

VALUE STREAM MAPPING FOR MAKE-TO-ORDER PRODUCTS IN A JOB SHOP ENVIRONMENT

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ABSTRACT

This paper investigates the use of Value Stream Mapping (VSM) for make-to-order products in a job shop environment, specifically the fabrication of Heating Ventilating and Air Conditioning (HVAC) sheet metal ductwork. The use of VSM for analyzing the production of repetitive units has proven to be successful in different industries. The use of VSM for studying the production of non-repetitive units requires some adaptation from repetitive-unit uses in order to successfully capture the attributes of multiple product families required at different frequencies and volumes. The VSM for a job shop environment has to be flexible to deal with the dynamic nature of job shops, e.g., maps may change daily according to the products scheduled for fabrication. Other aspects of the production system for sheet metal ducts that should be captured in the maps include the availability of a multi-skilled workforce for shop and site work, single flow of product and worker, and development of forecasts and capacity allocation to deal with frequent changes on incoming orders from project sites. Besides discussing the peculiarities of this job shop environment and their representation in a VSM, the authors discuss the process for elaborating VSMs for this production system and the definition of data used to develop them. Finally, the authors present a VSM for the fabrication of sheet metal ducts and discuss it using Lean Production concepts and recommend systematic data collection to reveal current practices and opportunities for improvement.

KEY WORDS

Value Stream Mapping, HVAC sheet metal fittings, make-to-order, job shop, Lean Production.

INTRODUCTION

Construction processes and supply chains have been mapped by a number of authors to depict the interactions and hand-offs between construction participants (e.g., Tommelein 1998, Arbulu et al. 2002, Elfving 2004, Alves and Tommelein 2003, 2004). In spite of the increasing acceptance of Value Stream Mapping (VSM)(Rother and Shook 1998) as a mapping tool in various industries, VSM has yet to be discussed in the construction literature. Fontanini and Pichi's (2004) paper on mapping of a supply chain for aluminum

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windows is an exception. A search in journals, including the Journal of Construction Engineering and Management, Construction Management and Economics, as well as the proceedings of the Annual Conference of the International Group for Lean Construction reveals that the use of VSM as suggested by Rother and Shook (1998), Rother and Harris (2001), and Duggan (2002) is yet to be implemented and published by construction researchers.

Possible reasons for the slow adoption of Value Stream Mapping (VSM) in construction may be related to the difficulty in defining production schedules and forecasts, as well as the difficulty of directly applying some of the key concepts/elements, (e.g., pacemakers and supermarkets explained later in this paper) used in VSM. The difficulty in representing some construction processes and their outputs reveals the complexity of the industry and the need for a language that can be understood by construction practitioners.

Construction supply chains and processes have been represented using simulation software symbols (Martinez 1996, Tommelein 1998, Alves and Tommelein 2004) and operations research symbols (Alves and Formoso 2000). While simulation tools and their graphic representation of processes are effective in modeling the dynamic interactions in such supply chains, they are not widely understood by construction practitioners. Operation research symbols are easier to interpret but do not show in a transparent fashion how processes and their associated information flow through a production system or a supply chain.

In contrast, VSM reveals the flow of work and information side by side. It also reveals waste of time by displaying the cycle time for each operation and the total lead time for a process. The waste of resources such as materials, equipment, and space are easier to recognize than the waste of time, which is hidden behind unnecessary actions and movements. When the total lead time is compared to the total cycle time to deliver a product, the result shows how much time is actually spent to deliver a product vs. time used to fabricate it, i.e., how much time worth of work the customer wants to buy vs. how long it takes the supplier to deliver it (Duggan 2002). For instance, in the case presented in this paper we illustrate that the customer wants to buy on the order of 20 minutes worth of work and that the company takes on the order of 32 days to deliver it.

Given the need to unveil waste and opportunities for improvements in construction and the relevance of VSM, the authors used VSM to map a make-to-order environment in a job-shop that provide parts for construction projects, i.e., Heating Ventilating and Air Conditioning (HVAC) sheet metal ductwork. Job shops are production systems that deal with orders that may comprise a variety of products, with different characteristics, and can go through different routes, i.e., different machines and operations, during fabrication. A make-to-order job shop deals with customized orders, which usually cannot be entirely or partially fabricated in advance.

Job shops have been long investigated and discussed in the operations research literature. But not enough attention has been devoted to this topic in the construction literature, in spite of the presence of job shops to deliver products in construction supply chains, i.e., sheet metal parts, precast concrete elements, pipes, architectural elements, various kinds of wood framing, etc.

For the fabrication of HVAC sheet metal parts, there are two main types of job shops that supply construction sites. The first is represented by a supplier who makes parts and supplies them to different customers who then install them. The second is the

(mechanical) contractor's fabrication shop, which supplies parts mostly for its own projects. Maintaining a fabrication shop under their own umbrella provides contractors control over production (e.g., the flexibility of having parts at any time) as opposed to having to accept supplier lead times.

This paper intends to contribute to a better understanding of how some peculiarities of construction systems and job shops may be investigated and represented in the development of VSMs. The discussion is based on the work of mechanical contractor's fabrication shops, but it can be extended to other supplier's fabrication shops with small adaptations.

VALUE STREAM MAPPING

“A value stream is all actions (both value added and non-value added) currently required to bring a product through the main flows essential to every product: (1) the production flow from raw material into the arms of customer, and (2) the design flow from concept to launch.” (Rother and Shook 1998, p.3). In order to build a value stream map (VSM), a set of production data and customer requirements is needed.

ESSENTIAL DATA

The first step to build a VSM is to select a family of products, i.e., groups of products that go through the same processing steps, to be investigated from the point of ordering raw materials until the point of final product delivery to the customer. Essential data for building the current state map includes (Rother and Shook 1998):

- Product family steps. Definition of the production processes the selected product family goes through, e.g., cutting, welding, shipping, etc.
- Production information. Information about changeovers from one type of product in the family to another as well as the frequency of raw material delivery. Number of shifts the plant works, working time and breaks for each shift, and number of working days in a month.
- Ordering. Customer requirements for each product of the family investigated, e.g., 100 products of type A and 300 type B needed every week. Packaging requirements for the orders, e.g., number of parts per pallet or box.
- Production Control. How often and by which means forecasts are received from the customer as well as sent to suppliers. How often and by which means production requirements are deployed from forecasts to production plans and sent to different processes.

CHARACTERISTICS OF A LEAN VALUE STREAM AND THE FUTURE STATE MAP

Once the current value stream map has been developed, the next step is to think about the future state map, i.e., the new road map for production considering guidelines to eliminate waste and streamline the flow of products and information. Guidelines used to develop lean VSMs are as follows (Rother and Shook 1998):

- Produce to your takt time. Takt time is the production rate that matches the customer buying rate. It is the division of a system's available work time per shift by the customer demand rate per shift. For instance, if a company works 7.5 hours per shift

(27,000 seconds), and the customer demand is 900 parts per shift, the takt time is 30 seconds: every 30 seconds the system should be able to produce a part to match the customer's demand.

- Develop continuous flow whenever possible. Products should flow continuously from one process to the next without sitting in inventories.
- Use supermarkets to control production where continuous flow does not extend upstream. Some processes cannot operate in a continuous fashion for several reasons, i.e., their cycle is too short or too long, process is unreliable and needs to be decoupled from other processes, parts are delivered by a supplier and one piece flow is not a realistic option. When the use of supermarkets (i.e., a buffer with a pre-defined amount of parts replenished as soon as parts are removed) to create continuous flow is impractical, a FIFO lane (i.e., a space for a limited amount of parts to accumulate and be released on a First-In-First-Out (FIFO) fashion) can be defined. When all the spaces are filled in the FIFO lane, the supplying process has to stop producing. The FIFO lane and the supermarkets have to be sized to absorb any imbalance caused by non-continuous flow upstream. They should be able to hold enough parts to feed the subsequent process and allow it to work continuously to match the takt time. If an excessive number of parts is kept in either, i.e., more parts than the actual imbalance between consecutive processes, the purpose of continuous flow is defeated because unnecessary inventory will accumulate between processes.
- Try to send the customer schedule to only one production process. “The pacemaker involves production steps that are dedicated to a particular family of products and responds to orders from external customers. A well run pacemaker sends smooth demand signals upstream to the pull loops of the remaining batch fabrication processes, which respond to requirements from internal customers.” (Rother and Harris 2002, p. 6). After the pacemaker, parts should flow continuously, no supermarkets are allowed.
- Distribute the production of different products evenly over time at the pacemaker process. Whenever possible (e.g., when product set-ups and cycle times are short, batches are small, line is flexible to accommodate changes), different products should be fabricated in the same line to match the customer's demand. Several product types can be fabricated in short time intervals. The rewards for the hard work needed to level a mixed production system are short lead times and low inventory levels, amongst others.
- Create an “initial pull” by releasing and withdrawing small, consistent increments of work at the pacemaker process. Release small amounts of work in a consistent increment of time, i.e., pitch. At every pitch, release a predefined amount of work to the pacemaker, based on the takt time for that product family, and collect the completed work produced in the same amount of time in the previous cycle.
- Develop the ability to make “every part every day” in the process upstream of the pacemaker process. With low changeover and cycle times, production batches can be reduced and parts can be fabricated in shorter time intervals, several times in a week. The definition of “every part every...” (EPE) informs the system how often a the system changes over to fabricate the required part.

VALUE STREAM MAPS FOR MIXED VALUE STREAMS

Duggan (2002) discusses four options for balancing mixed value streams with products whose work content exceeds the takt time for a constant number of operators. When products have a work content (i.e., amount of work required to fabricate them) greater than the takt time, the pacemaker will slow down when these products are fabricated.

- Option 1: Level the schedule and keep labor constant – build products in fixed sequence. The schedule can be leveled, based on the products' work content, so as to deliver a sequence of products with high work contents after products with low work content. The result is an average takt time for the line while using a consistent pitch. This option can be implemented in a line with discrete parts, low demand variation, and high volume.
- Option 2: Level the schedule and build ahead. Keep labor constant, use FIFO to shipping. In this case, orders are reviewed ahead of time and a production sequence based on work content is created. The pacemaker will have different speeds due to differences in work content; a FIFO lane, placed after the pacemaker, is designed to absorb these variations. This option can be implemented in a line with discrete and custom parts, and low demand variation. It works better if the pacemaker is located close to the end of the value stream.
- Option 3: Level the schedule with a supermarket and build to ship with FIFO. In this option, a supermarket is designed to keep commodity items, which are pulled when the total amount of custom and commodity product orders exceeds the production capacity. The use of a supermarket will allow workers to fabricate custom products to fill the orders, while commodity items ordered in the same period are pulled from the supermarket. When demand is low, workers produce to replenish the supermarket. This option is suitable for a line with discrete and custom parts, and high demand variation.
- Option 4: Balance to takt time and add labor when a product exceeds takt time. Try to build products to demand. The speed of the pacemaker is kept constant by adding more operators to the line to meet the takt time. This option is suitable for lines with discrete and custom parts, high demand variation, short lead times, and when there are processes between the pacemaker and shipping.

CASE STUDY BACKGROUND – HVAC SHEET METAL SHOP

This section presents characteristics of the way sheet metal shops operate. The information provided is based on research and field visits carried out by the authors in different sheet metal fabrication shops and other fabrication shops that serve the construction industry.

PRODUCT FAMILIES AND MACHINES

Different types of ductwork can be grouped in families, i.e., a group of parts that go through more-or-less the same machines. The time each product spends on each machine may vary according to the sizes and geometry of parts, type of material, changeover time, operator skills, etc. Also, the cycle time to finish an order depends on the number of parts that are batched.

Parts usually are not fabricated in advance because they are bulky, even if the shop knows which parts are in high demand. Some fabricators, i.e. companies that fabricate but do not install parts, keep the most common high demand parts in inventory. Fabricators can aggregate the demand coming from different companies and are able to keep a buffer of commodity parts in inventory. This inventory in fact helps them to reduce their lead times.

Machines are usually dedicated to one single operation and only a few machines are capable to work and stop automatically after being started. Automation (i.e., 'automation with a human touch', machines that are able to differentiate normal from abnormal conditions (Ohno 1988, p.6)) are not common in these fabrication shops. This makes it difficult to implement cells with a few workers in charge of several machines, as suggested by some authors (see Ohno 1988, Shingo 1989). In sheet metal shops, workers are multi-skilled: they may or may not carry a part (or a batch of parts) and work it on one machine after the other from the beginning to the end.

PRODUCTION INFORMATION AND CONTROL, DEMAND, AND ORDERING

A VSM usually displays a box containing schedule information. This box is linked to other processes in the value stream: the processes are ruled by the information defined in the schedule. The way orders are forecast, when they materialize, and how they are grouped for fabrication impacts all the processes in a value stream.

Research carried out by the authors in fabrication shops reveal that demand can be quite variable depending on factors such as quality of the site plans, reliability of specialty trades' plans, and level of coordination between trades, ordering instructions given to field personnel, to name a few. Orders should arrive in the shop within the time required by the shop to deliver parts on time without disrupting their production, but according to shop personnel in one of the companies visited 10% of the orders are emergency orders or "hot jobs". These are orders that must be fabricated and delivered within a day or so, and they put a great burden on the fabrication shop.

The take-off for ordering parts is done by areas, i.e., 3rd floor north side, resulting in orders that may contain different types of fittings requested as a single batch, i.e., round and rectangular fittings. This means that orders may contain pieces all different from one another. Once an order reaches the shop, it is usually not combined with other orders, even if other orders may contain pieces that could be combined to speed up fabrication by taking advantage of repetitive operations to fabricate parts. Other rules for combining parts in a same batch are used by field workers, detailers, and shop foremen, but they tend to remain tacit (Alves and Tommelein 2002, 2003).

Demand Types

When a contractor is awarded a project, its fabrication shop has an order of magnitude of the load for the shop, based on the overall contract cost, while that project is running. But the fabrication shop does not know when the demand will actually materialize and specifically how many parts of each type will be required.

There seem to be two subtypes of demand in fabrication shops. The first is the flow of incoming orders to the shop, we will call it virtual demand. These orders have due dates and should be fabricated taking these dates into account. Every day these orders reach the shop and could be taken into account to forecast the near-term load for the shop. The second is the actual demand; this refers to the orders that are actually fabricated based on

their due dates, whether they are emergency requests for parts or not. This demand includes the orders represented in the production schedule as well as incoming rush orders.

Which of these demands should be used to calculate the takt times for the value stream map?! Some may argue that the virtual demand should be used because it represents the total demand placed on the shop. But this system does not seem to have a known demand rate. Parts may stay for long periods of time in the queue of parts to be fabricated, distorting the actual demand.

The documentation of parts ordered and their due dates, the dates when parts entered the shop and left it, and the dates when orders were sent to the shipping yard give us an idea of how much inventory is kept and how much of the actual and virtual demand can be matched at any given time.

The wrong definition or the lack of a demand rate for fabrication may result in buffers that do not adequately match the level of uncertainty they are supposed to. The difficulty to pinpoint the causes of demand variation and, consequently, demand rates result in the design of buffers that fail to increase the efficiency of a production system. Due to these problems, buffers are either oversized and become part of the inventory problem, or are undersized and fail to protect production systems against the effects of uncertainty, and expose these systems to shortages and interruptions on its flow of work.

SHIPPING

Parts are shipped as they are needed on site. The desire to optimize transportation costs exists; however, sites are spread out in different areas and the optimization equation changes as sites are added to or deleted from the map. Also, order sizes and their timing vary according to different projects. Parts are usually shipped in different quantities; there is not a steady flow of parts going through the shipping department.

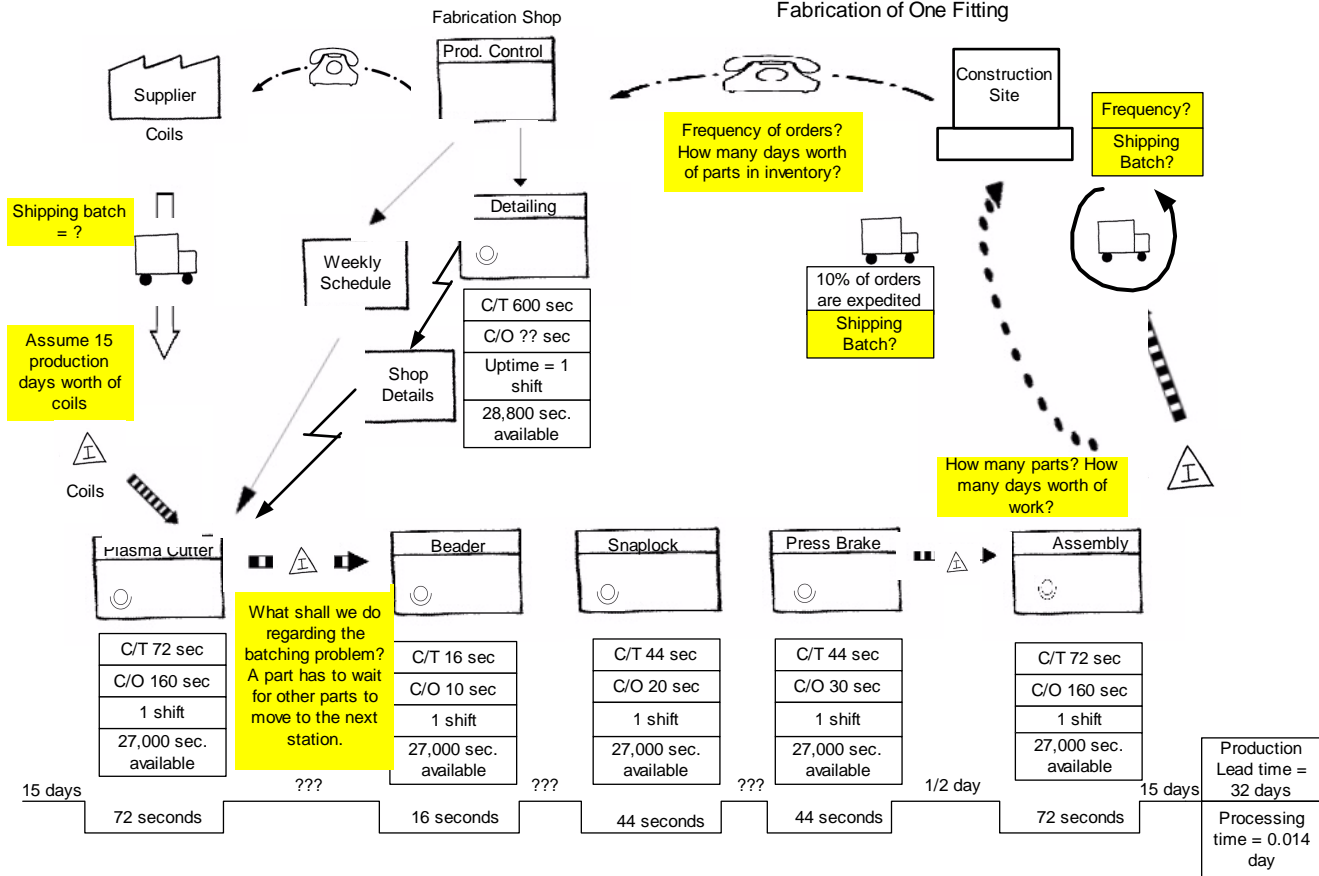
VALUE STREAM MAPPING FOR HVAC SHEET METAL JOB SHOP

The case study to illustrate the use of VSM for a HVAC sheet metal shop was developed based on real data collected from a time study in a large HVAC sheet metal shop and interviews with people in sheet metal shops. In spite of the effort to quantify outputs of each process, inventories, batch and buffer sizes for different processes and tasks, these numbers remain largely unknown. This is in part because companies do not keep track of this information in a systematic fashion. The release of production orders and withdrawal of finished goods from the system is erratic even for products in a same family. This reveals part of the complexity of the system studied.

The product family mapped is an abridged representation (i.e., some operations were suppressed) of the fabrication of rectangular ducts. The symbols used are the ones presented by Rother and Shook (1998). The working time was defined as one work shift minus breaks, equaling 27,000 seconds or 7.5 hours. After parts are cut in the plasma cutter, one worker is in charge of fabricating them: the parts and the worker travel together throughout the fabrication process. Cycle times were calculated as the time it takes for the two parts of a rectangular duct to be processed in each machine. Changeover times were considered to represent the time operators spend adjusting the machine before processing parts.

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Value Stream Mapping for the
 Fabrication of One Fitting



While the map was being drawn several questions came up regarding hand offs in this system as well as levels of inventories, buffers and batch sizes throughout the system. The questions are highlighted in the map presented. Another crucial question relates to which of the options suggested by Duggan (2002) for leveling mixed value streams is the more adequate to build a value stream for this system.

Products cannot be fabricated in advance; very few products can be kept in a supermarket - if any in a contractor's job shop; labor is usually kept constant as companies want to keep workers productive. In the current state, orders are received in advance and fabricated at any time when workers are free. Inventory builds up between fabrication and shipping. From the options presented two seem to have potential application for this system.

Options 2 and 4, as suggested by Duggan (2002), may be implemented provided that takt times can be calculated for this product family and workers can be added to the line when product cycle times exceed the takt times. The use of a FIFO lane would largely reduce the inventory of finished products in the end of the line, yet it would allow the order and fabrication of parts in advance. This is important in the context studied because field labor is pointed as the costly and risky part of the system. However, it would fit best in for a production line with low demand variation. The use of workers to balance takt time is also a viable option as in this system workers are multi-skilled and can perform different tasks in the production line. This would make feasible the implementation of option 4, which suits lines with short lead times and high demand variation, like the one investigated.

CHALLENGES AND RECOMMENDATIONS

The reason for developing a VSM is to reveal the inefficiencies that are hidden in a value stream and to provide a future state map showing directions on how to improve the system. The authors recognize that job shops are dynamic systems and need to be treated as such, meaning that takt times, batch and buffer sizes have to be constantly updated to reflect changes in the system. However, the system investigated does not systematically keep track of the data needed to develop lean future state maps. What follows is a list of important reference indicators that cannot be calculated due to lack of information about the system investigated. This highlights the dire need for further, systematic data collection.

- Takt time – the definition of takt time is contingent upon a certain demand, if demand is not known, neither is the takt time.
- EPE (Every Part, Every...) – Production schedules usually do not represent the amount of work required to fabricate each part. Only one of the companies visited by the authors actually keeps track of the time spent to fabricate orders by using a bar coding system and logging time on each machine. The actual load for the shop as well the demand for each family of product is not know.
- Batch sizes – Orders vary largely in number of fittings and work content. Therefore, the definition of a batch size that keeps a smooth flow of work and matches the takt time is a challenge.
- Paemaker – the absence of a takt time makes the implementation of a pacemaker hard achieve.

- Pack size – parts are shipped to the site according to site needs and there is no defined pack size. Fabricators try to achieve optimal truck loads, i.e., trade-off load and cost. Depending on the volume of parts, a larger or smaller number of parts may be shipped in small or large trucks. What actually rules the shipping sizes is the need for parts in the field, and this can vary significantly.
- The use of FIFO lanes and supermarkets, as discussed elsewhere in this document, are hard to achieve if product demand is not known.

The difficulty in setting these numbers hampers the implementation of lean concepts and techniques to streamline the production flow in a fabrication shop. As emphasized by Shingo (1988, p.87 and p.97), in the Toyota Production System great attention was devoted to the development of forecasts, which would later become part of their production schedule. A dynamic system set to collect market data in advance of production, as well as close to production time, is part of Toyota's schedule control. The collected information is subsequently fine-tuned and controlled via *kanban* cards.

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