LEAN SIX SIGMA SUPPLY CHAIN MONITORING AND CONTROL

by

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ABSTRACT

There is recent interest in expanding the benefits of Lean Six Sigma into other areas such as supply chain management. The Lean Six Sigma tools such as Value Stream Mapping and Cause & Effect Matrices allowed Company A to improve vendor delivery performance from 65% to 95% translating into over $100k annual savings. They also provide greater visibility into the inefficiencies of the supply chain (especially between firms), data driven analysis for choosing trustworthy partners, predictive monitoring and control, and a common language to facilitate alignment of strategies and objectives.

Keywords:

Lean Six Sigma

Supply Chain Management

Subject Terms:

Management

Organizational Change

To my perpetually encouraging wife, Kathy, and new baby daughter, Katelyn. And to my family who has always supported my lifelong learning.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

GLOSSARY

5s	Five terms beginning with 'S' utilized to create a workplace suited for visual control and lean production. 'Seiri' means to separate needed tools, parts, and instructions from unneeded materials and to remove the latter. 'Seiton' means to neatly arrange and identify parts and tools for ease of use. 'Seiso' means to conduct a cleanup campaign. 'Seiketsu' means to conduct seiri, seiton, and seiso at frequent, indeed daily, intervals to maintain a workplace in perfect condition. 'Shitsuke' means to form the habit of always following the first four Ss.
Jidoka	Technological innovation that enables machines to work harmoniously with their operators by giving them the 'human touch. It employs automatic and semi-automatic processes to reduce physical and mental load on the workers.
Just-in-Time	A strategy for inventory management used extensively in Lean in which raw materials and components are delivered from the vendor or supplier immediately before they are needed in the manufacturing process.
Lead Time	The amount of time, defined by the supplier, that is required to meet a customer request or demand. (Note: Lead Time is not the same as Cycle Time).
SMED	The Single Minute Exchange of Dies or setup time that can be counted in a single digit of minutes. SMED is often used interchangeably with “quick changeover”. SMED and quick changeover are the practice of reducing the time it takes to change a line or machine from running one product to the next.
Supermarket	In lean manufacturing terms, a supermarket is a tightly managed amount of inventory within the value stream to allow for a pull system. Supermarkets, often called inventory buffers, can contain either finished items or work-in-process. They are used to maintain continuous flow in the presence of a pacemaker process, manage uneven demand, and/or reduce finished goods inventory.
Takt Time	Lean Production uses Takt Time as the rate that a completed product needs to be finished in order to meet customer demand. If you have a Takt Time of two minutes that means every two minutes a complete product, assembly or machine is produced off the line. Every two hours, two days or two weeks, whatever your sell rate is your Takt Time.

1: INTRODUCTION

The sponsor company for this project, Company A, is a high tech manufacturing firm of large capital equipment[†]. Company A employs a complex supply chain with over 1000 vendors to manufacture its product line consisting of a configurable main engine with several options for add-on material handling automation devices. Approximately 90 of these vendors supply 80% of the parts.

In the last six months of 2007, Company A averaged 37% on-time delivery to its customers. Data showed this appalling result was largely attributable to a sudden drop in on-time delivery performance from its largest sheet metal component supplier. To correct the poor delivery performance, Company A launched a three-month project in early 2008 to address the issues of this supplier and raise on-time delivery to 95%.

This paper details the structure, findings, and results of the project with this vendor, Vendor X. Company A developed a strategy and plan for improvement using Lean Six Sigma techniques such as Value Stream Mapping (VSM), Cause and Effect (C&E) Matrices, and control charts.

Through weekly communication meetings with a functional team consisting of members from both firms, delivery performance successfully improved from 65% to 95% in three months. The team produced a Lean VSM to make the inefficiencies more visible and to facilitate brainstorming of improvement activities. The main improvement implemented was the dramatic reduction of finished goods inventory and creation of a WIP supermarket further upstream in the process. The supermarket was a tightly

[†] Because of the confidential and competitive nature of the information contained in this paper, the sponsor company has required that the names of the companies, products, and industries involved be disguised.

managed amount of WIP inventory within the value stream to facilitate effective management of finished goods inventories while maintaining promised lead times. This had several benefits including reduced inventory and simplified production planning making the process less vulnerable to demand spikes.

Root cause analysis was employed to determine the cause of every late delivery in the three months. The data gathered was categorized and responsibility was assigned for each late delivery. Some surprising findings showed that Company A was actually responsible for one third of the late deliveries.

This paper presents an internal and external analysis of Company A. A literature also outlines guidelines on how to identify firms that would make good Lean partners and how to monitor them to gain a fair and holistic view of their performance.

Lean Six Sigma has found proven success in many manufacturing applications. There is now a shift to leverage that proven success into non-manufacturing functions such as supply chain management.

2: INTERNAL AND EXTERNAL ANALYSIS

Company A is a high tech manufacturing firm of large capital equipment. Company A employs a complex supply chain with over 1000 vendors with 90 of these supplying 80% of the parts to support its manufacturing.

2.1 Strengths

Company A holds the majority of market share leading all competitors with a differentiated portfolio offering excellent quality and productivity. Company A's portfolio offers the widest range of automation options for their products. This is a key strength since most of the markets they serve are capital intensive that prefer to invest in equipment that is more efficient.

Company A also has the largest development team committed to leading the industry through innovation. Its brand is very well established and provides its customers with a strong sense of reputation, quality, and service. Company A also has strong intellectual property surrounding the core engine of its equipment. It is highly recognized and valued by the market.

2.2 Weaknesses

Competitors and customers regularly attack Company A on the grounds of poor reliability, while world class equipment reliability is key to maintaining strong market share. In addition, Company A's service business has traditionally had negative contribution margins. Last year, it crossed the line into marginally positive contribution for the first time. There is also market pressure to reduce service pricing and increase service entitlement.

Price of the equipment itself is higher for Company A than its competitors. So far, Company A has been able to command this premium because of its brand and market share. However, the maturity of the market is expected to drive prices down.

2.3 Opportunities

Company A has identified brand new markets in which it can leverage its strong IP in its engine technology. New customers have been identified and potential profitability in this new segment is high. The supply chain for this new segment will be the same as for its existing business.

Company A can leverage its strong partners with its majority market share and development team to improve productivity and reliability solutions.

One of the major market segments is undergoing consolidation, which is driving the desire for higher efficiency production. Company A's automation portfolio provides a solution for improved efficiency and productivity.

2.4 Threats

The competition is changing. Competitors have introduced new disruptive technologies that have adequate performance in some segments at a lower cost. One major competitor has ceased manufacturing, but has started distributing another competitor's product all in an attempt to bring lower cost solutions to the market.

Some companies that produced equipment for downstream processes are now introducing equipment that will be in direct competition with Company A. Competitors could position this equipment at a lower price with the opportunity to bundle with complimentary equipment.

Raw material costs have increased dramatically in the last six months. The price of cold rolled steel has increased approximately 60% while aluminium sheet has increased by 25%. Raw materials account for approximately 15% of the cost of goods, so this increase puts even more strain on margins and market pressures to reduce costs. All competitors however, would see this threat.

2.5 Rivalry

The degree of rivalry is moderate-to-high. Company A has only three main competitors and almost the entire market is shared amongst these few firms. However, market growth is declining. The only way to increase sales is to win market share from other players. Switching costs for customers are high due to the specific nature and complexity of the product. Nevertheless, exit barriers are high for the industry because of the asset specificity of manufacturing facilities.

2.6 Substitutes

The threat of substitutes is high. The current market and technology is mature, and there are disruptive technologies that are gaining popularity. These disruptive technologies can not match the specifications of incumbent technology, but are “good enough” for some segments.

2.7 Buyers

Buyer power is moderate-to-low. There are only a few buyers because of the high capital expenditures required for these products. However, the buyer switching costs are very high and producers supply a significant component of the buyers' output.

2.8 Suppliers

Supplier power is highly dependent on the particular supplier. Some suppliers possess strong intellectual property and, thus, have much power. However, for the most part, supplier power is moderate. Major suppliers can exert some degree of influence on cost of goods. However, although switching costs are not low, they are not excessively high. There is also credible backward integration threat by purchasers.

2.9 Barriers to Entry

Barriers to entry are very high. The industry is characterised by strong intellectual property, high capital cost of entry, asset specificity, and a large minimum efficient scale. Company reputation also plays a large role in this industry for perception of product reliability because of complexity of products and warranty issues. A well known and established brand is a great competitive advantage.

3: COMPANY A'S SUPPLY CHAIN

There are hundreds of different configurations for Company A's main engine product. It is a large capital investment, and customers require low volume, very specific customization. Typical volume of the main engine product is 120 per year. Because of this mass customization and high cost for its products, Company A employs a build-to-order manufacturing strategy. The number of configurations coupled with the pressure from a mature market to aggressively reduce costs are the major drivers that make Company A very susceptible to delivery problems.

Each machine consists of over one thousand parts, many of which have variations depending on the configuration of the machine. These parts are mostly cable assemblies, precision machined parts, and fabricated sheet metal components. These parts range in value from $0.01 to $10,000 each and have standard lead times of six to eight weeks. To further add to the supply pressures, Company A promises a six-week lead time to its customers. This time includes assembly, testing, and shipping with a two-day buffer. A certain level of inventory must be kept to accomplish this. But, keeping enough stock of each part in each variation at the low production volumes to support the six-week lead time is not practicable in terms of inventory costs. In order to support the demanding manufacturing requirements, Company A runs a Lean supply chain with a Just-in-Time inventory strategy aimed at reducing in process inventory and its associated carrying costs. Kanban triggers are used between Company A and its key suppliers to maintain a three-day lead time.

To support this aggressive lead time, Company A seeks vendors that are willing to hold some level of inventory either in finished goods or work in process (WIP). In exchange, Company A agrees to liability for this inventory in the event of an engineering change or end-of-life for the product. The amount of liability is based on the value of the part, the annual volume, and the time it takes to manufacture the part. Typically, this level of inventory held by the vendors can support a 20% increase in forecasted demand. Forecast accuracy has not been tracked in the past, but swings of 20% are common.

For Vendor X, Company A's largest sheet metal supplier, this demand spiked for six consecutive months (see Figure 1). Company A launched a new product at this time to strengthen its automation portfolio. This new product is an add-on device that attaches to its main engine to automate material handling. It consists of approximately 900 parts. Over 600 of which are fabricated sheet metal components that account for 75% of the COGS of the new machine. The launch of this new product had little effect on the other parts of the supply chain. Supply of sheet metal components was the most stressed by far.

Projected sales of this new product were only 40 per year. This new add-on product was itself a large capital investment with an approximate selling price of $200k.

Company A wanted to place all of the sheet metal for this new product with a single vendor to get a "volume discount" for low volume components in order to meet cost targets. Vendor X was chosen because it had the capability to produce all of the components, the financial health and physical space to hold the required inventory, and a well established relationship with Company A.

In June 2008, Vendor X committed to having the required inventory for meeting three-day lead times ready by August. Although this demand spike from Company A was expected and planned for, untimely demand from Vendor X's other customers spiked at the same time. Even though the total demand was still below 100% of Vendor X's theoretical capacity, on-time delivery performance began to struggle and dropped to 55%. With an average of 200 deliveries per week from Vendor X all on a three-day lead time, this poor delivery performance put an enormous strain on Company A's operations.

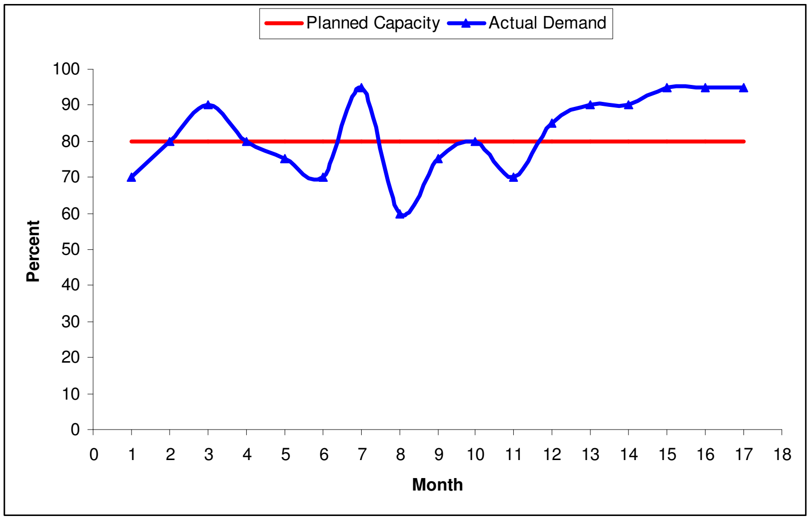


Figure 1: Vendor X Planned Capacity and Actual Demand

Vendor X now supplied Company A with over 1500 unique parts and averaged 65% on-time delivery. Company A's production lines shut down frequently due to sheet metal component shortages. Line workers were sent home during regular hours and asked to return for overtime on weekends. Costs for expedited delivery to customers to make up lost production time climbed substantially during this time as well.

Several visits were made to Vendor X to address the issue, but the only reasons found in these ad hoc meetings were unexpected delays in random operations. Equipment breakdown, welding rework required, and paint problems were among the most common causes for the delays. These delays are typical of a production sheet metal shop and staff at Vendor X verified these delays were not occurring any more frequently or with greater consequence than in the past. The problem was that Vendor X's finished goods inventories were depleted from the demand spikes, so each delay now had a direct effect on scheduled deliveries.

The solution, however, could not simply be to increase the level of finished goods inventory to help prevent this from recurring in the future. Doing so would increase inventory carrying costs, adding cost to a supply chain and product already under huge pressure for cost reduction. Lean Six Sigma techniques were an ideal approach in this case to dissect the entire order fulfilment process, follow the material and information flows, eliminate wastes, and devise a solution to meet customer requirements without increasing inventory costs.

4: LITERATURE REVIEW

This section of the paper provides examples from literature that support the synergies between Lean Six Sigma and supply chain management. A method for choosing appropriate supply chain partners that are trustworthy and will cooperate in an atmosphere of continuous improvement is provided along with a suggested set of metrics that provide a comprehensive view of the current performance of the supply chain. The Lean Six Sigma techniques that facilitate this manner of supply chain management are introduced as well.

4.1 Lean Manufacturing and Supply Chain Control

The ultimate goal of both Lean manufacturing and supply chain control is improved competitiveness through superior customer service. Organizations improve competitiveness by reducing costs, increasing flexibility to changing customer demands, and providing a superior quality product and service.

In supply chain control, this ultimate goal is supported by two things; namely the integration of a network of organizations and the coordination of information, material, and financial flows. Forming an integrated network of organizations into a supply chain requires choosing suitable partners that practice effective inter-organizational collaboration. Bold concepts of leadership in information technology (IT) strategies align the partners involved to coordinate information and material flows (Stadtler, 2005).

Similarly, Lean supports the goal of superior customer service through two concepts: operational availability and material movement and flow. Operational availability includes the application of Jidoka; Jidoka literally translates to "automation with a human mind". Jidoka are elements of a system that serve to identify, respond to, and eliminate abnormal conditions. The goal of the application of Jidoka is to free the system from the need for constant human attention in order to leave resources available for continuous improvement activities. Just-in-Time is a Lean inventory strategy aimed at reducing in process inventory and its associated carrying costs (Company A Lean Six Sigma Training, 2007).

Figure 2 and Figure 3, respectively, show how Lean and supply chain control support improved customer service. Each "house" is built on a foundation of basic concepts. Notice the pillars of the Lean house are closely related to the pillars of the supply chain management house.

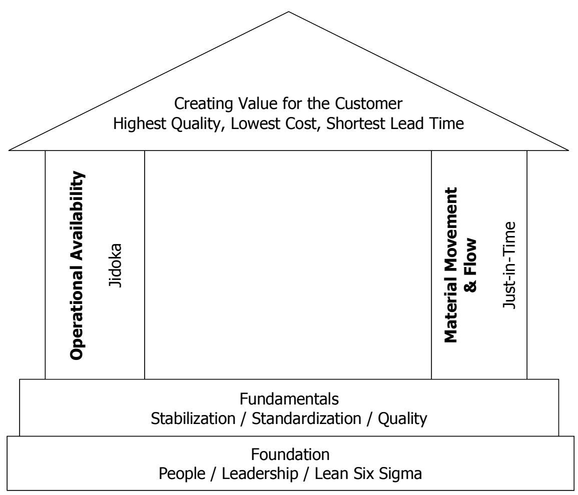


Figure 2: House of Lean Six Sigma (Source: Company A Lean Six Sigma)

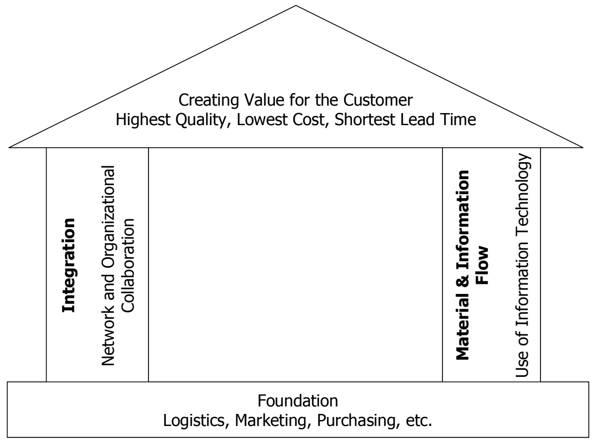


Figure 3: House of Supply Chain Management (Source: Stadtler, 2005)

4.2 Goals and Expectations

Table 1 suggests an initial test and simple evaluation of the rapport between vendor and customer and level of integration in the relationship. It is a preliminary appraisal of the potential for a partnership that can continuously grow in customer satisfaction and maintain competitiveness. The themes identified in this questionnaire might also be adapted into a Six Sigma Cause and Effect (C&E) Matrix where actual values can be assigned to the data for choosing the best supply chain partners. The dimensions used in such a C&E matrix are dependent on the business, but productivity, quality, inventory turns, and delivery performance are among the most common. A detailed example of how to construct a C&E Matrix is provided in section 5.3.

Table 1: Initial Test for Evaluation of Vendor Relationship (Jespersen and Skjott-Larsen, 2005)

Condition	Yes/No
Is there a continual, mutual exchange of information between key employees in the two companies?	
Can employees from different organisational levels speak freely with employees from the other organisation?	
Are the overall goals for a given project formulated totally and clearly communicated to participants from both organisations?	
Is there a constant exchange of both operational and financial data between the two organisations?	
Is forecast data exchanged at least twice a year?	
Is there a yearly evaluation of the total supply chain, with the goal of discussing present and future goals?	
Is there a shared process fro reporting and monitoring cooperation, which guarantees continuous feedback to both organisations, and the possibility of making adjustments?	
Are operational goals clearly articulated for both parties? Are these goals used to evaluate the success of the relationship for both parties?	
Is the necessary IT implemented to allow for catching and analysing data of key importance to the organisations?	
Does the company's overall culture support an open two-way communication with the selected vendors?	

4.3 Supply Chain Analysis

Before starting an improvement process one has to have a clear picture of the structure of the existing supply chain and the way it works. Consequently, a detailed analysis of the operations and processes constituting the supply chain is necessary. The Lean Six Sigma library includes such tools that support the adequate description, modelling, and evaluation of supply chains. This section discusses the issues regarding supply chain analysis and the modelling tools that are useful in assessing supply chain excellence.

4.3.1 Motivation and Goals

An accurate analysis of the supply chain serves several purposes and is more a continuous effort than a one time task. In today's fast changing business environment, although a supply chain partnership is intended for a longer duration, supply chains keep evolving and changing to accommodate best to the customers' needs. In the beginning, or when a specific supply chain is analysed for the first time, the result can be used as a starting point for improvement processes and a benchmark for further analyses. The initial analysis often helps to identify potentials and opportunities and may well be used for target-setting, e.g. for Kaizen events to measure the benefit a successful implementation has provided. On the other hand, supply chain analysis should evolve in parallel to the changes in the real world. In this way the associated performance measures keep track of the current state of the supply chain and may be used for monitoring and controlling the supply chain (Company A Lean Six Sigma Training, 2003).

In assessing supply chain performance, process modelling and performance measurement both play important roles. These two topics will be reviewed in the following sections.

It is important to remember to keep a holistic view of the supply chain while analyzing processes within it. This is important since costs of each member of the supply chain are not necessarily minimized even though each partner operates at his optimum given the constraints imposed by the supply chain partners. Consider an arrangement using vendor managed inventory (VMI). At the customer's side, the VMI implementation reduces costs resulting in a competitive price in the consumer market, which is followed by a gain in market share for the product. Despite this success in the marketplace, the supplier may not be able to recover the costs he has taken off the shoulders of his customer. Although some cost components decreased (i.e. order processing costs, costs of forecasting, etc.), these did not likely offset his increased inventory carrying costs. Although, the supply chain as a whole profited from the VMI implementation, one of the partners was worse off. Therefore, when analyzing supply chains one needs to maintain such a holistic view, but simultaneously find mechanisms to compensate those partners that do not profit directly from supply chain success (Surie and Wagner, 2005).

4.3.2 Process Modelling – Value Stream Mapping

The best way to trace a process is to follow the flow of materials and information. For example, a flow of goods is often initiated by a purchase order and followed by an invoice and payment. When analysing supply chains the materials and information flows need to be mapped from the point of origin to the final customer and probably all the way back, if returns threaten to have a significant impact. Special care needs to be taken at the link between functions, especially when these links bridge two companies.

An ideal tool for modelling processes is Lean Value Stream Mapping (VSM). Lean is an ideology centred on the continuous elimination of waste in a process to shorten lead times and increases process efficiency. The eight types of waste are overproduction, transport, motion, waiting, inventory, over-processing, rework, and underutilized people. VSM is the core tool of Lean defined as "the process of directly observing the flow of material and information, detailing the relationship between them visually, and envisioning a future state with much improved performance" (Company A Lean Six Sigma Training, 2003).

A VSM helps to visualize the entire product or process flow, not just a single piece of the process. This provides visibility to *see* the waste in the value stream for quick identification of improvement opportunities. It is often tempting to concentrate on a single piece of the process especially if evidence clearly suggests it the cause of inefficiencies. VSM, however, requires modelling of the entire process providing an overall view of how the processes flow together. This helps prevent sub-optimization and allows you to explain the mechanics and benefits of the project to any audience in the organization from the shop floor to high-level management.

There are four main steps in creating a VSM:

- Create the current state VSM to summarize the "as is" situation, gathering all the pertinent information into a centralized document.
- Identify waste in the Value Stream to find where the process breakdowns and disconnects in information/material flow are.
- Create the future state VSM defined by using Lean concepts such as 5s and SMED.
- Identify gaps between the current and future state VSM's to create an improvement plan defining projects and activities to achieve the future state (Company A Lean Six Sigma Training, 2007).

A current state VSM provides a visual representation of process, information, and material flows with which you can calculate the lead time and takt time for a product to move through the process. The Appendix provides a legend and detailed description of each of the symbols and their meanings.

4.3.3 Performance Measurement

After mapping the processes, it is important to monitor them to evaluate changes and to assess the performance. It is important to use metrics that are aligned with the supply chain strategy and that reflect important goals in the scope and within the influence of the organization responsible for the individual process under consideration (Surie and Wagner, 2005).

Performance metrics are also used to provide management information by which it can run its business. Performance metrics can have three basic functions:

- Informing – In this function, metrics are applied to support decision-making and to identify problem areas. Indicators can therefore be compared with standard or target values.
- Steering – Steering metrics guide those responsible for the process considered to accomplish the desired outcome.
- Controlling – Metrics are also well suited for the supervision of operations and processes.

The main disadvantage inherent to metrics is that they are only suited to describe quantitative facts. "Soft" facts, such as the motivation of personnel, are difficult to measure and likely neglected when metrics are introduced. It is important to stress that non-quantitative targets should be kept in mind when performing a process analysis (Surie and Wagner, 2005).

When using metrics for analysis, there a few key concerns. One is their correct interpretation. Appropriate measures with clear links connecting the metric to the underlying process must be found. Another concern is that the metric needs to be evaluated for how well it fits to the goals and partners of the supply chain. If there is no alignment between metrics and strategy, it may well happen that one partner pursues a conflicting goal or does not have sufficient power to influence it. The view on indicators might also be different considering the roles of the supplier and the customer. A supplier might want to calculate the order fill rate based on the order receipt date and the order ship date as these are the dates he can control. Whereas the customer would want to use the request date and the receipt date at the customer's warehouse. Both parties must agree on one perspective (Bolstorff and Rosenbaum, 2003).

Another noteworthy point is that data should be captured in a consistent way throughout the supply chain and between supply chains if comparing to other benchmarks. Failure to ensure consistent measurement standards may result in gross misinterpretation of performance and comparative effectiveness of one supply chain over the other.

Although each supply chain is unique and needs special treatment, some performance measures are applicable in most settings. These can be grouped into four categories: delivery performance, supply chain responsiveness, assets and inventories, and costs (Bolstorff and Rosenbaum, 2003). These metrics and their descriptions are conveniently summarized in a table in Appendix B meant to act as a "checklist" for vendor evaluation.

5: SUPPLY CHAIN ANALYSIS FOR VENDOR X: ON TIME DELIVERY IMPROVEMENT PROJECT

In the last six months of 2007, Company A averaged 37% on time delivery over its entire product line. This resulted in an estimated $100k in losses in 2007 due to overtime and expediting costs directly related to compensate for the late deliveries. This poor result was attributable to a sudden drop in on time delivery performance from its largest sheet metal component supplier, Vendor X. Company A launched a three-month project in early 2008 to improve Vendor X's on-time delivery to 95%. Lean Six Sigma and supply chain principles described in the preceding sections of this paper were used to construct a strategy and plan for improvement. This section of the paper will describe the improvement efforts for the "worst" supplier in terms of delivery performance and the results of that project.

5.1 Order Fulfilment Value Stream Map for Vendor X

Vendor X had the largest negative impact on Company A's operation in terms of delivery performance, so a project was launched to improve its delivery performance from 65% to 95%. A team consisting of members from both firms was formed to engage in a three-month project to achieve this goal. The Value Stream Map of Vendor X's order fulfilment process, shown in the following section, was created to identify sources for on time delivery improvement (the map has been split over several pages to facilitate readability).

A Lean Six Sigma group from Company A went to Vendor X to facilitate the meeting and gathered all the staff that is involved in the order fulfilment process. In Lean philosophy, it is very important to physically gather the team where the work you are studying is done. It is known as “going to Gemba”. It puts the team in the right mindset and allows them to observe the actual process if there are uncertainties or differences of opinion during the analysis.

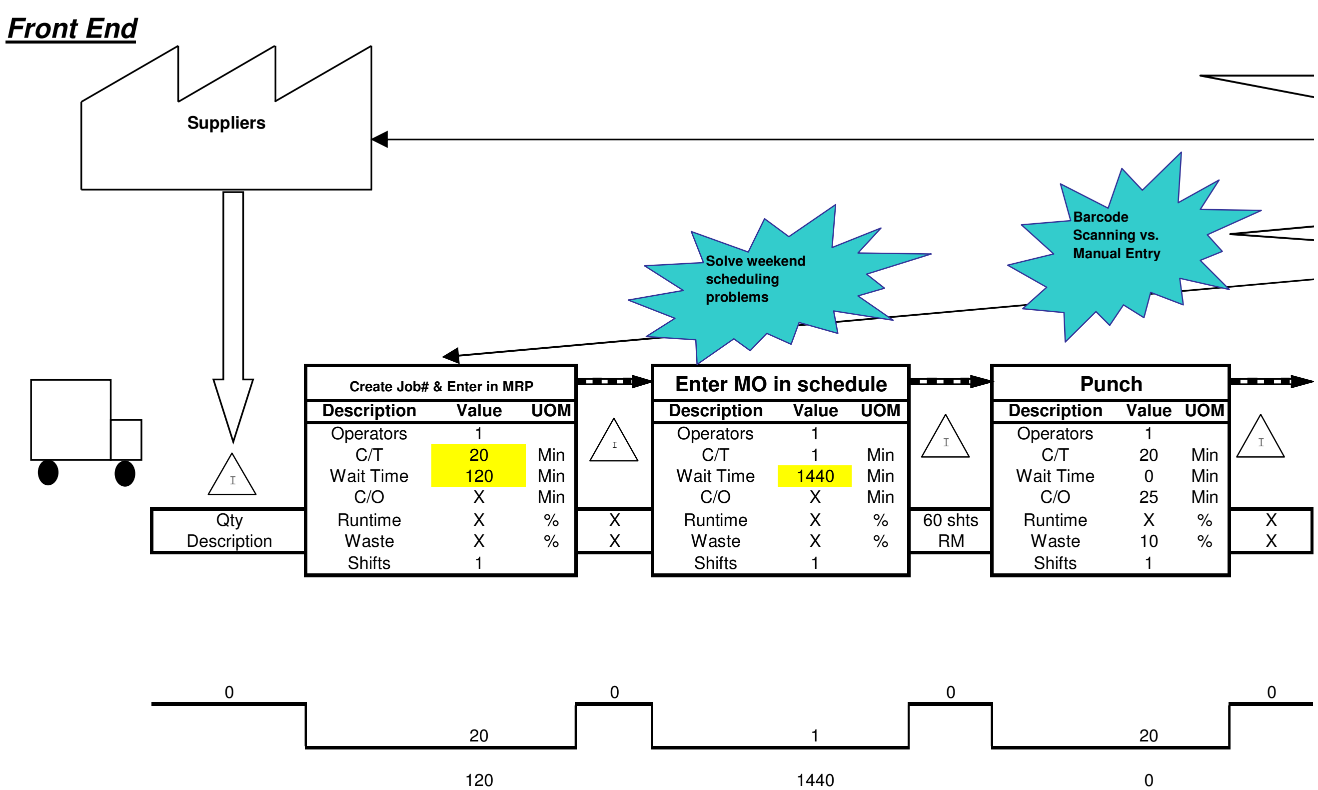
The first step was to create the current state VSM with everyone in the same room. The team identified the major steps in the process and put them in chronological order. The team was split into smaller groups (usually three people) and assigned a portion of the whole process to study in greater detail. Each group gathered the information in Table 2 for each step in their portion of the process. In this case, the runtimes and cycle times were almost identical for all the processes, so runtime was not included in this study. The current state VSM shown in section 5.2 (see Appendix A for a legend of the symbols in the VSM) was assembled with the information gathered by the smaller groups.

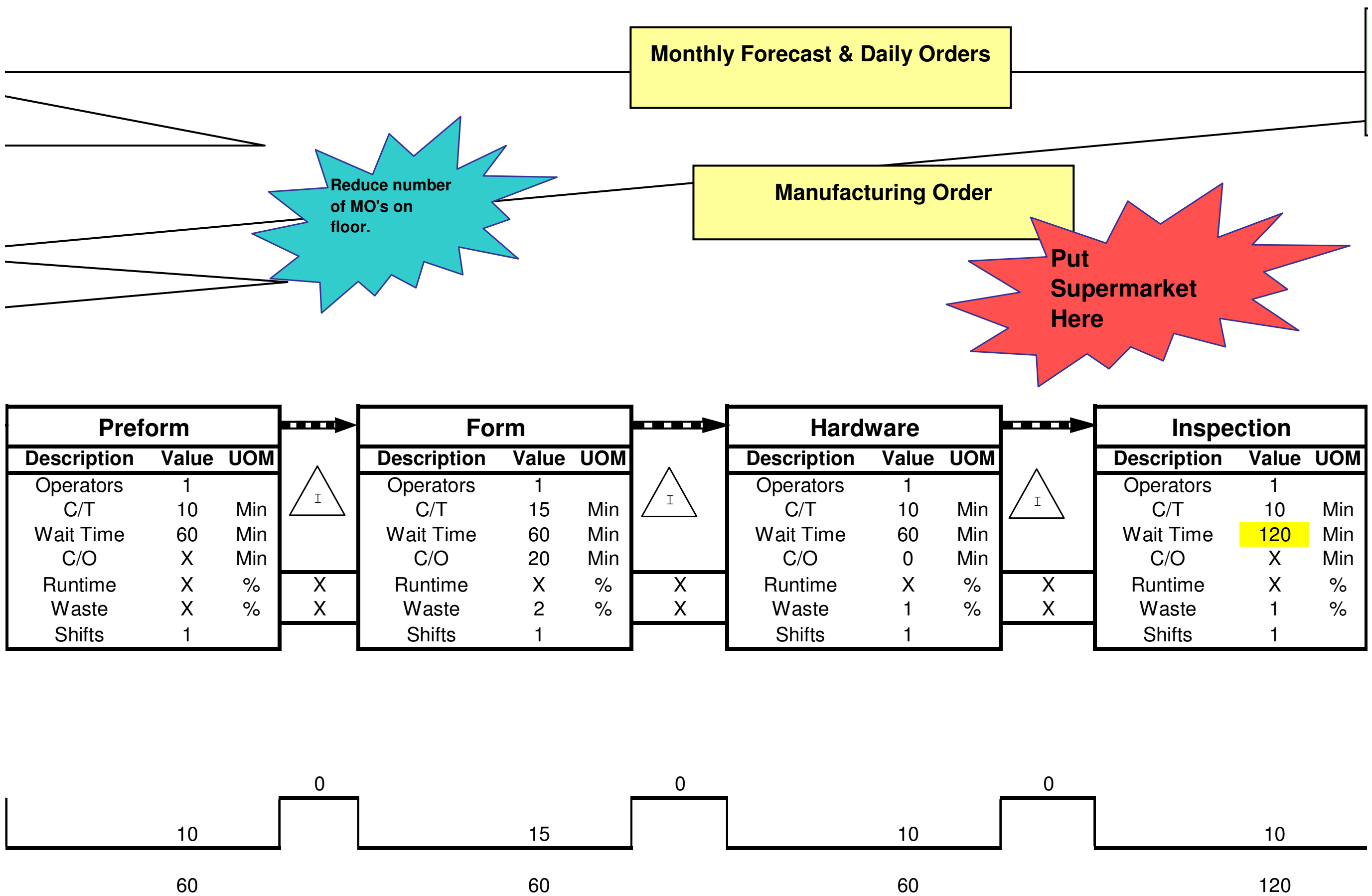
Table 2: VSM Required Information

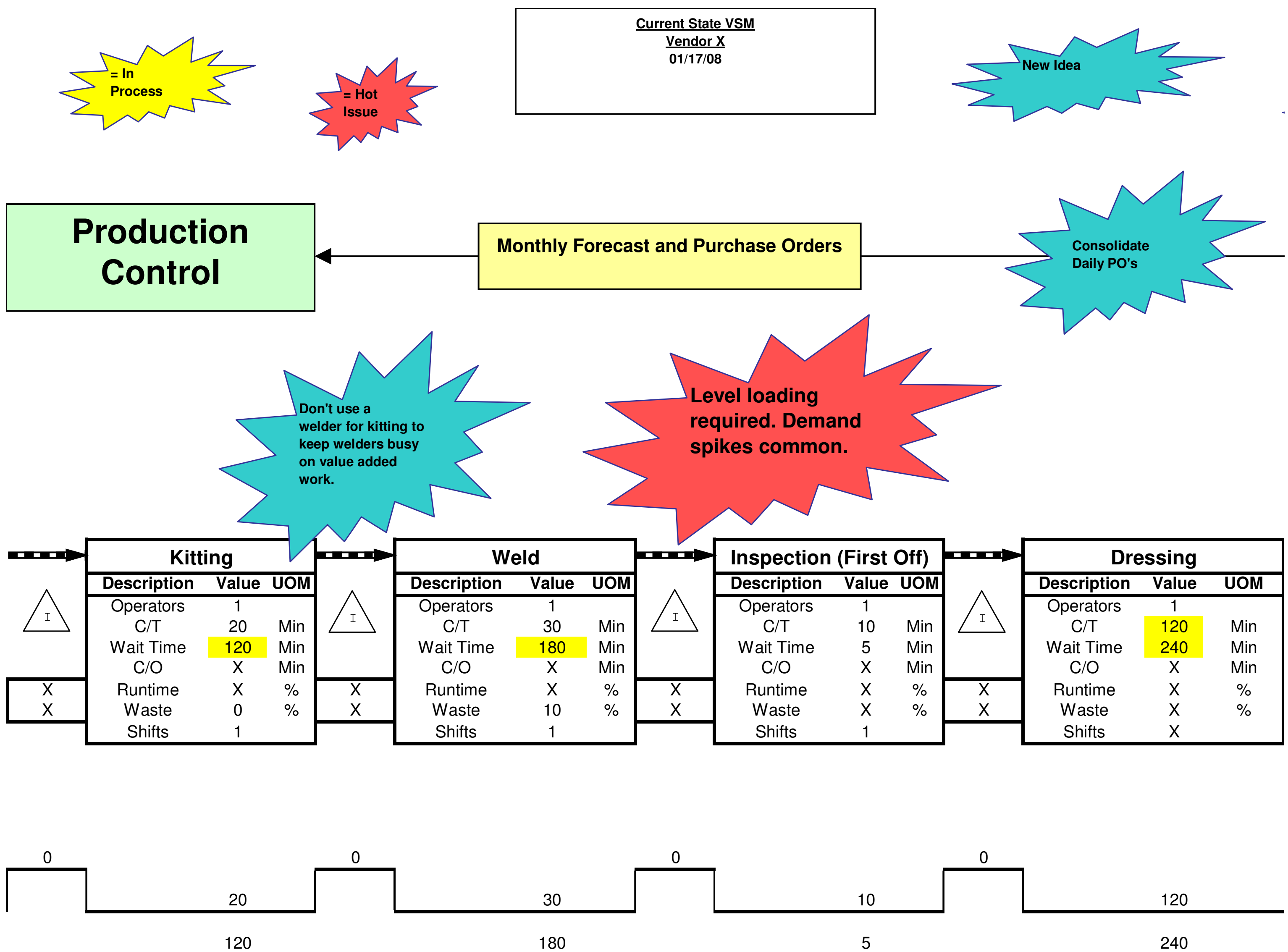
Type	Units	Value
number of operators	Count	
cycle time	Min	
wait time	Min	
change over time	Min	
runtime	Min	
number of shifts	Count	
amount of WIP and raw material inventory in front of the process	Count	

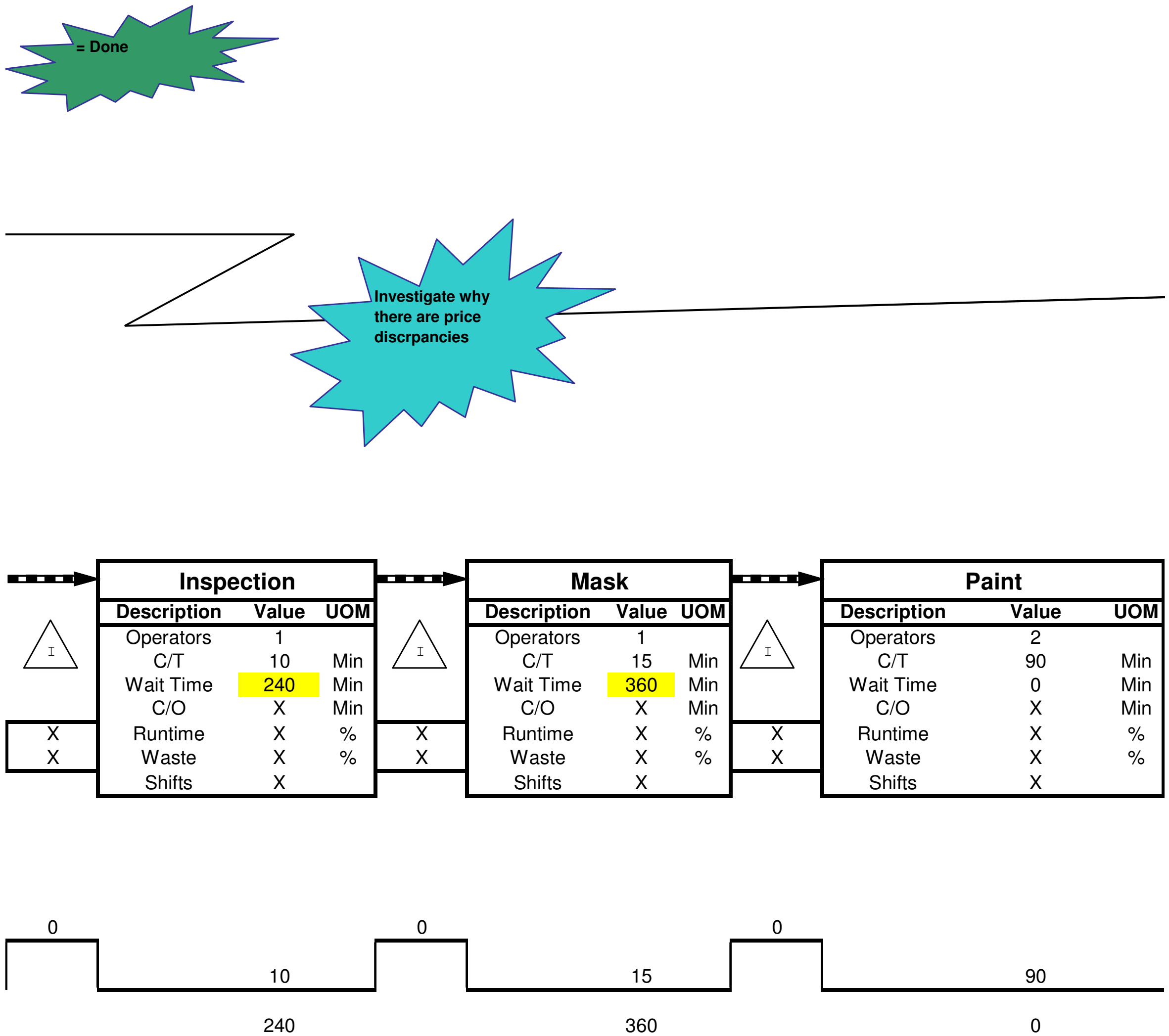
The cycle times and process times for all the processes were totalled. This can be seen in the bottom right hand corner of the VSM.

5.2 Value Stream Map




Monthly Forecast & Daily Orders
Manufacturing Order
Reduce number of MO's on floor.
Put Supermarket Here
Preform
Description Value UOM
Operators 1
C/T 10 Min
Wait Time 60 Min
C/O X Min
Runtime X %
Waste X %
Shifts 1
Form
Description Value UOM
Operators 1
C/T 15 Min
Wait Time 60 Min
C/O 20 Min
Runtime X %
Waste 2 %
Shifts 1
Hardware
Description Value UOM
Operators 1
C/T 10 Min
Wait Time 60 Min
C/O 0 Min
Runtime X %
Waste 1 %
Shifts 1
Inspection
Description Value UOM
Operators 1
C/T 10 Min
Wait Time 120 Min
C/O X Min
Runtime X %
Waste 1 %
Shifts 1
I
X
X
0
10
15
60
120


Current State VSM
Vendor X
01/17/08
= In Process
= Hot Issue
New Idea
Production Control
Monthly Forecast and Purchase Orders
Consolidate Daily PO's
Don't use a welder for kitting to keep welders busy on value added work.
Level loading required. Demand spikes common.
Kitting
Description Value UOM
Operators 1
C/T 20 Min
Wait Time 120 Min
C/O X Min
Runtime X %
Waste 0 %
Shifts 1
Weld
Description Value UOM
Operators 1
C/T 30 Min
Wait Time 180 Min
C/O X Min
Runtime X %
Waste 10 %
Shifts 1
Inspection (First Off)
Description Value UOM
Operators 1
C/T 10 Min
Wait Time 5 Min
C/O X Min
Runtime X %
Waste X %
Shifts 1
Dressing
Description Value UOM
Operators 1
C/T 120 Min
Wait Time 240 Min
C/O X Min
Runtime X %
Waste X %
Shifts X
I
X
X
0
20
30
10
120
120
180
5
240


= Done
Investigate why there are price discrpancies
Inspection
Description Value UOM
Operators 1
C/T 10 Min
Wait Time 240 Min
C/O X Min
Runtime X %
Waste X %
Shifts X
Mask
Description Value UOM
Operators 1
C/T 15 Min
Wait Time 360 Min
C/O X Min
Runtime X %
Waste X %
Shifts X
Paint
Description Value UOM
Operators 2
C/T 90 Min
Wait Time 0 Min
C/O X Min
Runtime X %
Waste X %
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15
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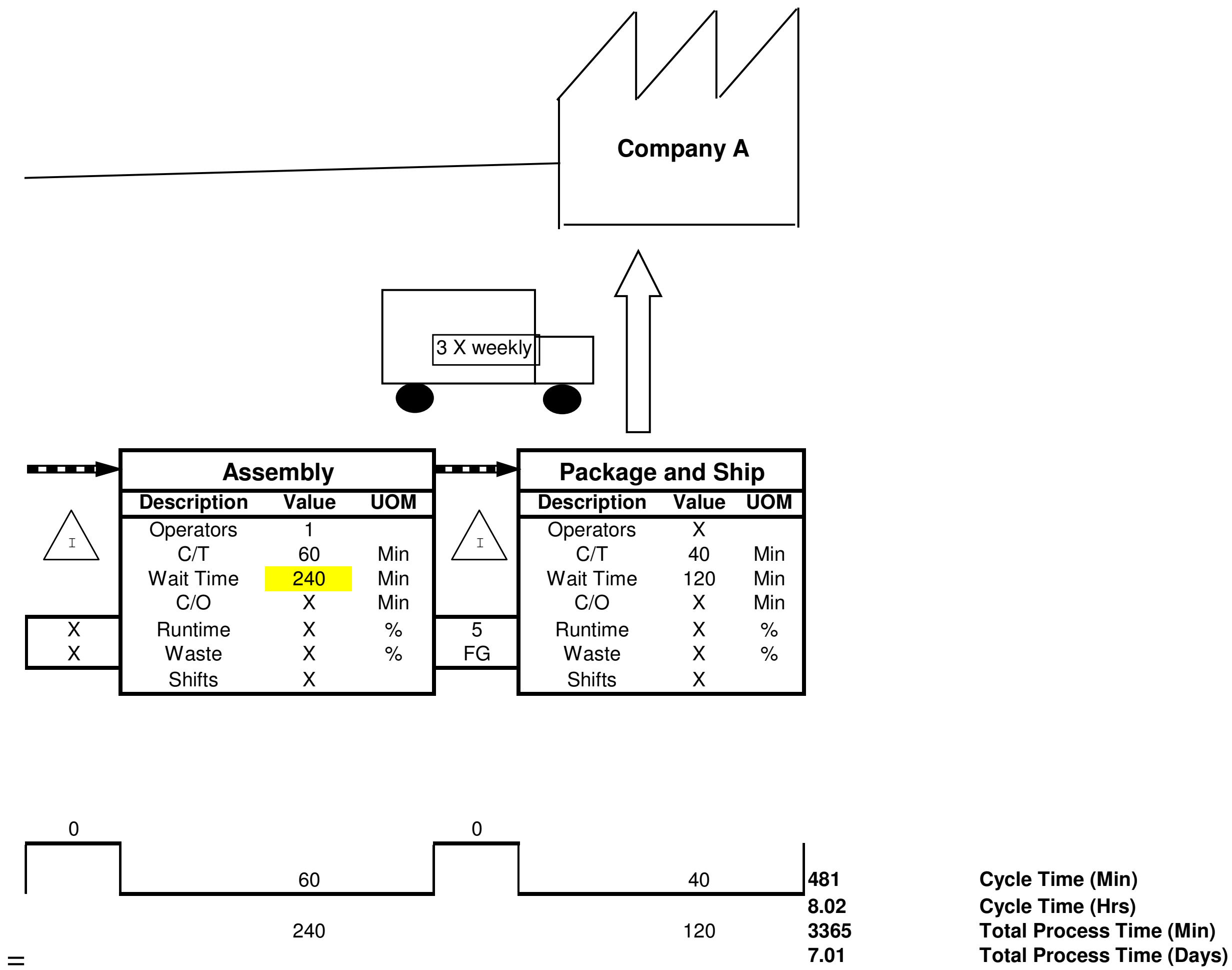

Company A
3 X weekly
Assembly
Description Value UOM
Operators 1
C/T 60 Min
Wait Time 240 Min
C/O X Min
Runtime X %
Waste X %
Shifts X
Package and Ship
Description Value UOM
Operators X
C/T 40 Min
Wait Time 120 Min
C/O X Min
Runtime X %
Waste X %
Shifts X
I
I
X
X
5
FG
0
0
60
40
240
120
481 Cycle Time (Min)
8.02 Cycle Time (Hrs)
3365 Total Process Time (Min)
7.01 Total Process Time (Days)

5.3 VSM Analysis

The main benefit of the VSM is that it helps make all the waste in the process visible and presents it in a standardized format that everyone can understand. Armed with the VSM, the team brainstormed ideas to remove the waste from the system. These ideas are known as “Kaizen Bursts” and are shown in the VSM as starbursts. In the VSM above, the project team identified eight kaizen bursts. The kaizen bursts were prioritized using the Cause and Effect (C&E) Matrix shown in Table 3.

The team agreed upon four dimensions that were important to Company A in this project. Delivery performance in terms of percent of deliveries on-time was the key dimension of this project, but cost, quality, and inventory could not be sacrificed to achieve delivery performance. The team rated these four dimensions on a scale from one to ten based on the importance to the customer and noted them on the top row if the C&E Matrix. Next, each kaizen burst was listed down the left hand column of the matrix. The team then assigned a value for each kaizen burst under each of the four dimensions. The value assigned was based on the amount of influence each burst had on that particular dimensions. The only permissible values for this portion of the exercise are 0, 1, 3, or 9. The purpose of this restriction is to force the team to decide which kaizen bursts have a strong influence as opposed to a moderate influence and makes it easier to prioritize actions in the next step. Finally, the customer importance ratings were multiplied by the influence ratings and summed for each kaizen burst. Once sorted in descending order, the team was presented with a priority list and strategy for taking action for process improvement.

Table 3: C&E Matrix

Rating of Importance to Customer	10	8	5	5	
Kaizen Burst	**Delivery Performance**	**Cost**	**Quality**	**Inventory**	**Total**
Put supermarket before kitting	9	1	3	9	158
Level workloads across operations	9	0	0	9	135
Weekend scheduling problem	9	0	0	1	95
Don't use welders for kitting	0	9	0	0	72
Investigate why there are price discrepancies	0	9	0	0	72
Barcode scanning vs. manual entry	3	3	0	0	54
Reduce number of MO's on floor	3	3	0	0	54
Consolidate daily PO's	3	1	0	0	38

The C&E Matrix exercise showed the establishment of a supermarket and levelling of workloads are the activities with the largest potential for reaching the project goal without having an adverse effect on any of the other dimensions that are important to the customer. This result was not surprising since examination of the VSM reveals that inventory is not stored anywhere in the process except at the very end as finished goods. The process step with the most inventory before it is usually the bottleneck of the process and is often the focus of improvement efforts.

Vendor X immediately started building WIP inventory before the kitting operation and reduced finished goods inventory. The team also decided to hold weekly meetings to review each late delivery from the previous week to review the root causes and track them to identify any other systemic problems. This also allowed management at both firms to keep visibility on the progress of the on time delivery improvements and provided a convenient forum for the firms to discuss issues openly and resolve them in a timely manner.

5.4 Results

Creation of the VSM quickly illuminated a large problem. The total lead time for an average part was eight days (cycle time + process time). Company A works on a Lean manufacturing system that requires a three-day lead-time on most items. Vendor X was mostly keeping up with this by using finished goods inventory for 85% of its products. Further discussions with Vendor X revealed that demand had been above planned capacity for the past six consecutive months as shown in Figure 1. As a result, finished goods inventory levels were almost at zero. Efforts to replenish finished goods inventory were stalled because production planning was seeing jobs take many days longer than anticipated.

The VSM highlights the fact that inventory was only kept at the finished goods level for most of Vendor X's product. This had two main negative consequences:

- The inventory held a very high value in its finished state, and therefore, tied up more money in inventory.
- Since the inventory was so far downstream in the process, planning had greater exposure to opportunities for delay in shipment because products had to successfully make it through the entire process all at once. Demand

spikes occurred and depleted safety stock levels leaving high risk of not meeting delivery times.

It quickly became evident that Vendor X had to put a supermarket buffer in place before the kitting operation to provide some safety stock to buffer from demand spikes. Vendor X already had a similar system in place for the remaining 15% of its products, so implementation was relatively straightforward.

This change also made it easier for Vendor X to plan production. The production scheduling department no longer has to worry about scheduling the punch, pre-from, form, and hardware operations. The supermarket was set up with predefined stock levels. Now, once a part in the supermarket falls below this pre-defined level, an automatic notification (kanban) is sent to the manufacturing floor to make a pre-defined quantity of this part for stock in the supermarket.

Now when Vendor X receives an order, it need only schedule the kitting, welding, dressing, masking, painting, and assembly operations. Notice that the lead time (cycle time + process time) for these operations is 32 hours. With two 8 hour shifts, this is a two-day lead time which is within Company A’s three-day requirement.

Results from the project were dramatic. Figure 4 shows the delivery performance of Vendor X in each week of the 12-week project and beyond. The formal start of the project (i.e. week 1) was six weeks after Vendor X began stocking the new supermarket. In those 6 weeks, delivery performance was consistent at 65%-70%. It can be seen in Figure 4 that in week two of the project (seven weeks after Vendor X began stocking its new supermarket), the supermarket was stocked to a level at which a significant improvement in delivery performance was seen feasible.

It is possible, however, that this marked improvement was partially a result of the fact that Vendor X was being watched more closely. By week six, Vendor X met its target of 95% on time delivery and managed to maintain this level of performance.

Figure 5 is a control chart graphing the on time delivery data for Vendor X for the 12 weeks of the project and the 6 weeks preceding it. The obvious upwards shift in the data on the upper graph of the control chart coincides with the implementation of the new supermarket. Notice also that the week-to-week variation of delivery performance decreased with the implementation of the new supermarket. This is shown by the tighter control limits on the lower graph of the control chart. Smaller variation on a process is a sign of better control.

Control Charts are a powerful tool used in Six Sigma to monitor process performance. When performance falls outside of the red control limits, it is an early warning sign that the process is beginning to fall out of control and management should take action immediately to bring it back within the control limits. This tool could be used to track delivery performance and give management at both firms early warning signs that the process is under stress, and action should be taken to alleviate that stress.

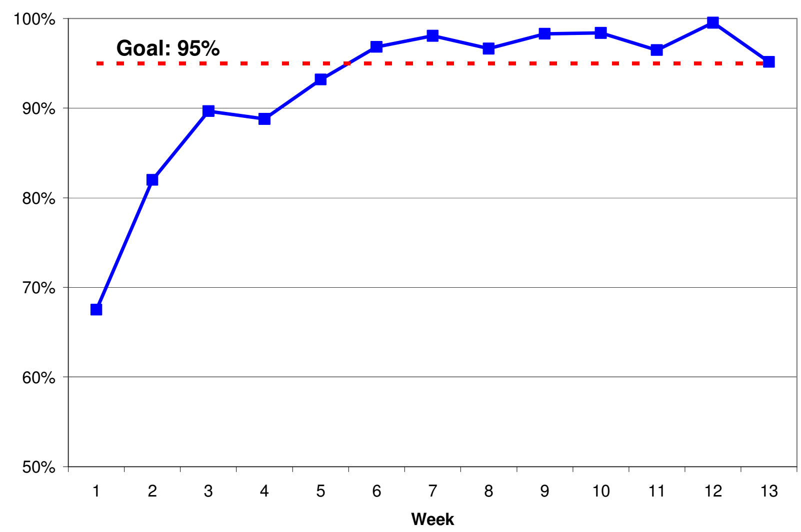


Figure 4: Vendor X Delivery Performance

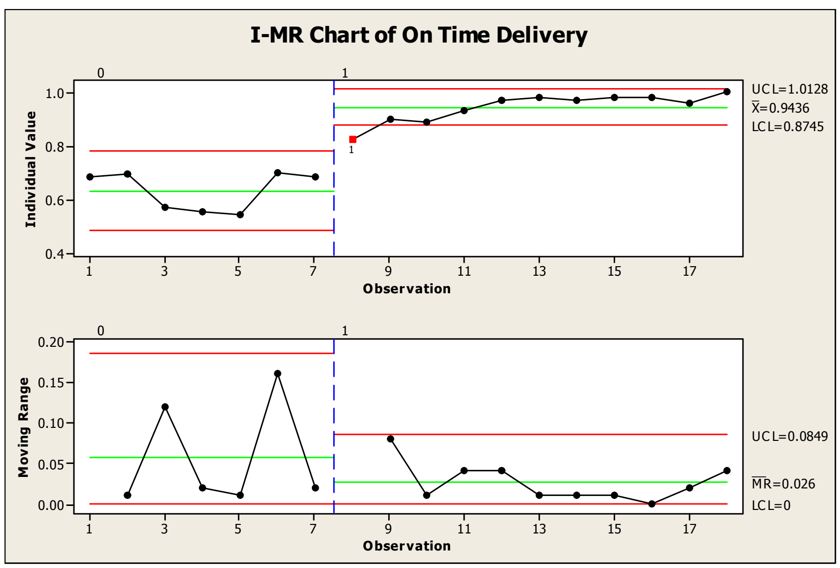


Figure 5: Control Chart for On Time Delivery

One of the main benefits of the application of Lean is that it makes the waste and problems in a process visible so management can work to solve them. Figure 6 shows the frequency of causes for late deliveries and breaks them down by week. In week-one, the second most common cause for late deliveries was ‘unknown’. By week-two, when the implementation of the kaizen improvements was almost complete, the ‘unknown’ causes were eliminated. In this project, the application of Lean made it easier to identify the root causes for the late deliveries.

The weekly status meetings surfaced other interesting information. Figure 7 shows similar data to Figure 6. However, Figure 7 shows which firm was responsible for the cause of the late delivery. At the outset of the project, it was suggested the trucking company delivering product from Vendor X to Company A was causing a significant portion of the late deliveries. The data in Figure 7 shows only four of the 150 causes for late delivery were attributable to the trucking company, proving the trucking company was not responsible for a significant portion of the late deliveries as originally suggested. Conversely, the data showed that 45 of the 150 causes for late delivery were actually caused by Company A. These causes were data entry errors, miscommunications, orders being released late, poor planning, and inaccurate forecasts. It was known that Company A was responsible for some of the instances of late delivery. However, it was surprising to see that Company A was responsible for nearly one third of the on time delivery lapses. Because of these unexpected findings, Company A launched a Lean study of its own internal processes for order entry and receiving.

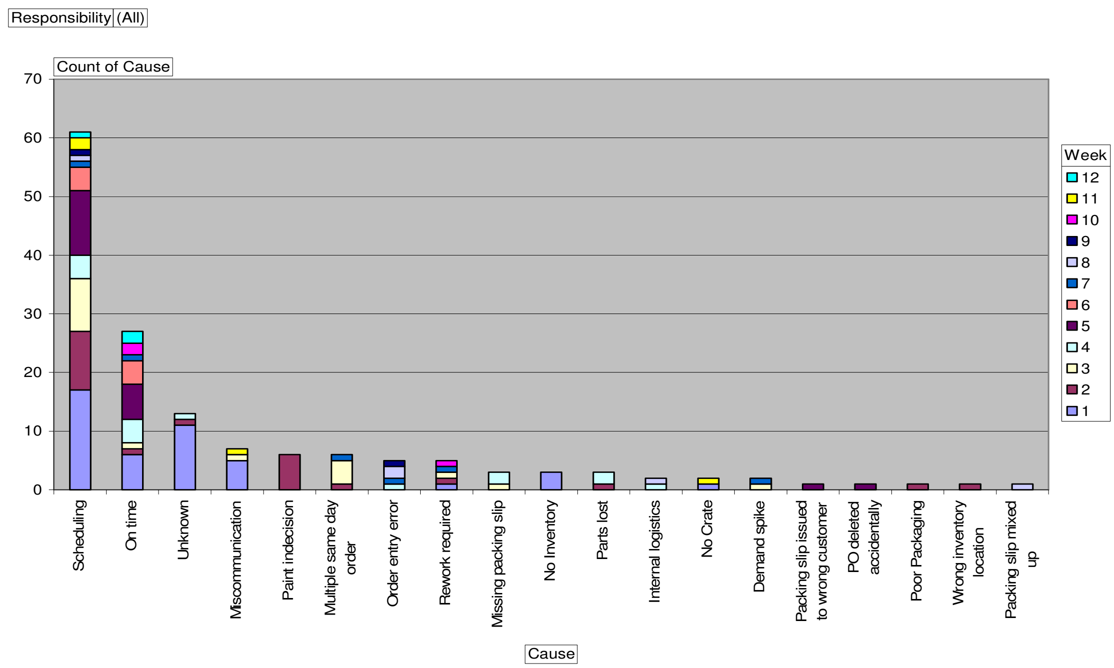


Figure 6: Causes for Late Deliveries Broken Down by Week

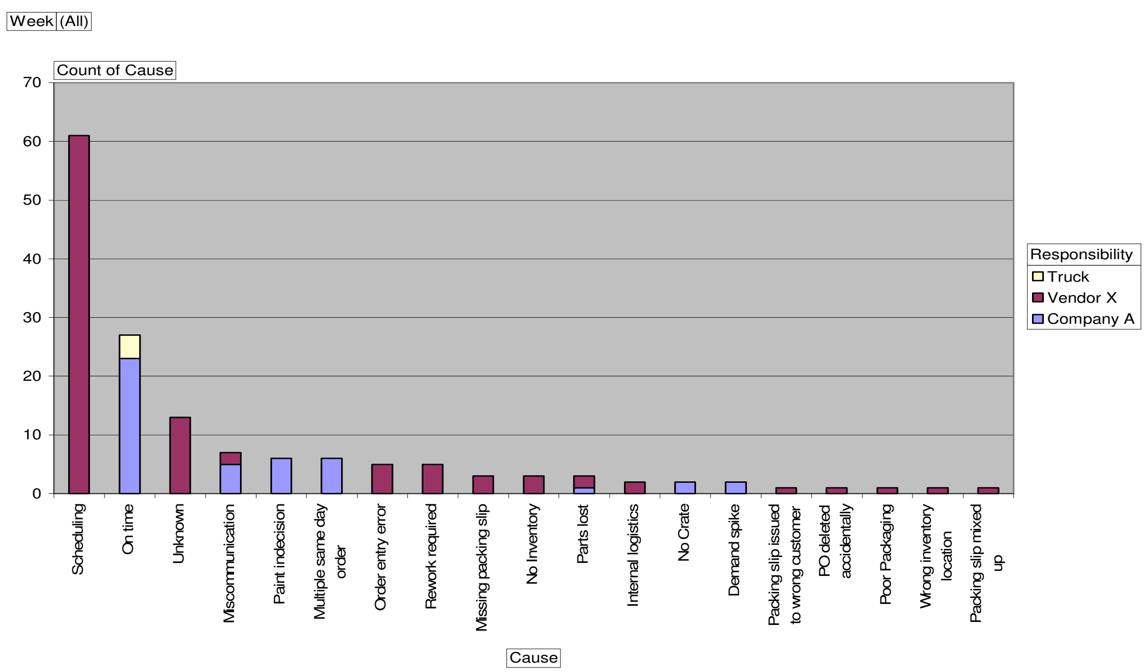


Figure 7: Causes for Late Deliveries Broken Down by Responsibility

6: CONCLUSIONS

The case study presented shows how proper application of Lean Six Sigma can aid the cooperation of two firms in a common goal. In this example, delivery performance improved from 65% to 95% in three months. The team produced a Lean VSM to make the inefficiencies more visible and to facilitate brainstorming of improvement activities. The main improvement activity identified was to remove finished goods inventory and create a WIP supermarket further upstream in the process. This had several benefits. First, it reduced the value of inventory held by the vendor because the inventory was held further upstream, freeing up valuable cash. Second, it made production planning easier because planning did not have to worry about scheduling processes upstream of the new supermarket. Third, it made the process less susceptible to demand spikes. As long as the new supermarket stays stocked, only the processes downstream of the supermarket, as opposed to the entire manufacturing process, pose a risk for delaying deliveries. These benefits proved to be enough to push the vendor's delivery performance to a sustainable 95%.

The team used Six Sigma control charts to track the weekly delivery performance and verify that statistically significant change in performance had actually occurred. The firms will continue to use the control charts as an early warning system to give management time to react if delivery performance should start to fall again.

Company A also led weekly status meetings to monitor progress of the project and encourage communication between the firms. Close tracking of the project also likely pushed Vendor X to deliver positive results because of the visibility to management. Data gathered from these meetings were helpful and surprising, showing that Company A was actually responsible for approximately one third of the late deliveries. These results prompted internal projects on improving order entry and receiving procedures.

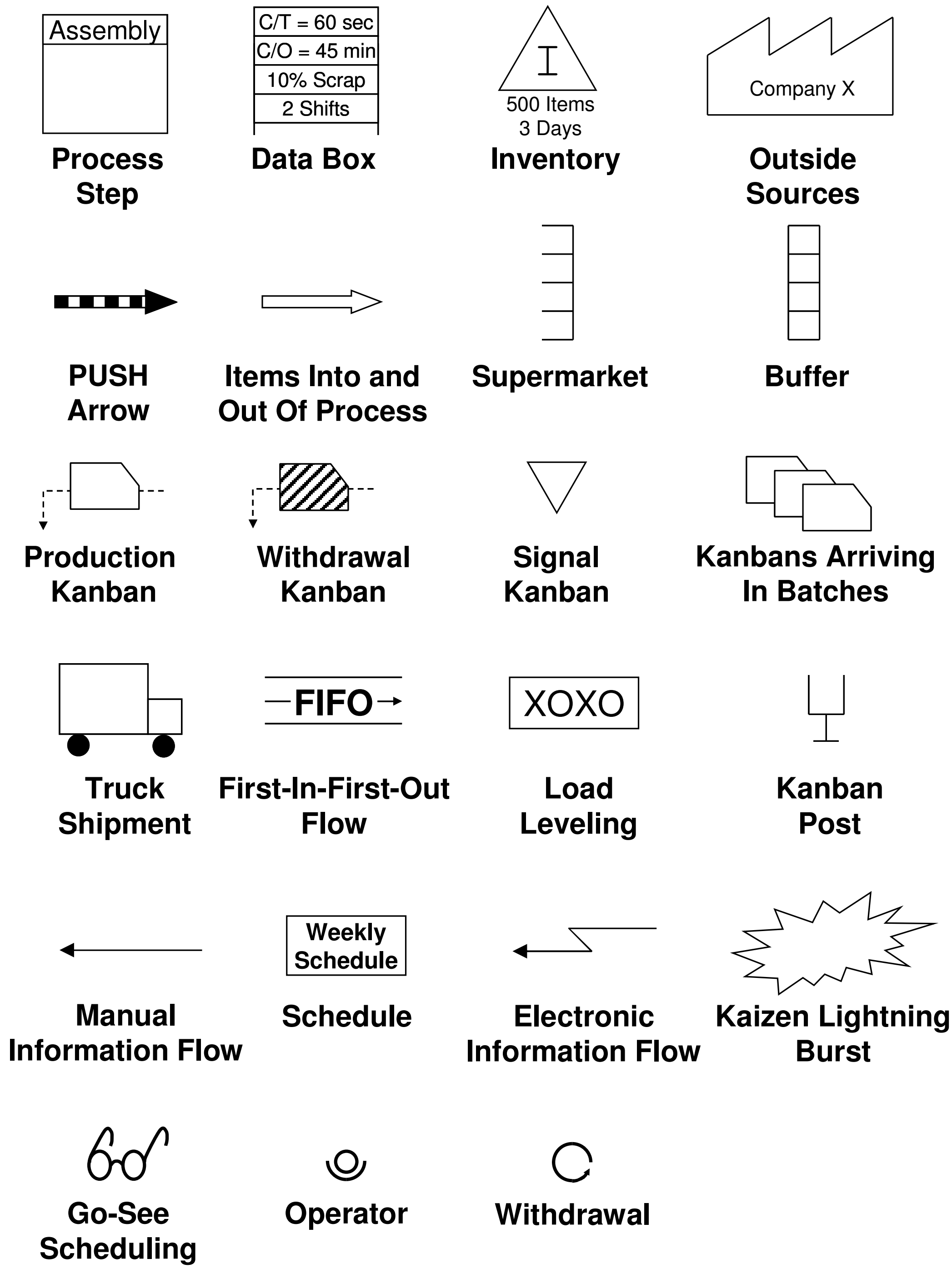
The weaknesses in delivery performance stem from the fact that Company A has significant market pressures to reduce cost, but maintain hundreds of configurations for its high value capital equipment. This forces Company A to run a very Lean supply chain demanding Just-in-Time inventory strategies and three-day lead times from its suppliers. Reducing the number of configurations and/or redesigning parts to make them universal would help alleviate this situation.

The literature supports that both Lean Six Sigma and supply chain control aim to create customer value and maintain the competitiveness of the supply chain. The literature shows strong parallels between these two methodologies suggesting that Lean Six Sigma tools are a good fit for monitoring, controlling, and improving supply chain operations. The two “pillars”, namely, integration and material flow, support the goal of customer value. Lean Six Sigma offers proven, structured, and data driven tools to help facilitate the building of these pillars.

Given these Lean Six Sigma tools, we need to delineate a set of metrics that accurately, fairly, and holistically describes the supply chain. The list of metrics provided in Appendix B proposes such a set of metrics. The paper also suggests criteria for determining if a supplier is a cooperative partner in growing a continuously improving supply chain.

Competent application of Lean Six Sigma tools in supply chain management gives valuable credibility to the firm, allowing the firm to lead confidently and align the strategies and goals of each member of the supply chain.

APPENDIX A


Assembly
Process Step
C/T = 60 sec
C/O = 45 min
10% Scrap
2 Shifts
Data Box
I
500 Items
3 Days
Inventory
Company X
Outside Sources
PUSH Arrow
Items Into and Out Of Process
Supermarket
Buffer
Production Kanban
Withdrawal Kanban
Signal Kanban
Kanbans Arriving In Batches
Truck Shipment
FIFO
First-In-First-Out Flow
XOXO
Load Leveling
Kanban Post
Manual Information Flow
Weekly Schedule
Schedule
Electronic Information Flow
Kaizen Lightning Burst
Go-See Scheduling
Operator
Withdrawal

- **Process Step**: one area of material flow, ideally continuous flow; most inventory should lie between rather than within the defined process steps
- **Data Box**: used to gold information about process steps on a value stream map
- **Inventory**: material held between process steps; use one inventory symbol for each physical storage location
- **Outside Sources**: customers of or suppliers to processes
- **Items Into and Out Of Process**: arrows to indicate the movement of material into or out of a process
- **Supermarket**: a buffer used between steps wherever continuous flow cannot be maintained; so named because the supermarket buffers behave just like supermarket shelves in which various items are stocked in the shelves and replaced when they are taken from the shelves by customers
- **Buffer**: traditional buffer that holds a block of material – generally desirable to replace a buffer with a supermarket
- **Production Kanban**: kanbans sent from a supermarket to an upstream step to request production of a defined amount material
- **Withdrawal Kanban**: kanbans sent to an upstream supermarket to release a defined amount of material to a downstream process step
- **Signal Kanban**: kanbans are used in large batch situations to trigger production once a set number of Withdrawal Kanbans are released

- **Kanbans Arriving in Batches**: used when multiple kanbans are sent simultaneously – often to set the daily schedule for the pacemaker step
- **Truck Shipment**: used to indicate a shipment by truck
- **First-In-First-Out**: in a FIFO buffer the total amount in the buffer is capped; items pass to the downstream process step in the order in which are placed into the buffer from the upstream step
- **Load Leveling**: releasing Kanbans to the Pacemaker gradually, not in a single batch; accomplished traditionally by slotting the day's Kanbans in a Load Leveling Box (Heijunka)
- **Kanban Post**: physical location where a Kanban is posted
- **Manual Information Flow**: passing of scheduling information through physical means
- **Electronic Information Flow**: passing of scheduling information through electronic means
- **Kaizen Lightning Burst**: used on a Current or Future State Value Stream Map to indicate improvements that must be made to achieve the Future State
- **Go-See Scheduling**: ad-hoc scheduling based upon perceived needs of the process
- **Operator**: individual involved in processing items in a value stream

- **Withdrawal**: used to indicate the pull of material, usually from a supermarket; often used when Kanbans are not utilized but pull is still occurring (e.g. pulling material from a Raw Materials supermarket at the start of a process)

APPENDIX B (BOLSTORFF AND ROSENBAUM, 2003)

Performance Attribute or Category	**Performance Metric**	**Definition**	**Benchmark Source**
Delivery Reliability Supply chain performance in delivering the correct product, to the correct place, at the correct time, in the correct condition and packaging, in the correct quantity, with the correct documentation, to the correct customer.	Delivery Performance	Delivery performance measures the percentage of orders delivered "on time and in full" to customer request date and/or to customer commit date	
	Fill Rates	Fill rates measures the percentage of ship from stock orders shipped within 24 hours of order receipt. Some companies use Line Item Fill Rates as an alternative metric measured by the percentage of lines filled within "committed to" hours of order receipt.	
	Perfect Order Fulfilment	Perfect order fulfilment measures the percentage of orders delivered "on time and in full" to customer's request date and flawless match of purchase order, invoice, and receipt.	
Supply Chain Responsiveness The velocity at which a supply chain provides products to the customer	Order Fulfilment Lead Time	Order fulfilment lead time measures the number of days from order receipt in customer services to the delivery receipt at the customer's dock. Originally intended only for "Make-to-Order Items", many firms broaden it to include stock and engineer-to-order items.	
Supply Chain Flexibility The agility of a supply chain in responding to	Supply Chain Response Time	Supply chain response time measures the number of days it takes a supply chain to respond to (plan, source, make, and deliver orders) an unplanned and significant	

marketplace changes to gain or maintain competitive advantage		increase or decrease in demand without cost penalty.	
	Production Flexibility	Production flexibility measures the number of days to achieve an unplanned 20% increase or decrease in orders without cost penalty.	
Supply Chain Costs The costs associated with the supply chain	Cost of Goods	Cost of Goods measures the direct cost of material and labour to produce a product or service.	
	Total Supply Chain Management Cost	Total supply chain management cost measures the direct and indirect costs to plan, source, and deliver products and services. Make costs are often captured in COGS while return costs are calculated in warranty/returns processing costs.	
	SG&A Cost	Sales, General, and Administration costs measures the indirect cost of sales, administration, engineering, and lab to support a product or service.	
	Warranty/Returns Processing Costs	Warranty/returns processing costs measures the direct and indirect costs associated with planned maintenance, and excess inventory. This includes entire reverse logistics process	
	Value-Added Employee Productivity	Value-Added Employee Productivity is an indicator which is calculated by dividing the difference between revenue and material cost by total employment (measured in full time equivalents of employees). Therefore, it analyses the value each employee adds to all products sold.	

Supply Chain Asset Management Efficiency The effectiveness of an organization in managing assets to support demand satisfaction. This includes the management of all assets: fixed and working capital.	Inventory Days of Supply	Inventory days of supply measures the number of days that cash is tied up in inventory.	
	Asset Turns	Asset turns is calculated by dividing revenue by total assets including both working capital and fixed assets.	

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