermeasures and kaizen implementation.*

| Root causes | Countermeasures | Kaizen burst[a] |
|---|---|---|
| Lack of standardization | Process standardization: combine and eliminate processes | Standardization: standardize design models, drawing formats |
| | Work standardization: separate and balance engineer workload | Automation BOM: writing special microprogram in 3D engineering design application to automate the process of generating BOM |
| Inefficient communication | Improve communication with customer | Frozen zone: control the expediting changes from customer |
| | Improve communication with supplier | Work log: summarize production feedback on daily basis for engineers; increase the speed of making essential changes for mass production documents before releasing |
| Insufficient engineering capacity | Improve work method | Online-check: the engineering management check the documents online to eliminate paper waste and unnecessary processing time |
| | Increase people utilization | Capacity: utilize all the engineering supervisors and managers for checking process |
| Inefficient layout | Reorganize work layout | Layout: move necessary office supplies close to engineers; propose work cell layout for current work environment |
| Inefficient engineering design tool | Use 3D dimension-driven engineering design solution | Design tool: utilize 3D engineering solution to reduce the chance of making design errors and reduce the number of ECOs |

[a] BOM = bills of material; 3D = three-dimensional; ECOs = engineering change orders.

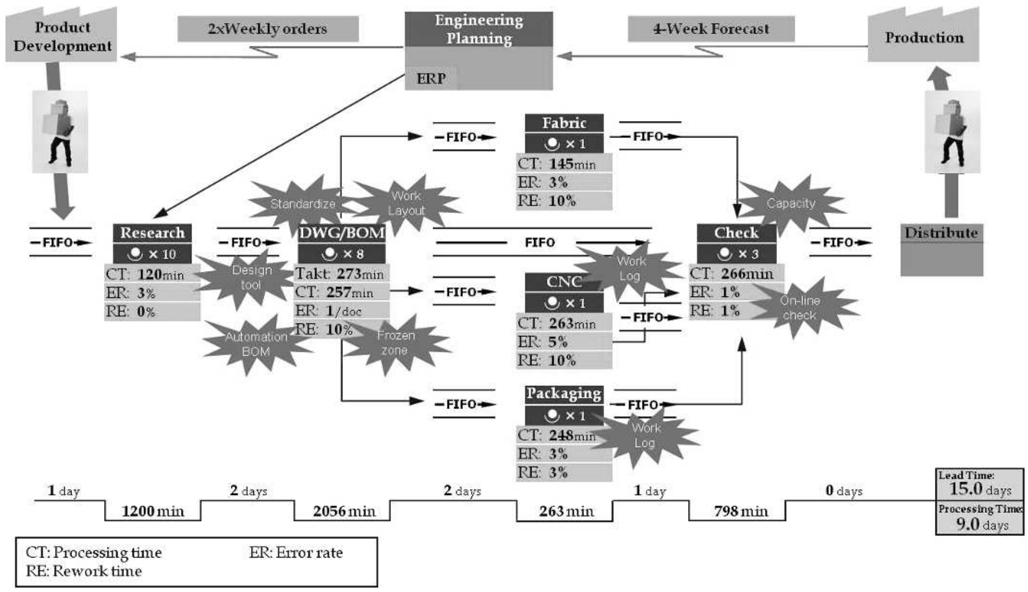


*Figure 7.—Future state value stream map. ERP = engineering requirement planning; FIFO = first-in, first-out; DWG/BOM = drawing, BOM, check, compile.*

engineering application. Standardization of drawings can help reduce engineering error rate and shorten the lead time. The redesigned work layout targets to facilitate teamwork and reduce lead time because the work cell makes the communication much easier among engineers. Furthermore, Table 6 would be utilized to establish a dashboard of target performance metrics with which design engineers can gauge, monitor, and sustain their improvement progress toward the future state value stream.

From a practical point of view, potential risks in the future state VSM may also impact the reliability of some countermeasures that also need to be considered. For instance, in order to deal with inefficient engineering capacity, it is proposed in the previous section that all of the engineering management check engineering documents. However, this may not be possible because one supervisor was in charge of checking drawings and the other of making engineering plans and distributed tasks. Also, the second supervisor needed to spend a great deal of time on the shop floor to solve potential engineering issues in the manufacturing process. Furthermore, the engineering manager's main responsibility was to approve engineering documents and new orders and to communicate with suppliers and customers. Therefore, a flexible way was needed to allocate the job capacity on checking drawings. For example, at regular times, when the number of customer orders is not significant, one supervisor should be capable of dealing with existing jobs. But when the number of orders becomes bigger, the other supervisor and the manager can be used as the ''buffer'' and ''safety'' resources to handle the expedited orders.

*Table 6.—Metrics comparison: Current state versus future state.*

| | Process cycle time (%) | Error rate (%) | Rework time (%) |
|---|---|---|---|
| Research | 0 | 0 | 0 |
| Drawing | 66.4 | 23 | 50 |
| BOM[a] | | | |
| CNC | 30 | 60 | 50 |
| Check (preproduction) | — | — | — |
| Packaging | 20 | 40 | 40 |
| Compile | — | — | — |
| Check (mass production) | 61.8 | 50 | 66.7 |
| Fabric | 0 | 0 | 0 |

[a] BOM = bills of material.

## Conclusions

Our research followed the structure of defining process boundaries, identifying main processes, analyzing customer needs, selecting and measuring process metrics, calculating system metrics, and then generating current and future state VSM. The current VSM analysis indicated that the current engineering process was inefficient. The processes of drawings, check, and compile exhibited long processing cycle times, and the engineers took a lot of overtime to address expediting orders. Waiting, interruption, inefficient engineering system, and uneven workload were typical problems resulting in long lead times for the engineering process.

Based on the above symptoms, a root cause analysis was conducted, and it was found that lack of standardization is the major cause behind drawing's delays. Also, insufficient engineering capacity was a major contributor resulting in the check bottleneck because the engineering supervisor always had to deal with other important tasks, and it was difficult to guarantee the daily work time needed to check and sign off on engineering documents. Another bottleneck process, compile, also took a long process cycle time. This was because sequential engineering involved a lot of time to fix design flaws and errors before releasing the final engineering documents.

In addition, bottlenecks and large inventories also showed in secondary engineering processes such as CNC and packaging. Lack of people in the secondary processes also led to capacity shortage, especially when overproduction happened in the upstream processes, making it even harder to pace the customer demand. Excessive inventory piled up between these processes.

Overall, from this case study, it was found that the current engineering process was exhibiting many types of waste (interruptions) that distracted engineers from creating value-added work. From the current state VSM, the processes with the longest processing cycle time and the largest inventory were identified. In future state VSM, several fundamental countermeasures were proposed to balance and level the engineering process. Point kaizen was effective to standardize and stabilize individual process, such as drawings. Frozen zone had significantly helped to reduce design iterations so that, for example, check processes were reduced from two to one and compile process had been eliminated from the current value stream. Standardization also helped to reduce development cycles. For example, the standardization of product structures saved a lot of engineering efforts in new product development. Also, from the future state VSM, the FIFO lane was used to make the overall process predictable, leading to the reduction of engineering lead time. The lead time was reduced from 133.9 to 14.7 days. In all, VSM presented its effectiveness to help visualize, control, and improve the engineering process of the case study company.

## Limitations and Future Research

The research also exhibited limitations. First, the sample size for the investigation was three engineers, and although they were the best associates available to generate meaningful data, it was still not sufficient to reflect the general performance of the overall system. Also, they might have worked harder than usual knowing that they were being monitored. Second, the limited time frame restricted the research to be conducted within a 1-month period. More accurate and exclusive conclusions might be made if there were enough time to address more monthly data. Third, it would be ideal to have several kaizen events to be implemented based on this study in the case study company. However, the geographical constraints and limited research funding prevented the countermeasures from this research from being implemented and the results verified. Future research will focus on tracking the implementation of the future state VSM.

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