Improving Supply Chain Responsiveness for Diesel Engine Remanufacturing

by

Diego A. Méndez de la Luz

B.S. Mechanical and Electrical Engineering, ITESM, Monterrey, Mexico, 2002
M.Eng. Materials Science and Engineering, MIT, Cambridge, 2004

Submitted to the MIT Sloan School of Management and the Engineering Systems Division
in Partial Fulfillment of the Requirements for the Degrees of

Master of Business Administration
and
Master of Science in Engineering Systems

in conjunction with the
Leaders for Global Operations Program

at the
Massachusetts Institute of Technology

June 2011

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Signature of Author

Certified by

Thomas W. Eagar, Thesis Supervisor
Professor of Materials Engineering and Engineering Systems

Certified by

Stephen C. Graves, Thesis Supervisor
Abraham Siegel, Professor of Management

Certified by

Steven J. Speirs, Thesis Supervisor
Senior Lecturer, Massachusetts Institute of Technology

Accepted by

Nancy Leveson, Chair, Engineering Systems Division Education Committee
Professor, Aeronautics and Astronautics and Engineering Systems Division

Accepted by

Debbie Berechman, Executive Director of MBA Program
MIT Sloan School of Management
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Abstract

Achieving a significant reduction in order-to-shipment lead-time of remanufactured diesel engines can dramatically decrease the amount of finished goods inventory that Caterpillar needs to carry in order to meet its delivery commitments to Cat dealers around the globe.

This project was launched to devise ways to hold less finished goods by reducing the order-to-shipment lead time for diesel engines. To achieve this goal, a team was formed with representatives of all business units involved in the supply chain. Following the first three steps of a DMAIC methodology, the team used the following techniques and made the consequent findings:

(1) Define: using Value Stream Mapping, a first-ever value stream map of the supply chain was developed. This identified gaps and focused efforts on key areas.

(2) Measure: using statistical lead time analysis, a Montecarlo simulation was performed to estimate order-to-shipment lead times for the baseline and optimized scenarios of a build-to-order scheme. This identified an opportunity to reduce lead times by increasing parts inventory.

(3) Analyze: an inventory model was developed to quantify the economic implications of reducing lead time by increasing inventories. The results were compared to the savings of holding less finished goods to find out the best lead time reduction scenario.

Results show that holding inventories as spare parts to enable a build-to-order strategy is less costly than relying on a build-to-stock strategy, but there is a point of diminishing returns.

Our research has shown that having all business units collaborate in the process of overhauling the supply chain is key when looking for results that are optimal for the enterprise as a whole. It has also been observed that, if left unattended, a supply chain can be shaped by decisions that, at best, manage to achieve only local optima. In the worst case, the whole supply chain may evolve into a system that has little to do with the company’s strategic goals. These observations highlight the need, and support the recommendation, to have a “process owner” who is responsible for coordinating efforts across the supply chain.

Thesis Supervisor: Thomas W. Eagar
Title: Professor of Materials Engineering and Engineering Systems

Thesis Supervisor: Stephen C. Graves
Title: Abraham Siegel Professor of Management

Thesis Supervisor: Steven J. Spear
Title: Senior Lecturer, Massachusetts Institute of Technology
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Acknowledgments

The author wishes to thank the Leaders for Global Operations Program for its support of this work. Being a part of the LGO class of 2011 is without a doubt one of the greatest honors in my career.

This research could not have been carried out without the generosity of Caterpillar, Inc. and the Remanufacturing and Components Division, who offered access to its facilities, processes and personnel and were willing to take the challenge of tackling a complex problem in collaboration with the MIT Leaders for Global Operations Program.

Kenneth J. Hoefling provided the vision that initiated this effort. Roger D. Baker, our Company Sponsor, assembled a cross-divisional team that made possible the search for an enterprise-wide optimization. Nolan W. Wartick, Company Supervisor, provided guidance, valuable insights and, most importantly, an avid appetite for learning and creative thinking.

Because this research was conducted as a team, it is only fair to recognize the team members: Nolan Wartick, Chad Goodman, Joel Moser, Gary Bear, Chris Dunn, David Barker, Marty Lyons, and Chad Vonk.

The author also wishes to thank his thesis supervisors: Thomas W. Eagar, Stephen C. Graves and Steven J. Spear, three experts with outstanding professional achievements, and with one characteristic that made them an extraordinary resource to this and many other projects: the willingness to share their knowledge and to mentor students.

This section would not be complete without thanking two MIT Sloan alums that opened the doors of Caterpillar to LGO and to me as the first LGO intern to do research at that company: Tana Utley and Daniel Shockley.

Last, and most importantly, I thank my family, who have always supported me and motivated me to pursue the things I am passionate about. Especially, I thank my wife and partner of a lifetime, Iliana, for her commitment to the journey we started together so long ago.
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Chapter 1. Introduction

In May, 2010, when the economy first started giving signs of recovery, demand for remanufactured engines rose and caught Caterpillar with a supply chain that had been optimized for slow sales and was not able to ramp up production fast enough. Inventories, both at Caterpillar and at its suppliers, had been cut down, workforce had been adjusted, and demand quickly became overwhelming.

In 2009, two products – out of several thousands of orders – missed their on-time delivery commitments, and by May 2010, five more products were added to that count; all of them were remanufactured engines belonging to the Product Family studied on this thesis\(^1\). These incidents quickly received the attention of senior management and a project was launched to guarantee the supply chain for remanufactured engines was optimized.

A team including representatives from all business units involved in the Supply Chain\(^2\) was tasked with finding ways to add robustness and responsiveness to that value stream. This thesis gathers some of the key learnings that were extracted from the research performed by the team.

To understand the context of this project, Chapter 2 provides some background information about Caterpillar, the Remanufacturing and Components Division and about the Product, including a brief description of the current state of the value stream in question, focusing on explaining the challenges that are unique to this closed-loop supply chain.

Because taking a team-based approach was instrumental to this project’s success, Chapter 3 highlights the relevance of involving representatives of all business units involved in the Supply Chain as means of fostering success on a complex system that involves several divisions in the company, each with its own goals and reporting structures.

\(^1\) This thesis deals with one specific product family within the Cat Reman engine lineup. The name of such product line is not mentioned in this document for confidentiality reasons. The specific product family is referred to as “the Product Family” or as “the Product” on this document.

\(^2\) The supply chain that produces “the Product” is referred to as “the Supply Chain” on this thesis.
Chapter 4 creates a “burning platform”, by highlighting the relevance of the problem in question and the motivation behind the launch of this project.

The next three chapters describe the first three stages of the DMAIC (Define, Measure, Analyze, Improve, Control) methodology that was followed for this project. Chapter 5 explains the first phase of the project. It proposes the use of Value Stream Mapping as a tool that can provide a level ground for all members in the optimization effort and can help identify problem areas, define boundaries and focus efforts. Chapter 6 uses statistical analysis of lead times and presents the results of Montecarlo simulations to estimate total lead times from information collected in each step in the order-to-shipment process. It proposes the possibility of reducing lead times by increasing the amount of parts that are held in stock, but also acknowledges the need for economic analysis to assess viability. Chapter 7 describes the efforts to estimate the cost of increasing parts inventories, as well as the effect of the corresponding decrease in finished goods inventory. A conclusion is found by balancing these two factors.

Finally, Chapter 8 offers the conclusions of the first three stages in this on-going project, highlighting the possibility to optimize a supply chain by involving representatives from all business units who can then focus on finding solutions that are optimal on an enterprise-wide scale. It recommends the existence of a “process owner” who can be in charge of coordinating efforts to avoid the inefficiency of local optimization.

Because this project is an on-going effort at Caterpillar Remanufacturing and Components Division, the final results of its implementation are not available to be included in this thesis; however, the results to date allow us to distill relevant insights that can be generalized to other divisions at Caterpillar and are applicable to other industries.
Chapter 2. Caterpillar Remanufactured Diesel Engines

To understand the context of this project, we need to review some basic information about the company, the business unit (division) and the specific product we are dealing with. In the following pages, the author will provide a brief sketch of Caterpillar Inc., the Remanufacturing and Components Division and of the Product Family. For this, the author will focus only on those details that are most relevant to this project, knowing that abundant information can be found about other aspects of these entities.

2.1 Caterpillar

“For more than 85 years, Caterpillar Inc. has been making sustainable progress possible and driving positive change on every continent. With 2010 sales and revenues of $42.588 billion, Caterpillar is the world’s leading manufacturer of construction and mining equipment, diesel and natural gas engines, industrial gas turbines and diesel-electric locomotives. The company also is a leading services provider through Caterpillar Financial Services, Caterpillar Remanufacturing Services, Caterpillar Logistics Services and Progress Rail Services. More information is available at: http://www.caterpillar.com.”

(Caterpillar Inc., 2011)

Originally well-known for its agricultural products, Caterpillar now focuses on the construction and mining industry.

2.1.1 Current Context

During 2010, Caterpillar had revenues of $42.58 billion and employed 104,000 people worldwide. 28% of Caterpillar’s revenue in 2010 came from engine sales3, with the remainder coming from machinery sales (Caterpillar Inc., 2010). These numbers reflect a growth of 31% in revenues against 2009, but are still well below 2008 results, which amounted to over 51 billion (Caterpillar Inc., 2008).

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3 Does not include internal engine transfers of $2,523 million, which brings this figure up to 34%
For more information about the current context see Appendix 1 Current context: New CEO, new corporate strategy, and Appendix 2 Current context: The Caterpillar Production System.

In 2010, most of Caterpillar’s growth came from developing economies as well as from improved economies in North America and Europe, as well as a strong demand for mining products. As an example, engine sales in Latin America increased by $485 million (up 45%) with respect to 2009. (Caterpillar Inc., 2010)

2.2 Remanufacturing

The term “remanufacturing” was first formally defined by Robert T. Lund as “an industrial process in which worn-out products are restored to like-new condition by employing old and new parts.” (Lund, 1984). This processing can be done in several ways, but one key distinction between different remanufacturing options comes from the fact that individual parts may either keep or lose their identity, and may therefore be re-incorporated into a different product than the one they originally came from.

One key distinction between different remanufacturing processes comes from the conservation of individual component identity through the process. In some cases, remanufactured components are tracked to guarantee they are re-assembled together into the same unit. In other cases, components lose their identity after being disassembled and become part of a pool of available components, so when they are used to build new products there is no possibility of telling where each part originally came from. In the case of Caterpillar, the most common practice is for components to lose their identity after disassembly⁴.

2.2.1 Remanufacture vs. Repair vs. Rebuild vs. Refurbish vs. Recycle

To understand the specific challenges that a remanufacturing supply chain faces, it is important to point out the differences between remanufacturing and other processes that are normally associated to it.

⁴ There are some exceptions to this practice: some components need to be keep together to guarantee adequate physical fit to reassembly.
Remanufacturing is considered to be different than Repairing. The former term involves a complete tear-down of a system and the individual assessment of the state of each component (or assembly), followed by a process that restores its properties to a same-as-new condition. Repair, on the other hand, focuses on fixing a failed or worn out component (corrective or preventive maintenance), while ignoring the rest of the system or device. Simply put, a repair operation only fixes what is evidently broken, while remanufacturing can add value by guaranteeing that all components in a system are in good shape to withstand the same challenges as a new device.

Remanufacturing is different from Refurbishing. The latter expression is normally used almost exclusively for electronic products and normally involves goods which have been damaged (aesthetically or minor functional defects) and are brought up to same-as-new specifications. Refurbishing normally deals with almost-new products (barely or never used) that cannot be legally marketed as new products and are therefore sold at a discount, even though their characteristics may be the same as those of a new product. In a nutshell, remanufacturing uses end-of-life goods as inputs, while refurbishing normally focuses on new or almost-new products (mostly electronics).

Remanufacturing is not the same as Rebuilding. The second term implies taking the elements of a system and putting them together without necessarily improving their condition. In the world of internal combustion engines, the term rebuilding is normally used as a synonym for overhauling, and implies a partial tear-down of an engine, followed by the cleaning of some parts and the replacement of others (worn-out or damaged) and the eventual re-assembly of the system. Engine rebuilds or overhauls are normally performed by trained professionals at an independent repair shop or an original equipment dealer, while remanufacturing is normally performed and guaranteed by the original equipment manufacturer.

Remanufacturing should be distinguished from Recycling. The reason for this is that remanufacturing does not necessarily involve transforming end-of-life materials into raw materials for an industrious process. Although recycling can be understood as simply making a material available for a
new use (without loss of previously added value), it often involves the separation and classification of the different materials in a product, followed by steps that recondition those distinct materials in a way that makes them suitable for use as inputs to another productive process. These reconditioning processes normally strip materials of all previously added value. Remanufacturing, on the other hand, normally tries to conserve as much value as possible from the components of a system and discards only those parts that cannot be brought back to same-as-new conditions (with a reasonable investment). While some by-products of a remanufacturing operation can be recycled, the main intention of remanufacturing is to conserve added value, not to strip materials from it.

It should now be clear that remanufacturing is an industrial activity that is different than other processes that take part in closed-loop supply chains. More information about remanufacturing at Caterpillar will be included in the following sections.

2.2.2 Remanufacturing at Caterpillar

At Caterpillar, remanufacturing is defined as “the process of returning a product at the end of its life to same as "new" condition in a manufacturing environment” (Caterpillar Inc., 2011). This process operates as a one-for-one exchange in which the customer receives a remanufactured product and is entitled to return an end-of-life product in exchange for a deposit. It must be noted that according to this business model, products that return in end-of-life condition do not necessarily return to their previous owner once they have been remanufactured. This is the reason why at Caterpillar, once a component has been disassembled, all parts lose their identity and are classified and either discarded or processed to be considered available for final assembly. This is different from the way other industries and companies do it, since in many cases preserving component identity is not only required by customers, but may even be mandated by laws or regulations (Duncan, 2011) (Duncan, 2011).

The following are the basic steps in the remanufacturing process at Caterpillar:

- **Inspection**: products are inspected to assess their condition and to define the adequate amount to be reimbursed.
- **Disassembly**: products are completely disassembled into their constituent parts, down to the level of every individual nut and bolt. The parts are cleaned and then inspected for remanufacturability.

- **Remanufacturing technology**: individual parts are remanufactured to same-as-new condition.

- **Engineering updates and assembly**: all appropriate engineering updates are included. Remanufactured components are assembled from the finished remanufactured parts.

- **Test and paint**: components are tested, painted and made ready for sale as a Cat Reman product.

### 2.2.2.1 Remanufacturing and Components Division

In 2010, two divisions merged to form the Remanufacturing and Components Division at Caterpillar Inc. Cat Reman, as this division is commonly referred to, supplies remanufactured parts to Cat dealers all around the world through Caterpillar Logistics Services, Caterpillar’s customer-facing organization.

Cat Reman supports many products in the Cat® product line. It supports new products and it also provides support for products that have been a part of Caterpillar’s portfolio for decades; in some cases, it even supports products that are no longer made new.

Currently, Cat Reman has 18 facilities worldwide.

### 2.3 The Product

#### 2.3.1 Cat Reman Product Line

Remanufacturing at Caterpillar began in the 1970’s, when the company started producing remanufactured diesel engines for on-highway applications. In recent years, Caterpillar’s line of remanufactured products has expanded significantly, driven by two forces: (1) the growth of Caterpillar’s product offering, including those products marketed by other Caterpillar-owned brands, and (2) the ever increasing demand from customers who wish to reduce the total cost of ownership of their machinery and equipment.
Today, Cat Reman offers more than 700 different products, and sells more than 6000 different part numbers. Some examples of their product line are engines, hydraulics, drivetrain (transmissions and final drives), fuel systems and even tires.

Caterpillar produces machines that are used in industries that are capital-intensive. Many of Caterpillar’s clients have large fleets of trucks and machines and require to be guaranteed support when they need it. One of the ways Caterpillar does this is by providing training and know-how to Cat dealers around the world, which then provide support services to end users.

Cat dealers are able to perform some repairs at their shops, and for those repairs they normally require Caterpillar products. Additionally, some products are sometimes too complex or too expensive to be repaired locally, so Cat dealers rely on Caterpillar to perform remanufacturing operations that can provide low-cost alternatives for their customers.

Some key aspects of this Product Family\(^5\) are: (1) high value, when compared to other Cat® parts and components, (2) high complexity, because a single engine has hundreds of distinct components (part numbers) that go into them at assembly level\(^6\), and even thousands of components if one considers those elements of which more than one is required in an engine’s bill of materials (BOM); and finally (3) high weight, because these machines are mostly made of steel and cannot be broken down for shipping without compromising their integrity, which normally imposes constraints on transportation and makes that process relatively expensive – especially for air freight –.

\(^5\) Throughout this thesis, the author refers to “the Product Family” as the engine line that this project was based on. This Product Family involves a very specific type of engine in the Cat Reman lineup, not all engines made by Cat Reman.

\(^6\) Assembly level means the point at which the engine is put together in the final assembly line. In that context, a water pump, to give an example, is considered a single component, although it may actually consist of hundreds of individual parts.
2.4 The Supply Chain: Current State

- **Suppliers**: independently owned, they provide new parts to the Assembly Plant upon request. They have pre-negotiated prices and lead times for their products. They also provide new parts for the assembly of new engines at the Assembly Plant.

- **Final Assembly**: is done by the Assembly Plant, which is owned by another Caterpillar division. This plant mainly does the final assembly of new diesel engines that go into new machinery. It does its own parts procurement and places orders for new parts on suppliers. The remanufacturing operation is a small fraction of their production.

- **Distribution**: is done by Caterpillar Logistics Services, another Division of Caterpillar. They are the customer-facing organization that acts as an intermediary between Cat dealers and manufacturing plants. All transportation is coordinated by CLS.

- **Cat dealers**: independently owned, they order parts and equipment from CLS and sell directly to the customer. They provide support services to their clients, many times offering other exchange options besides the sale of remanufactured products (such as repair operations, overhauling, etc). This means that end-of-life engines do not necessarily return to Caterpillar, since Cat dealers can decide to repair those engines and sell them back to customers.

- **End users**: interact only with Cat dealers. End users require support options that extend the life of their assets while reducing the total cost of ownership. Reman products cost a
fraction of the price of new products\textsuperscript{7} and offer the same performance and guarantee as a new component.

- **Salvage**: is performed by Cat Reman, but is done at a facility that does not report to the general manager in charge of the Product. Cores are received from Cat dealers all over the world and are processed to obtain remanufactured parts, which are then sent to the Assembly Plant to be incorporated into engines.

### 2.4.1 Inherent Challenges

Closed-loop supply chains normally have more complex structures than their open-loop counterparts. In many cases the former are subject to constraints and uncertainty that limit their ability to perform in a robust and responsive way, or that simply impose high tolls on success. Some of the challenges that the Supply Chain faces are:

- **Reverse logistics**: for products coming back in end-of-life condition. Requires CLS to devise transportation strategies for this segment in the value cycle.

- **Variability in “core” quantity and quality**: because the exact amount of end-of-life engines that will be available for remanufacture cannot be known ahead of time, and because the physical state of those engines is also uncertain, there is a need to carry enough safety stock of new parts to make up for those use parts that may not find their way to the assembly line when they are needed.

- **Product mix**: because Cat Reman supports more than 50 different engine arrangements, some of which are very slow moving and/or have been discontinued as new products.

- **Highly complex products**: engines are intrinsically complex because of the amount and variety of systems they include.

\textsuperscript{7} This is including the core deposit, which is paid back to customers once they return their “cores”. Originally, the cost of a remanufactured component is comparable to that of a new product, which offers a significant incentive for customers to return cores back to Caterpillar.
• **Part stocking decisions:** are complex when there are so many sources of uncertainty that can drive up safety inventories, but even more so when it is necessary to figure out appropriate inventory policies for both new and remanufactured parts.

• **Cross-divisional interaction:** because the only link on the supply chain (see Figure 1) that is operated by Cat Reman is the salvage operation, and even that facility is run by a different organization within Reman.

• **Final assembly:** since this operation is performed by a plant that belongs to a different division, but has to run the remanufacturing assembly line, which adds a lot of stress to the operation and only contributes with a (very) small fraction of their revenues.

All the above reasons make the Supply Chain a complex problem, but also one that has a lot of potential for improvement. The most positive aspect of this complexity is that it can offer significant opportunities to devise solutions that may be applicable to other product families both new and remanufactured.
Chapter 3. A Team-based Approach to Supply Chain Optimization

A project that cuts across several organizations can increase its chances of success if it has support from all the key decision makers. This is especially true when the people involved in the decision-making process are not in the same reporting line, but actually belong to different organizations, with very different objectives and reporting structures.

Several people in the management team responsible for launching this project were new to their roles when the project began. In fact, most of the people in the management team had been involved in the Supply Chain only for a few weeks. The project leader and Logistics and Sourcing Manager, was recruited by his supervisor to lead the team as his first project in the Remanufacturing and Components Division. The project sponsor and Market Sector Director had just returned to Reman after a 10-year period in other divisions. The General Manager had recently returned to the U.S. after a 7-year stay in Asia and Europe with Cat Reman. The Engineering Manager had also recently returned from an assignment in Asia with Cat Reman. The Senior Project Engineer, the person responsible for the final assembly operation and the only person at the final assembly plant who was a part of Cat Reman, was the only individual who had been involved with the Product Family before the project was launched. The following is a simplified organizational chart of the current management structure. 8

![Organizational Chart]

8 The names of all people in this organizational chart have been omitted for confidentiality reasons.
Most people involved in managing the value stream of the Product did not work directly for the Remanufacturing and Components Division. As can be seen in the simplified version of the value stream map, there are several business units that work together on this Product Family (see Figure 3). Of those, only the Salvaging Facility belongs to the Remanufacturing and Components Division, and it does so through a different general manager than the one in charge of optimizing the Supply Chain.

Our team was integrated in a way that guaranteed all business units in the Supply Chain were represented. The General Manager and the Market Sector Director, fully aware of the importance of developing links between all business units, decided to staff our team by including at least one representative from all the business units that interact to fulfill dealer orders for the Product. This decision was a key factor in guaranteeing the success of the project for at least two reasons: (1) it ensured the team would have access to first-hand information (data and insights) for all the relevant processes, and (2) it indirectly involved all general managers in the project, guaranteeing any proposals would be discussed and analyzed by the group while keeping the best interest of all organizations in mind.

To ensure everyone in the team had a good understanding of the whole value stream, our team decided to visit all the facilities that were directly involved in the supply chain and to hold working sessions at each facility. We held working sessions at the Reman headquarters, in Peoria, IL, at the final assembly plant, as well as in the salvaging facility. We also held meetings at the CLS headquarters and at the Product Marketing\(^9\) office, both in Peoria, IL. Being present at those facilities helped all members in the team understand the challenges that each facility faces and ensured all proposals for change were consistent with the prevailing practices and constraints at each location. If nothing else, meeting in different venues helped all team members focus their attention on our project without being interrupted by the events that happen every day at their home facilities.

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\(^9\) The "Product Marketing office" mentioned here is the one specifically in charge of managing the relations with the client base of the Product Family.
A word about the language on this thesis

The author has made a conscious decision to use a language that acknowledges that this research was the result of a team effort that required the commitment of several people in the organization working together over a period of four months\textsuperscript{10}.

The results presented in this thesis are not the final conclusion of the Lead Time Reduction project, but rather a summary of the key issues that, from an academic perspective, offer the possibility of extracting learnings that can be applied to similar problems in other industries. Thus, it should be noted that the team has continued to work on this initiative and will most likely stay active for months to come\textsuperscript{11}.

\textsuperscript{10} Between August and December 2010.

\textsuperscript{11} As of March 15, 2011, the team has continued to meet on a regular basis and has been making significant progress defining a roadmap for the Supply Chain.
**Chapter 4. The Need for Supply Chain Responsiveness**

Once we have understood the basics of the remanufacturing business at Caterpillar Inc., we will now spend some time explaining why there was a need to launch a project to improve supply chain responsiveness in the specific product we are dealing with.

**4.1 Customer expectations**

Caterpillar Remanufacturing sells all its products through the extensive network of Cat dealers. Cat dealers then fulfill orders from end users, many times by holding finished goods inventory at their facilities. In order to facilitate the interaction between Cat dealers and the specific business units that manufacture products, Caterpillar uses an organization that acts as the main link between customers (Cat dealers) and suppliers (manufacturing plants). That organization is Caterpillar Logistic Services (CLS), which is one of about 25 Divisions in Caterpillar Inc.

**4.1.1 Order types**

At Caterpillar, there are several types of orders, each with an associated lead time expectation. A user’s need for an engine can come from several causes, some of them foreseeable and others completely unexpected. Those needs need to be satisfied in a manner that is in accordance to the urgency with which the engine is needed. In some cases, when an end user has planned to replace an engine on a piece of machinery, an order may be placed months ahead of time. On the other hand, when a piece of machinery has suffered a sudden failure and is stranded, the corresponding order may require the replacement part to be available on very short notice. Table 1 shows two different order types that Caterpillar uses to prioritize its manufacturing and shipping scheduling.

<table>
<thead>
<tr>
<th>Order Type</th>
<th>Scheduling Priority</th>
<th>Customer lead time expectation</th>
</tr>
</thead>
<tbody>
<tr>
<td>LL</td>
<td>1</td>
<td>90 days (or more, if specified by customer)</td>
</tr>
</tbody>
</table>

12 For the sake of simplicity and for confidentiality issues, only two order types are mentioned in this analysis.

13 Caterpillar uses different values for scheduling priority and lead time expectation, depending on the product family in question. The values on Table 1 apply to the Product Family.
Before discussing the details of each type of order, we must understand the difference between “scheduling priority” and “lead time expectation”. Scheduling priority is related to the criterion that is used to allocate a production “slot” to each part being manufactured. According to this criterion, if there are two parts that need to be produced to be delivered on the exact same moment, the part with the highest priority (numerically lowest) will be processed before the low-priority part. When it comes to customer lead time expectation, it is defined as the amount of time a dealer is willing to wait to have a part shipped from the closest distribution center. This expectation is associated with the type of need the dealer is trying to fulfill. According to this logic, parts that are needed to repair a machine that is stranded in a worksite have more urgency than parts that are needed to re-stock a dealer’s warehouse.

Each order type on Table 1 has a different purpose. SL orders are meant to replenish dealer’s inventories and thus have a low scheduling priority, since they are not required by a specific end user. The lead time expectation associated to these orders is rather short, since Cat dealers need to be able to rely on Caterpillar to fulfill orders relatively fast and, in many cases, transit times between a distribution center and a dealer are measured in days and to the overall order fulfillment time. In other cases, SL orders are meant to help Cat dealers deal with unexpected customers needs and therefore have a short lead time expectation.

In some cases, LL orders are Caterpillar’s way of providing superior support to large customers who are willing to enter a service contract with a dealer. This type of order normally occurs when a machine that is covered by a service agreement has an unexpected failure and needs a component to regain its functionality. In the certain industries it is common to have this type of service contract, since this type of machinery is very capital-intensive and a failure can lead to significant financial losses. Caterpillar offers this service as a fundamental part of its value proposition: to have the lowest total cost of ownership. Production orders are meant to fulfill Caterpillar’s internal need for components that go into new machinery.
LL orders have the longest lead time expectation; however, there are some significant differences in their use. LL orders are used to fulfill the needs of a dealer who, as part of a service contract with a customer, has agreed to schedule a repair operation on a piece of equipment. This type of order is considered to be firm, meaning the dealer may not make changes to the committed delivery date after the order has been placed. LL orders, on the other hand offer more flexibility and are used to help Cat dealers make plans for the demand they expect to experience from their customer base. This type of order can be modified for some time after being placed, which allows Cat dealers to fine-tune their inventory management as demand firms up and their needs for components are more certain.

4.1.2 The implications of the different order types

Upon analyzing the information on Table 1, one can see that lead time expectations are rather polarized. SL orders need to be shipped from the closest distribution center very soon after an order is placed, while LL and LL orders have to be shipped after 90 days. This fact creates a clear distinction between those two groups of orders, and this distinction should allow the company to tailor its supply chain strategy to the specific customer needs.

While orders can wait up to 90 days to be shipped to a customer from a distribution center, the amount of time that it takes for Cat Reman to fill the internal order that CLS places is significantly longer. The remanufacturing lead time that CLS has been experiencing and has come to expect from Reman is around 126 days14. A natural question arises from this information: how is Caterpillar able to fulfill Cat dealers’ lead time requirements when their internal (remanufacturing) lead times are significantly longer than those expectations?

Currently, all orders placed by Cat dealers are fulfilled from CLS’s inventory, which is then re-stocked by Cat Reman. This situation is a natural consequence of the range of values that remanufacturing lead times and customer expectations currently have. The traditional way of dealing with such a situation

14 This lead time is given as the 95th percentile of a lead time distribution for all orders fulfilled over a period of time. In practical terms, this means that 95 percent of all orders are fulfilled in 95 days or less.
is to carry enough finished goods inventory to guarantee a certain service level to customers. Caterpillar Logistics Services follows this approach, since they are the customer-facing organization that has to fulfill orders on time while dealing with long lead times from its internal supplier.

Reducing the order-to-shipment lead time would result in a reduction in the amount of finished goods that CLS needs to hold in order to maintain its current service levels. The financial implications of such a reduction are significant, and this fact is one of the main reasons why this project was launched.

4.2 Deteriorating Delivery Performance

Delivery performance results in 2010 were less than optimal for Caterpillar Remanufacturing. During 2009 Caterpillar fulfilled over 10,000 LL line items with only two delays\(^{15}\). By May 2010, 3,000 orders had been fulfilled, and the number of misses was up to five. All seven misses in between January 2009 and May 2010 had been remanufactured engines of the Product Family.

In 2010, demand for remanufactured engines grew, testing the supply chain’s responsiveness. During late 2008 and throughout 2009, the world’s economic situation negatively impacted demand for machinery and components; the Product Family was not the exception. As companies tried to stretch their assets as far as they would go, pushing back scheduled maintenance and postponing the acquisition of new machinery, demand for remanufactured engines fell. Caterpillar and its suppliers adapted to the situation, in many cases reducing working capital and controlling expenses, and it was not uncommon to see steep declines in inventory and adjustments in workforce at all tiers in the supply chain. In late 2009, after 18 months of low sales, the economy started showing signs of improvement and demand for machinery and components started its recovery (see Figure 2). The growth in demand was higher than originally expected, since many customers suddenly decided to re-establish their maintenance programs and to execute repairs that were long overdue, all in a short period of time. All these factors created a

\(^{15}\) Both delays were due to suppliers not delivering parts on time, not due to Caterpillar’s processes.
scenario that tested the Supply Chain and its ability to keep up with demand while many of its capabilities (workforce, inventories, suppliers, etc.) had been recently trimmed down.

![Graph showing demand for remanufactured engines from January 2008 to April 2010.](image)

**Figure 2 Demand for remanufactured engines.**

In the summer, 2010, a customer placed an unusually large order of remanufactured engines that could not be fulfilled on time and delayed production for all Products. A large customer, who approximately four years earlier had purchased several machines from Caterpillar, realized it was the right moment to replace the engines on its fleet in preparation for the financial recovery. Those engines were the most complex configuration of the Product Family, and required additional resources in terms of labor and components. As if this was not enough to strain the supply chain, the customer had specified it would require certain components to be brand new on all its engines. This meant that even if Caterpillar had been able to predict the surge in demand for this specific engine arrangement, the parts it would have procured – normally a mix of remanufactured and new parts – would not have been enough to satisfy this customer’s needs. Needless to say, the supply chain was not able to withstand this test and most engines in that large order were not delivered on time. This setback affected all Product orders, as it meant the assembly facility had to delay the completion of other orders while it struggled to finalize that unique order.
As a result of the delays in the Assembly Plant, the delivery performance\textsuperscript{16} of the Product, which had been soaring at near-perfect levels in early 2009, began to fall below the target values for the year. This fact immediately caught the attention of senior management, and the decision to launch a project to address this problem soon followed.

4.3 High cost of finished goods

To be able to respond to dealer orders, CLS needs to hold finished goods. As we mentioned in section 4.1, Caterpillar Logistics is the customer-facing organization that acts as an intermediary between customers and producers. It is CLS that has to be able to guarantee an acceptable service level to all Cat dealers, and must frequently carry finished goods inventory to be able to satisfy customer lead time expectations when manufacturing or procurement lead times are long.

Demand uncertainty increases the amount of finished goods that CLS needs to carry as safety stock at any given time. The main drivers for this are: (1) product variety – including all the variations within a product family –, (2) demand variability, which, like we saw in section 4.2, can be significant and is especially challenging for slow-moving products, (3) demand origin, in terms of the geographical location of each customer, which must be serviced by a specific distribution center. For all these reasons, CLS normally holds large amounts of finished goods in it warehouses around the world. The cost for that inventory can be staggering, especially when the products in question are highly valuable products.

Caterpillar Logistic Services holds between 250 and 350 engines\textsuperscript{17} in its world-wide network of distribution centers. At present demand levels, that is the amount of engines that need to be strategically held at the distribution centers to guarantee availability on all types of orders. Although this number may seem high, it is not so vast considering there are more than fifty engine configurations in this Product

\textsuperscript{16} In this context, delivery performance is defined as the ratio between on-time deliveries to the internal customer, Caterpillar Logistics, and the total amount of orders placed in a given period.

\textsuperscript{17} This figure refers only to the Product.
Family and there are more than ten distribution centers around the world. However, the amount of money that is tied up in this finished goods inventory represents millions of dollars in working capital.

The cost of holding long-lead-time, high-value products in the CLS network can be extremely high. Besides the cost of the capital that is invested in finished goods, there are other costs that should be considered when trying to assess the risk involved in carrying significant amounts of inventory in the network. One such cost is the one associated with inventory obsolescence, which stems from the fact that Caterpillar is continuously making improvements in its product line. This fact can mean that an engine that sits on a warehouse for too long a time may end up being outdated by a new version of the same product. In that case, even though there are mechanisms to recover some of the value, there are always significant losses and rework involved. Because many of the engine arrangements in this Product Family are slow moving, the risk of having an engine become obsolete should not be overlooked.

4.4 Problem Statement

In 2010, Caterpillar Remanufacturing realized the supply chain that remanufactured this engine family needed to be optimized to meet customer expectations while keeping costs under control. Fulfilling LL orders on time is a non-negotiable priority that applies to every business unit in the company. Being able to meet customer expectations could imply an increase in costs, but was it possible to improve the overall supply chain responsiveness and to reduce costs at the same time? This is what the “Lead Time Reduction Team” was tasked to investigate.
Chapter 5. Focusing Efforts Through Value Stream Mapping

Following the DMAIC methodology, our first step was to define the problem. Our team knew our problem was limited by the constraints listed in Table 2, but needed to understand the supply chain to identify the areas that needed to be addressed.

<table>
<thead>
<tr>
<th>In scope</th>
<th>Out of scope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remanufactured engines (the Product)</td>
<td>New engines(^{18})</td>
</tr>
<tr>
<td>Order-to-shipment lead time(^{19})</td>
<td>On-time delivery policies (LL)(^{20})</td>
</tr>
<tr>
<td>Reman and supplier inventories</td>
<td>CLS finished good strategy(^{21})</td>
</tr>
<tr>
<td></td>
<td>Changes to assembly process</td>
</tr>
</tbody>
</table>

In order to focus our team efforts, we needed to familiarize ourselves with the complete supply chain and understand the key drivers for long lead times. To do this, our team used a tool that is well known in the lean manufacturing world: Value Stream Mapping (VSM). The information it provides is useful when trying to identify the main players and actions involved in a process. In our case, this proved to be exactly the type of tool that could provide us with a general overview of the whole supply chain.

The results of the value stream mapping allowed our team to identify a handful of areas that had great impact on the overall lead time.

5.1 Background: no precedent for this value stream map

Most individuals involved in managing the Supply Chain were relatively new to the operation at the time the project was started. As discussed in Chapter 3, the management team in charge of optimizing

\(^{18}\) New engines are included in new machinery and are also sold as replacement parts.

\(^{19}\) Remanufacturing lead time is given in days and is defined as the amount of time that passes between the moment when a dealer places an order and the moment when the remanufactured engine is built, tested and ready to be shipped to the appropriate distribution center.

\(^{20}\) The team also focused on a type of orders known as LL, which have very similar characteristics to LL orders, but for simplicity, the author mentions only LL orders in this document.

\(^{21}\) Caterpillar Logistic Services constantly optimizes its finished goods inventory to guarantee component availability to the world-wide dealer network. A reduction in remanufacturing lead time would impact the amount of engines they hold as finished goods; however, it was not up to our team to propose changes to their stocking policies.
the Supply Chain had moved into their roles relatively recently. This fact made the need for a complete value stream map even more relevant to our team.

No single person at Caterpillar is responsible for coordinating efforts across the Supply Chain. As of today, there is no person at Caterpillar who is the process owner for this family of products. There are people who have specific responsibilities related to this Product Family, for instance, there is an Engine Product Manager, but his responsibilities are not to oversee the supply chain for the Product, but rather to provide support from an engineering perspective (engineering changes, customer support, etc.). This lack of a dedicated “process owner” meant that there was no single person who knew the value stream well enough to even be able to explain it to the rest of the team. Although this may initially seem like a disadvantage, it proved to be beneficial, as it required the participation of all business units –through their representatives on our team– and resulted in a product that was not biased by previous conceptions of the process.

Because this project was a collaboration between several business units, it was important to ensure all members of the team had a thorough understanding of the process from the moment an order is placed, until the engine has been delivered to the dealer/customer.

5.2 Method: Value Stream Mapping

Value stream maps are a valuable tool for understanding the flows of materials and information in the organization. Additionally, they can provide information about the groups and individuals that have specific responsibilities in the process, as well as lead times for each step and key deliverables and/or checkpoints.

At Caterpillar, Value Stream Mapping is frequently used as part of the basic tools in process optimization. This means that most people in the company have, in one way or another, been involved in projects that require the elaboration of a value stream map. It is important to point out that this familiarity with VSM and its results helped our team complete this task successfully and efficiently, and it also helped us communicate our results to the key stakeholders without much trouble.
CPS has specific training and guidelines for performing Value Stream Mapping. One unique aspect of the Caterpillar Production system is the existence of Black Belts, who are individuals with 6 Sigma/Lean Manufacturing training that lead process improvement projects as their main responsibility in the organization (i.e. they are dedicated, full-time Black Belts). The team leader has been a Black Belt and later a Master Black Belt and is well versed in the tools of CPS.

Our team decided to perform a VSM as the first step in our project. To make sure we were able to gather all the relevant information, we worked together with the members of our team, who represented all business units involved in the Supply Chain.

This part of the analysis was accomplished during several working sessions, held at three different locations during a period of 1 month. The final product required several iterations as our team came across significant findings by interviewing people who currently were or had at some point been involved with any part of the process. Not surprisingly, most of the problems our team was able to identify occurred at the interfaces between two business units.

5.3 Data: Remanufactured Engines Value Stream Map

Figure 3 is a simplified version of the value stream map that the team developed for the Supply Chain. This VSM has intentionally been portrayed as an open-loop supply chain, but we are already familiar with the fact that the Supply Chain is a closed-loop system in which finished goods spend a lifecycle at the end-user and eventually return to Caterpillar to be remanufactured.

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22 This value stream map has been disguised to protect Caterpillar’s confidential information.
The following are some observations about the Supply Chain:

- **There are at least six entities involved in this supply chain:** Cat dealers, the Product Marketing group, CLS, the Salvage Plant, the Assembly plant, and part suppliers. The Salvage Plant is the only business unit that reports through the Reman organization, although it does so through a different General Manager than the one in charge of the lead time reduction initiative.

- **Only one person in the supply chain reports to the General Manager leading the lead time reduction project.** This person manages the remanufacturing operation at the Assembly Plant.

- **The Product represents only a fraction of the Assembly Plant’s product line.** In fact, that facility only uses some of its capacity on remanufactured engines; the rest is used on new engines.

- **Work done at the Assembly Plant is the longest process in the supply chain.** The objective of this project is to reduce the order-to-shipment lead time, and in that realm, only the Order Management process is a collaboration between CLS and the Assembly Plant, the rest of the time is spent between the Scheduling and Shipping steps.
5.4 Discussion: Focus on Ordering/Scheduling and Final Assembly

Once our team had a good understanding of the way this supply chain worked, we were able to focus our efforts on the part of the process that would have an effect on the metric we were concerned with: the order-to-shipment lead time. Because most of that lead time was spent at the Assembly Plant, we knew we would need to perform an in depth analysis of all the sub-processes that occurred at that facility.

The vision for this supply chain was to be able to run the order-to-shipment lead time to just 30 days, but we did not know if this goal would be consistent with the current process and if that goal would achievable. It was clear that this would be a great challenge since most of the value added work happened between Ordering and Shipping steps, which represented a large fraction of the operations in the supply chain. The time spent in transit to the distribution centers was also relevant, but not because we could change those processes, since we knew transportation was out of scope, but rather because it limited the time Caterpillar had to remanufacture engines.

One main conclusion from the VSM was that we needed to understand the shipping process to be able to understand how much the order-to-shipment lead time needed to be reduced to be able to meet the 90 day order-to-delivery expectation that Cat dealers had for LL and LL orders.

5.5 Next step: Can we improve? By how much? At what cost?

Having compiled and analyzed all the information that is included in the value stream map of the Supply Chain, the team had already identified several key areas that could be addressed to provide a significant reduction in order-to-delivery lead time.

It was clear that the shipping process placed constraints on the amount of time that was available for other operations, but it was not clear what those constraints were.

It was also clear that most of the reduction in order-to-shipment lead time was going to take place at the Assembly Plant, since that was the place where most of the value add steps happened and those processes were within the scope of our project.
Our team now needed to move on to the Measure phase of the DMAIC methodology. It was time to carry out some quantitative analysis to have a better understanding about where the reductions in lead time could come from. The questions we needed to answer in our next stage were:

- How much time does the shipping process take? How much is left for the order-to-shipment process?
- How much time does it currently take to build an engine after an order has been placed?

All these questions will be addressed in Chapter 6.
Chapter 6. Quantitative Analysis of Lead Time Reduction

Once it has been established that the longest process in the supply chain takes place at the Assembly Plant, it was time to understand what the key drivers of lead time were at each step of the process.

6.1 Background: Need to quantify potential reduction in lead time

To be able to propose a reduction in lead time, our team needed to understand what were the key processes that needed to be changed. We also needed to quantify the potential for lead time reduction in each case.

Because the vision that had been set by senior management was to achieve a state in which engines could be built to order and shipped to Cat dealers from the closest distribution center within the 90 day lead time expected by LL orders, it became necessary to estimate how long such a process would take. This required analyzing not only the process at the assembly plant, but also the shipping process.

6.2 Method: Statistical analysis of lead time components.

To be able to understand the impact of each step in the overall lead time, a process was established to measure the duration of each step according to a simplified process map (see Figure 4)

![Simplified process map of the order fulfillment process.](image)

The process that was used for this assessment consisted of the following steps: (1) analyzing the available historical process data for all sub-processes, (2) simulating a build to order scheme according to the lead time information for each step in the process, (3) prioritizing processes, based on potential reductions in lead time, (4) estimating reduced lead times for some select steps.

6.3 Data: Historical Lead Times by Sub-Process

The data used in this study was collected as part of the process tracking routine that the Assembly Plant follows on all its products. The period of time selected for this analysis went from January 2007 to
July 2010. All engine orders completed in that period of time were analyzed, but in some cases it was necessary to filter out some outliers and to modify the time range of the data to verify its consistency with the current demand (and production) levels. In this respect, 2007 and the first half of 2008 are very similar to 2010 in terms of production level, so a direct comparison was available when needed.

It was not possible to obtain reliable information for all steps in the process, since processing times are not collected for all steps; however, it was possible to gather enough information for the processes shown in Figure 5. The number of engines analyzed, our data sample, was well above one thousand cases, so statistical significance was not an issue for our analysis.

![Simplified process map of order fulfillment process](image)

**Figure 5 Simplified process map of order fulfillment process (some steps aggregated for lead time analysis)**

In Figure 5 “Scheduling” refers to the process of receiving and managing orders of all types and allocating each engine to a specific “time slot” on the production line schedule; “Part Procurement” is the process of obtaining the necessary parts (new or remanufactured) to assemble and engine; “Assembly, Test, Paint, Ship” are self-explanatory; and finally, “Transit” refers to the amount of time it takes an engine to travel between the Assembly Plant and the Distribution Center it is destined to.

The results of this analysis are included below for the most relevant steps in the process. The information has been disguised for confidentiality reasons.

### 6.4 Discussion:

Figure 6 shows the results of the first step on the analysis. We see that there are significant differences in the average time it takes to complete each process. It is also observed that variability around those averages is considerable. More details about the implications of these results will be given in the following section.

The second step in our process revealed the amount of time it would take to perform a build-to-order operation instead of the traditional build-to-stock scheme. To estimate this build-to-order lead time,
the author used a Montecarlo simulation that accounts for the uncertainty in the duration of each step by randomly selecting a lead time for each sub-process based on the likelihood of having such an outcome (from the lead time distributions shown in Figure 6).

![Figure 6 Lead time distribution for key sub-processes.](image)

The results of the total lead time estimation are graphically shown in Figure 7. All sub-processes are “stacked” to help visualize the relative effect that each sub-process has on the total lead time. The average total lead time would be around 170 days if a build-to-order scheme were in place, while the 95th percentile would be at 210 days.

A couple of key assumptions in this model are: (1) that no process would be significantly changed if a build-to-order scheme was implemented, and (2) that lead times are independently distributed for each step in the process and distributed according to Figure 6. This last assumption means there are no reasons to believe that the outcome of one process will have any influence in the outcome of the following step. The validity of this assumption can be disputed, as it may seem reasonable that an engine that has been delayed at final assembly could be shipped in a faster mode to compensate for the lost time. However, it should be mentioned that even such a drastic change in transportation modes, while possible from a

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23 Data is reported as relative frequency (relative units) in the vertical axis and lead time (time units, bucketed in days) on the horizontal axis. The data shown has been disguised for confidentiality reasons.
practical perspective (since all it would imply would be contracting one transportation mode versus another), would only reduce the total lead time by around six weeks. Expediting shipping for the Product, which literally weigh tons, is not an inexpensive cheap thing to do, so that option is really only used when there are emergencies and normally not for planned orders (LL and LL). While other processes may also be expedited, there are constraints in Caterpillar’s production capacity, so this could only be done with a small fraction of all engines.

In general, after careful review, we see that the result given by the proposed model will most likely give a reliable estimate for the total build-to-order lead time. After all, the intention at this point is to compare the current process with the 30-day lead time vision, and even if there were an error of a few weeks in the real average of a build-to-order lead time, the conclusion would be the same: the current state of the supply chain is tremendously far from the 30-day vision.

![Figure 7 Lead time simulation for a build-to-order scheme.](image)

### 6.4.1 Sub-process: Scheduling

The scheduling process contributes with a little over a month to the total lead time. The main driver in this case is the fact that orders are compiled by CLS and passed on to the Assembly Plant only
once a month. The consequence of this process is that dealer orders spend 15 days on average waiting to be formally scheduled, and while some lucky orders can be scheduled very soon after being placed, there are others that need to wait a full month before being scheduled. But if scheduling orders on a monthly basis adds only 15 days on average, why is it that this process is said to add a complete month to the overall lead time? The answer comes from the fact that once orders are received by the Assembly Plant, they are organized into production slots in an order that does not interfere with some manufacturing constraints\textsuperscript{24}. Once orders are “slotted”, they are given an estimated “ready to ship” (RTS) date; those RTS dates occur at the beginning of the month being planned, while others happen at the end of the month. This is why running the scheduling process monthly adds a complete month to the total lead time.

Compiling the orders, doing the slotting and getting approval from the Assembly Plant takes some time, and weekends sometimes get in the way, this is why the whole scheduling process effectively contributes a little over a month to the total remanufacturing lead time.

An obvious way of reducing the impact of scheduling is to increase the frequency with which the process is run. After analyzing this idea with the people directly involved with this step, it was determined that a reduction would not only be possible, but was actually being done for other product families. There are, however, limits to the gains that can be achieved in this process, but a reduction to two weeks would be straightforward, and a further reduction to just a week could potentially be achieved with some additional work.

\subsection*{Sub-process: Part Procurement}

As mentioned above, the Part Procurement period is the amount of time that passes between the moment when an engine is scheduled and the moment when the engine begins to be built. Of course, not all parts in the bill of materials of an engine have the same supplier lead time; in fact there is great variation amongst them. However, the Part Procurement period is a parameter that is not determined by

\textsuperscript{24} Although the Assembly Plant has a capacity to build a given number of engines per day, it does not take the same time to build 4-cylinder engines as it takes to manufacture 8-cylinder units. This is why slotting must be done in a way that guarantees a feasible production schedule.
supplier lead times, but rather one that is determined by management at the Assembly Plant as a way of defining their procurement and inventory policies.

To better understand this step, let use the following example. Suppose an engine consists of only two parts: part A has a supplier lead time of 5 days while part B has a supplier lead time of 10 days. If the Part Procurement period were greater than 10 days, it would be possible to wait until an order was scheduled to begin procuring the necessary parts; this would completely eliminate the need to hold parts inventory (safety stock). On the other hand, if the Part Procurement period were shorter than 5 days, there would be no time to procure parts after an order was scheduled, so all parts would need to be procured in advance. Finally, if the Part Procurement period were between 5 and 10 days, part A could be ordered after an order was received, but part B would need to be held in stock in preparation for an order to arrive.

In short, the relative length of the Part Procurement period and supplier lead times will determine which parts can be ordered in reaction to an order and which need to be procured in preparation for an order. Only those parts that need to be ordered ahead of time will require a safety stock, sized appropriately according to each part’s supplier lead time and forecast demand.

It is worth noting that the amount of safety stock that is needed at the Assembly Plant can be reduced by having a longer Part Procurement time, and this is a strong incentive for increasing this parameter. The counterbalance in this case is the urgency with which the internal customer (CLS) requires the Assembly Plant to fulfill orders. However, if by any reason the internal customer does not demand shorter lead times, the Assembly Plant will naturally tend to set longer Part Procurement times.

It is clear, from the information in Figure 6, that the Parts Procurement process is the largest contributor to the total remanufacturing lead time. After investigating some of the causes for this, our team gathered the following observations:

1. The parts procurement lead time is a parameter that can be directly modified by the Assembly Plant. This parameter is an input to the materials requirement planning (MRP)
software that the plant uses to estimate inventories for each part and to define when each part needs to be ordered to guarantee its availability during assembly.

2. The parts procurement lead time is kept at the same value as for the new engine assembly operation, but there are no clear reasons why this needs to remain this way.

3. There is an incentive for the Assembly Plant to keep this number as high as possible, as it helps guarantee part availability.

4. There is an incentive for not reducing the parts procurement lead time parameter, since it would mean more part orders would be based on expected demand, as opposed to based on actual demand. The fact that demand would stay uncertain for a larger number of parts and for a longer period of time means that safety stocks would need to grow to guarantee service levels in spite of all uncertainty (supplier lead times, delivery performance, actual demand for each engine arrangement). When safety stocks grow, holding, handling, shrinkage and obsolescence costs can grow to, raising overhead expenses for the plant.

All these observations made it clear that there was a major opportunity for improvement in this area; however, it was not clear whether changing this process would be economically convenient for the company and whether this parameter could really be manipulated freely.

Although it was clear than on average the parts procurement process added several weeks to the total remanufacturing lead time, the variation around the average lead time (see Figure 6) still had to be explained. After all, even if the parts procurement parameter could be set to zero, and all other processes (scheduling, assembly, test, paint, and ship) could also be reduced to zero, just the variation around the mean would make it impossible to fulfill orders on time while offering a 30-day lead time to CLS. In other words, something had to be done about this variation, and a first step towards that was trying to explain it.

In section 6.4.1 we noted that the monthly scheduling process added variability to the parts procurement time. This happens because engines are slotted one month at the time and the average parts
procurement time can vary by as much as 15 days. This fact alone explains some of the variation in the normal process.

Another source of variability is due to engines that are slotted outside the month being planned at the moment of scheduling. Those engines are special cases, either because there is a need to ship them as soon as possible to fulfill an order, or because they are not part of a committed order and can be pushed back to allow other orders to start earlier.

A third source of variability came from an even simpler cause: a change in procedures. As can be seen in Figure 8, the lead time distribution for the parts procurement process has been shifting its average since 2007. The result of this shift is that in 2010 the average lead time was around 30 days longer than in 2007. The reason for this shift was that at some point in 2009 (not unrelated to the economic crisis) the Assembly Plant decided to begin enforcing a policy that mandated the slotting process should be carried out three months in advance. Up to that point, although the same policy had been in place, it was common practice to run the slotting process only two months in advance, but this caused trouble because it magnified safety stocks, as more parts needed to be ordered based on expected demand, with all the uncertainty that it entails. So, in an effort to reduce working capital, the parts procurement lead time grew by 30 days by the end of 2009.

When the data was analyzed in bulk, it appeared as if there had been a large variation around the mean, while in reality this variation around the average is not that large. This is an important finding because it means that it might be possible to reduce average parts procurement lead time while keeping variation around that average under control by doing three things: (1) running the scheduling process more frequently, (2) minimizing the amount of engines that are scheduled outside of the planning horizon, and (3) not changing the procedures too often.
If all actions mentioned above can be implemented, it should be possible to reduce the parts procurement lead time significantly. As a matter of fact, because this is actually an input that can be modified – almost arbitrarily – it would even be possible to reduce this period to zero, or even make it less than zero. All that would mean is that for those suppliers that happen to have a lead time longer than the specified parts procurement time (and all of them have lead times larger than zero), parts would need to be ordered before the scheduling process is run, based on expected demand instead of on firm orders.

Figure 9 graphically explains the implications of changing the parts procurement period. In this example, Supplier A has a shorter lead time than the parts procurement period, so orders for parts can actually be placed at \( T=10 \), based on actual orders. On the other hand, Supplier B has a longer lead time.
than the parts procurement period. This means all parts ordered from Supplier B must be ordered before the scheduling process is done, and those orders can only be based on a forecast demand, as information for firm orders is not available.

We have established that the parts procurement period can be reduced by any amount, although we will later need to evaluate the cost of this procedure. What is important at this point is that we have realized a way to drastically cut the remanufacturing lead time.

6.4.3 **Sub-process: Assembly, Test, Paint and Ship (ATPS)**

During the initial interviews the author did at the Assembly Factory, it was generally believed that the time it took to assemble an engine to the point where it was tested and ready to ship was around 14 days. Once this process was measured, it soon became evident that this was not the case. Although the lead time distribution peaks at around 14 days, the average lead time is closer to 20 days and the 95th percentile is 45 days.

We see that the lead time distribution (see Figure 6) for the ATPS process looks somewhat like a normal distribution with a “long tail”. It is then straightforward to infer this could be due to problems with the processes that lead to delays, affecting only the right side of the distribution. To verify if this was the case, a study was done to see the effects of process delays in ATPS lead time. The data used for this analysis contained all the reports that are generated during the assembly operation. Those reports indicate whether a particular engine had to be delayed in the assembly line due to a problem, like not having enough parts available.

Figure 10 shows the results of the analysis to confirm whether improvements to the assembly process could reduce the ATPS lead time. The dotted line represents all engines that had no issues during the ATPS process, while the solid line represents all engines that went through the process – both with and without issues. The relative frequency distribution chart shows that engines with no issues were completed in a shorter time on average, which is evident by the shorter tail that the distribution shows. The cumulative frequency chart illustrates how much difference there was between the two populations.
While average lead times are not significantly different (15 days vs. 16 days), the 90th percentile is 34 days for all engines and only 26 days for engines with no issues. The 95th percentile is even more revealing, at 45 days for all engines and only 30 days for uneventful engines.

Figures 10 Relative frequency and cumulative frequency charts for ATPS process

Fixing the problems in the ATPS part of the process does not depend entirely on the people directly involved in those steps. In fact, many of the delays that an engine experiences in those processes come from parts in short supply. This is an important observation because, although changing the way engines are built and tested is not within the scope of this process, reducing lead time variability can actually be impacted by improving component availability, which is one of the key steps in this project.

Reducing lead time variability is as important as focusing on the average lead time: if one does not address variability, taking actions to reduce the average does not offer significant benefits. This is why in the ATPS sub-process, as well as in other steps in the remanufacture of engines, the proposed approach is to control variability first and attempt to reduce average lead times later. In the case of ATPS, most gains in lead time will come from a reduction in variability, not from a reduction in the average value of processing time.

6.4.4 Sub-process: Transit to Distribution Center

Because transportation is one of the main responsibilities of Caterpillar Logistics, this part of the process, as well as the finished goods inventory may not be modified by our team. This is why our team
did not spend any time quantifying any potential reductions in lead time for this sub-process. However, as part of our efforts towards modeling the remanufacturing process and understanding its constraints, some observations regarding finished good transportation are made in this section.

The transportation relative frequency lead time distribution seen in Figure 11 is definitely bimodal. The main reason for this is the fact that engines are preferentially shipped in three transportation modes, according to the most cost effective option: (1) by sea, for those locations far from the continental United States, (2) by land, to all locations reachable by land (mostly the continental U. S., and (3) by air in those rare occasions when an engine needs to be delivered urgently to a location away from the continental U.S. Those engines shipped by land or by air arrive at their destinations in a matter of days, while those shipped by sea take between 5 and 9 weeks to reach their destination.

The average lead time for the transportation sub-process is 50 days, while the 95th percentile is 55 days and 100% of all engines are transported in 60 days or less. The 55-day figure is a fundamental constraint for our project, since it is the lead time that will determine how long the rest of the processes would need to take in order to be able to meet the 90 day expectation while shipping products to all locations. In short, 55 out of the 90 days are spent in transit; that leaves only 35 days to complete an engine order after it has been placed by a dealer. Furthermore, since the ultimate goal is to have 100% on-time delivery, this 35-day period could actually need to be reduced to just 30 days, which matches the vision set by the senior management team.

Figure 11 Transportation lead time distribution.
6.4.5 Key Takeaways from Statistical Lead Time Analysis

After analyzing all four sub-processes (as described in Figure 5), there are some conclusions we can extract. From those observations we can then develop a simulation for the whole system that estimates the overall remanufacturing lead time, based on an expectation for lead time reduction in each case, which we will consider to be a best case scenario.

- **Scheduling**: the key driver is planning frequency. It can be reduced to two weeks without much trouble or to one week with more effort.

- **Parts procurement**: it can be reduced and set to any value, but it has the consequence of increasing safety stocks. Our best case scenario will be to set this time to zero.

- **Assembly, Test, Paint and Ship**: it is one of the least flexible parts of the process, but it can improve by reducing part shortages. We will use the “no issues” distribution shown in Figure 10.

- **Transit**: it will remain untouched. The same baseline values will be used.

The results of the lead time estimation for the best case scenario are shown in Figure 12. The most striking feature about this distribution is that it is dominated by the effect of transit times on the overall lead time, turning our previously unimodal distribution into one that is clearly bimodal.

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25 Best case in terms of lead time, but clearly not in terms of cost.
The simulation for the optimized lead time has some very positive implications to our project’s goals. First, the average lead time is 72 days, with a 95\textsuperscript{th} percentile of just 90 days. And, of course, it can be said that 5\% of all engines would take longer than 90 days, but it could also be argued that those engines could be taken care of by scheduling them to start being assembled sooner rather than later in the planning period, and some expediting could be used in some select cases. Although these results are only estimations, they are promising because they show much can be done to add responsiveness to the supply chain and achieving a situation in which all orders can be built to order and fulfilled in 90 days.

6.5 **Next Step: Should these improvements be implemented?**

Figure 13 shows a comparison of the lead time distributions for the baseline and the best case scenarios. It is obvious that transforming the baseline state into the best case scenario is not an easy task, especially considering the net reduction in lead time that is being proposed; however, the analysis has shown that these changes to the way engines are processed are not impossible to imagine, but are in fact reasonable once the procedure has been broken down into sub-processes and analyzed in detail.
Now, the fact that we have been able to reduce lead times so dramatically in the best case simulation relies heavily in the ability for the Assembly Plant to reduce their parts procurement period. And even though this single idea could potentially have a large impact on the performance of the whole supply chain, this does not mean all efforts should be done to implement it immediately. In fact, there is a very important analysis that Caterpillar needs to consider when evaluating the viability of the proposed improvements: it is necessary to evaluate the economic implications of reducing lead times by improving the processes discussed in section 6.4.

Although we have discussed ways to improve the Scheduling, Parts Procurement and ATPS processes, in Chapter 7 we will focus only on the Parts Procurement process. We will do this because it offers the most significant time savings, nonetheless it has the potential to cause an increase in inventories and, hence, a risk of increasing costs, perhaps dramatically. Intuitively we know that reducing the parts procurement period will increase costs, but we don’t know how much of an increase that would be. Additionally, we know that these additional costs could potentially be outweighed by a reduction in finished goods inventory, but we need to know what the balance of those to drivers will be.
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Chapter 7. Inventory Modeling for Cost Estimation

7.1 Background: Need to estimate cost of reducing parts procurement period

We have shown that the time currently being used to procure parts for the final assembly process is a main driver for order-to-shipment lead time. Furthermore, it has also been explained that this parts procurement period can be reduced dramatically by holding more spare parts in stock in preparation for the reception of actual orders. Now it is necessary to evaluate what the cost of such a strategy would be. Just as important is the need to understand what the implications of reducing the parts procurement period are on the amount of finished goods that need to be held to fulfill dealer orders on time.

Intuitively, one would expect the total cost of inventories – both, in spare parts and finished goods – to have an optimum value directly related to a specific order-to-shipment lead time. Outside of that optimum value, if lead times are further reduced, the cost of spare parts would grow significantly with not much reduction in finished goods inventory. Conversely, if lead times are higher than the optimum value, spare parts inventories could diminish, but this would be outweighed by an increase in finished goods inventory. Now the challenge is to find out where the current state is in terms of overall inventory costs and to estimate how far the current scenario is from the optimum.

7.2 Method: Inventory model

In order to make a cost comparison between different scenarios, we decided to base our calculations on the cost of inventories, as opposed to using holding costs as the metric. This decision simplified the calculations, but also allowed our team to communicate the results to the stakeholders, who normally are very aware of the amount of dollars they carry as inventory in their books, but are sometimes not as familiar with the expense these inventories signify to the business unit. For a complete description of the inventory model, please refer to Appendix 3 Inventory Model for Spare Parts.
There are two main components to this estimation: the cost of spare parts and the cost of finished goods. Because the finished good strategy is out of scope for this project, only the calculations related to spare parts inventory are included in this section. However, the division responsible for defining the finished goods strategy for this product, CLS, kindly provided estimations for the amount of engines that would be needed as a result of reducing order-to-shipment lead times; those estimates are included in this report and are used to define the optimum strategy for the Supply Chain.

The method for estimating the added cost of carrying more spare parts was quite simple and involved the following steps: (1) using historical data to translate engine demand into demand for specific parts (through the bills of materials), (2) using future demand forecasts to estimate future demand for parts, (3) estimating the cycle stock and safety stock needed to provide the service level required by the Assembly Plant given the uncertainty in demand and the difference between each part’s lead time and the parts procurement time, and (4) converting the average inventories (cycle and safety) to costs, by using parts price data from all suppliers.

In the end, we had a model that could estimate the average inventory for spare parts (in dollars) and had the ability to use the following parameters as inputs: service level for parts, parts procurement lead time, and future demand forecast.

7.3 Data: Demand '07-'10, supplier lead times, cost per part, BOM's

Once the process had been defined, the necessary date was gathered. The main pieces of information that went into the model were:

- **Historical demand data**: historical demand for the period January 2007 – July 2010 was used to model the behavior of the individual demand for each engine arrangement.

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26 Those parts held at the Assembly Plant as part of the cycle and safety stocks needed to produce engines. For this simplicity, these calculations do not distinguish between new and remanufactured parts. For accounting purposes, the cost of those two types of parts is the same.
• **Future demand**: a five-quarter extended demand forecast, provided by Caterpillar Product Marketing, was used.

• **Supplier lead times**: the information currently in the MRP system at the Assembly Plant was used. It included lead times for all part numbers included in the bills of materials of all engine arrangements in the Product Family.

• **Unit cost per part**: this data also came from the MRP system at the Assembly Plant.

• **Bills of materials**: also came from the MRP system. They included all the parts that are required at “assembly level” in all the available configurations in this Product Family.

This information was fed into the model, which was then tested by estimating the inventory levels that the Assembly Plant would need to hold according to demand conditions at the moment of the calculation. The model was able to predict inventory requirements with an accuracy of around 90%\(^27\).

A second method for verifying the results was circumstantially provided by a vendor who at the time was offering Cat Reman software that could help run the materials procurement process at a new facility. The software was tested by loading the same data used in our model and the results were compared. The needs for additional inventory at different lead time reduction scenarios were a very close match.

### 7.4 Discussion: cost is significant, but not compared to FGI reduction

The results of the inventory model are shown in Figure 14\(^28\). There are significant cost savings to be achieved by reducing the order-to-shipment lead time. Savings can be up to 28% if lead times are reduced to 45 days, but after that point the cost of parts inventory grows more than the decrease in finished goods inventory.

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\(^{27}\) Based on a comparison of the predicted cost of inventories (safety, cycle, work-in-process) and the actual values as reported by the MRP system at the Assembly Plant in November 2010.

\(^{28}\) The actual values are intentionally not included in this document to protect Caterpillar’s confidentiality.
Figure 14 compares the cost of parts inventory, finished goods inventory and total inventory (parts and finished goods) for different lead time scenarios. The order-to-shipment lead time includes the first three processes described in section 6.4 (Scheduling, Part Procurement, and Assembly, Test, Paint, Ship), leaving out transit time between the Assembly Plant and the Distribution Centers, which are outside the scope of this project.

![Graph showing cost implications of lead time reduction scenarios](image)

Figure 14 Cost implications of lead time reduction scenarios (normalized to baseline scenario).

Some relevant observations from these results are:

- **The lowest total cost is achieved at a lead time of 45 days.** Any further reduction in lead time increases the total cost.

- **Further reduction to a 35-day lead time scenario is not attractive.** Although there could be improvements in responsiveness and the difference in total cost is not significant between the 45-day and the 35-day scenarios, there are complexities associated with optimizing the processes to achieve such a reduction. To be brief, the difference in inventory costs is not the only cost associated with changing the processes.

- **Even if a build-to-order scheme is not achieved, there are significant savings in reducing lead times.** Although achieving a 35-day lead time potentially allows fulfilling all LL orders on time using a build-to-order strategy, all lead time reduction scenarios provide savings as they help reduce the amount of finished goods that need to be held.
• **A 65-day lead time scenario allows a build-to-order strategy for some orders.** Those customers that are serviced by distribution centers that are in the continental U.S. have short transit times, which allows for a higher build-to-shipment lead time.

• **Even a 35-day lead time scenario requires carrying finished goods.** Because CLS needs to execute orders that have a 3-day, 2-day or even same-day fulfillment time, it still needs to hold several engines at its distribution centers worldwide.

After analyzing the inventory requirements associated with a reduction in order-to-shipment lead times, it is clear that moving in the direction of lead time reduction will be a rewarding initiative. Additionally, the fact that the benefits of a lead time reduction can start to be realized even without reaching the 35 (or 35) day vision is encouraging, as it allows a gradual implementation that minimizes the risk associated with changing the way a supply chain works.

### 7.5 Next steps: Should this be implemented?

So far, we have defined the key opportunity areas in the Supply Chain, we also have measured lead time drivers and found the most critical steps to be improved, and have finally analyzed the cost implications of reducing lead times by moving towards a build-to-order strategy. It is clear that there is great potential for improvement in this supply chain and that, although many things will likely need to be enhanced, the outcome of this project may offer significant improvements in customer satisfaction and a reduction in the overall cost to Caterpillar.

The next two steps in the DMAIC methodology are not part of this thesis, but they are being performed as these lines are being written. *Improving* to the supply chain and *controlling* the new processes is not an easy task. There are significant challenges to come, but the outcome of this analysis has shown that this initiative is worth pursuing.
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Chapter 8. Conclusions

8.1 Key Learnings

8.1.1 The importance of total optimization

The Supply Chain is currently far from its optimal state. The reason is not lack of ability or commitment from the very capable individuals that oversee parts of this supply chain at the different divisions at Caterpillar. In fact, it could be argued that it is because these individuals have been doing a great job managing their businesses that this supply chain has “naturally evolved” into its current sub-optimal state. The concept is quite simple: everyone in the supply chain has been seeking improvements that benefit their business unit and improve its results but they have not considered the effects on the supply chain as a whole when making these decisions.

We have a case of a “sequential supply chain”, in which each party makes decisions independent of what happens in other parts of the supply chain. A sequential supply chain is an ineffective strategy because it fails to identify what is best for the supply chain as a whole (Simchi-Levi, 2010).

Just one example of this, although one that is noteworthy, are the reasons that have made the Assembly Plant set its currently long parts procurement time. Doing that has helped them reduce working capital by cutting parts inventories (a big effort during the recent crisis), and has allowed them to manage their business efficiently by eliminating uncertainty in demand. From their perspective, this was the right decision to make, since many parts suppliers offered them long lead times and they did not want to be caught with excess inventory. Unfortunately, those initiatives have contributed to the current long order-to-shipment lead times that the Assembly Plant offers to CLS. As a consequence, CLS, who does not have the prerogative of providing long lead times to its customers, has had to purchase large amounts of finished goods in preparation for the ever uncertain demand.

Though this work has proposed a solution to this specific problem, and that solution involves increasing the amount of spare parts held in stock, this does not necessarily mean that one business unit will benefit while the other one has to suffer. Even if this decision could be brought up to senior
management, who would then have to agree on which business unit takes a hit (hopefully with the consequent adjustment in metrics for that business unit) this decision does not have to be made that way.

The alternative in this case is to make the information available to the right stakeholders and to develop ways to transfer the “cost of savings” \(^{29}\) in a way that is fair for all parts. There are many ways to design supply contracts that deal with this issues, but one way that is particularly interesting in this supply chain is the possibility of having the downstream business unit pay for the added inventory costs. Another possibility is adjusting the transfer price of engines to help the Assembly Plant deal with the increased cost of inventory. Both options are preferable to the win-lose solution described in the previous paragraph because they offer win-win situations that have better chances of being successful in the long run and can help set a precedent for this type of collaboration.

8.1.2 Inclusive teams and process ownership

It should now be clear that a supply chain that cuts across several business units can have some inherent challenges when it comes to finding solutions that are optimum on a global scale. This problem is highlighted in closed-loop supply chains, which make the usual players collaborate in unusual ways.

Overhauling a supply chain that works, regardless of how efficiently it performs, is not an easy task. There is always a risk of attempting to implement changes that may end up damaging the current state, but that risk is much higher if the people in charge of doing it are not familiar with the supply chain. That is one key reason why having a team that can collectively understand a supply chain was such a big asset in this project.

But understanding the challenges is not enough. Having representatives of all business units participate in the efforts of optimizing a supply chain guarantees that the proposed solutions will have taken into account the goals and priorities of each organization. This is not a minor feature, because, besides helping get support from the decision makers at each business unit, it helps to keep efforts

\(^{29}\) The cost that one business unit needs to incur in order to allow another business unit to realize some savings.
centered on finding solutions that are convenient for the supply chain as a whole, instead of seeking benefits for one small part of the productive chain. A team that has a sense of ownership of the complete value stream must have the ability to gather information, identify tradeoffs and make informed decisions.

Process ownership does not stop after the team has finished proposing solutions. As discussed in the previous section, a sequential supply chain that is left unattended naturally evolves into a sub-optimal state as a consequence of a series of local optimization efforts. One way of guaranteeing that a supply chain stays competitive is to have periodic sessions with all the stakeholders, but this author believes there is also a need to have an individual coordinate those efforts.

A Process Owner can be tasked with overseeing continuous improvement in a supply chain, and can be particularly impartial and effective if he or she does not report directly to any of the business units directly involved in the process. The Supply Chain is a perfect setting for this idea, since the people in charge of this Product Family don’t own or directly manage any of the business units involved in the value stream.

8.1.3 Raw Materials vs. Finished Goods.
A tradeoff exists between the amount of components (raw materials) and the amount of complete engines (finished goods) that need to be carried in stock in order to meet customer expectations. In general, increasing one of those two leads to a decrease in the other, but the total cost of both inventories can be significantly different in each scenario. Finding where a supply chain is along this continuum is important as it may help define the direction that strategic changes should follow.

Customer expectations are the fundamental constraint that dictates what the order fulfillment strategy should be. One can build-to-stock, finish-to-order, or even build-to-order, but this decision is subject to customer needs and preferences, and cannot be arbitrarily made.

Although a build-to-order strategy is fundamentally different than a build-to-stock scheme, these are not necessarily mutually exclusive. We have seen in this thesis that the exact same supply chain can
act as a build-to-order supplier for some clients (the ones with shorter transit times in our case) or simply build-to-stock. The build-to-stock strategy can help minimize inventory costs by pooling resources, but is not applicable to all types of orders and does not work for some clients, so although savings cannot be achieved in all cases, efforts should be made to find the “sweet spot” for the specific conditions.

8.2 Recommendations

There are four main recommendations that the author wishes to make as a result of the analysis described in this thesis.

(1) **Move the Supply Chain towards a build-to-order fulfillment strategy.** This does not mean that a build-to-order strategy can, or should, be applied to all products, but the evidence shows all efforts in this direction have the potential to translate to benefits for the enterprise as a whole.

(2) **Find an effective way to handle the “cost of savings”**. Either by having the business unit that benefits from the savings directly pay for the additional costs, or by implementing other type of supply contract.

(3) **Consider the option of having a Process Owner**. This individual can help maintain the supply chain competitive as conditions change.

(4) **Rely on cross-divisional teams to overhaul complex supply chains**. This will summon support from all business units, facilitate information sharing and focus efforts on finding globally optimal solutions.

Other recommendations will come out of the project once the last two stages of the DMAIC methodology are completed.

8.3 Further study

The natural next steps in this line of work are to continue with the next two stages in the process. Naturally, being able to reduce the order-to-shipment lead times by 65% is not an easy task, much less if the intention is to achieve this while keeping costs under control and even reducing inventory costs by as
much as 28%. That is why it would not be reasonable to expect to see the initiatives discussed in this thesis in the short term.

Senior management has committed to implementing some changes over a period of two years starting in January, 2011. This will afford Cat Reman enough time to re-assess some of the recommendations included in this work once progress has been made and some of the uncertainty surrounding the results and implications of these efforts has been eliminated. At that point it may be necessary to reformulate the main questions we have tried to solve: Can this supply chain be more robust and responsive? How much improvement can be achieved? And, what are the economic implications of such improvements?
**Glossary**

**Assembly level**: level of detail with which a bill of materials is specified at the Assembly Plant. At this level, all assemblies (or parts) that go into an engine are listed, but not the individual components that make such assembly. As an example, at assembly level a fuel pump may be listed, but the individual bolts that hold the components of such pump together are not.

**Cat Reman**: colloquial term for Caterpillar Remanufacturing and Components Division

**Core**: used to designate an end of life component that goes back to the original manufacturer to be remanufactured. The word can refer to the complete device or to any piece that is obtained from its disassembly. A common mistake is to believe a core is only the quintessential part of a device (for example, the main block in an engine) or a set of parts that defines the “backbone” of a system (for example, in the case of an engine, the block, crankshaft, cylinder head(s), pistons, and connecting rods). Core can normally be substituted in a sentence for the words “reusable end-of-life component(s)”.

**Core credit**: amount of money that is originally charged to Cat dealers (and customers) when they buy a remanufactured product. The purchase of a remanufactured product entitles Cat dealers (and customers) to return an end-of-life component and be reimbursed the core credit.

**CLS**: Caterpillar Logistic Services is the division that links customers (Cat dealers) and internal suppliers (manufacturing plants), providing a single point of contact for Cat dealers to place orders on Caterpillar. It manages the world-wide inventory of parts and machinery through an extensive network of distribution centers.

**LL**: Long lead time order. A type of order that Cat dealers use when planning for repairs that are expected to be performed on customers’ equipment.

**DMAIC**: a 6 Sigma approach to problem solving. Includes five basic steps: Define, Measure, Analyze, Improve and Control.
**Parts Procurement Period**: is a parameter, entered in the Materials Requirement Planning software that specifies the amount of time available after an engine has been scheduled for production and before that engine begins to be assembled.

**Salvage**: operation by which an end-of-life component is processed in a manufacturing environment to guarantee its adherence to same-as-new specifications.

**Time slot**: a sequential window of time that can be used to build an engine at each station in the assembly line. Example: if an engine can be built by a person in one hour, an eight-hour work day is considered to have eight time slots.

**VSM**: Value Stream Map or Value Stream Mapping. A lean manufacturing technique that aims at mapping all the processes and actors that play a role in the value chain of a product or service.
References


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Appendix 1 Current context: New CEO, new corporate strategy

New CEO, new corporate strategy

On July 1st, 2010, Doug Oberhelman stepped up as the new Chief Executive Officer of Caterpillar Inc. Oberhelman defined a new corporate strategy intended to propel the company towards success in the next decade. The new corporate strategy was defined by a vision consisting of eight points, and a business model that needed to be executed. Table 3 shows that Vision and Business Model.

<table>
<thead>
<tr>
<th>Table 3 Caterpillar Inc. Vision 2010-2015 and Business Model</th>
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<tbody>
<tr>
<td><strong>Vision 2010-2015</strong></td>
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<tr>
<td>We are recognized as the leader everywhere we do business.</td>
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<tr>
<td>Our products, services and solutions help our customers succeed.</td>
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<tr>
<td>Our distribution system is a competitive advantage.</td>
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<tr>
<td>Our supply chain is world class.</td>
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<tr>
<td>Our business model drives superior results.</td>
</tr>
<tr>
<td>Our people are talented and live Our Values in Action.</td>
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<tr>
<td>Our work today helps our customers create a more sustainable world.</td>
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<tr>
<td>Our financial performance consistently rewards our stockholders.</td>
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<tr>
<td><strong>Business Model</strong></td>
</tr>
<tr>
<td>We win by delivering valued, quality products, services and solutions to our customers that provide the lowest total owning and operating lifecycle costs. This value proposition, enabled by our unmatched customer support, creates the largest global field population, highest customer loyalty and attractive profitability through the business cycle.</td>
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The implications to our project were that we needed to make sure that all efforts were in alignment with the new corporate strategy. Specifically this meant that: (1) products needed to be able to help customers by providing high quality, availability, on-time delivery and a competitive cost over the life of the product, (2) the distribution system was to remain one of Caterpillar’s competitive advantages, so Cat dealers were going to continue to play a key role in executing the business, (3) Caterpillar’s supply chain had to be world class.
The Caterpillar Production System

In early 2004, Caterpillar began a company-wide effort to develop its own “lean” production system. Up to that point, Caterpillar had become proficient in 6 Sigma practices, but needed a program that could further improve its capabilities without being limited to manufacturing. They needed a system that had the ability to permeate the whole organization. In that context, the Caterpillar Production System Division was created to, first, define the architecture of the Caterpillar Production System (CPS) and to then implement the new philosophy everywhere in the company.

In the summer of 2010, after a successful CPS implementation, the Caterpillar Production System Division underwent significant changes that included a significant downsizing and the loss of the status of “Division”. At that point, it was considered that CPS principles, and the 6 Sigma philosophy that it was based on, were sufficiently engrained in the company culture.

With the new vision, set by the CEO, CPS remained at the center of the corporate strategy (quite literally, see Figure 15). This meant that our team needed to ensure all our efforts followed the CPS philosophy. The practical implication of CPS to our project was that we were expected to follow a 6 Sigma approach, using the Define, Measure, Analyze, Improve, Control (DMAIC) methodology.
Figure 15 Caterpillar's new corporate strategy.
Appendix 3 Inventory Model for Spare Parts

The inventory model

To estimate the impact of a change in procurement policies for spare parts, an inventory model was developed. The model quantified the needs for each part, in terms of cycle and safety stock, based on a desired service level and an order-to-shipment lead time. All results were measured in terms of average inventories, and were reported in dollar amounts to facilitate a comparison with the traditional process and to estimate the net effect of changing the order-to-shipment lead time on total working capital.

To avoid unnecessary complexity, the model’s output was the dollar amount of average inventories, as opposed to the expense associated to holding those inventories. This allowed a direct comparison with the legacy inventory levels and allowed all stakeholders to understand the necessary increase in working capital that a reduction in order-to-shipment lead time would entail.

Basic algorithm for quantifying average inventories

The basic logic of the inventory model is the following:

1. A desired service level is provided.
2. A desired order-to-shipment lead time is provided.
3. The desired order-to-shipment lead time is used to estimate the corresponding Parts Procurement period needed to satisfy the lead time requirements.
4. All supplier lead times are compared to the available Parts Procurement Period.
   a. Those part numbers that have a re-stocking lead time longer than the Parts Procurement Period are identified. Those parts will need to be held in safety stock and as cycle stock (mostly work in process).
   b. Those part numbers that have a re-stocking lead time shorter than the Parts Procurement Period are identified. Those parts will only be held as cycle stock (mostly work in process).
5. Future demand for each part number is obtained from two sources: the most current demand forecast and the bills of materials for all engine configurations.

6. Appropriate inventory sizes are estimated.
   a. Safety stocks are calculated based on historical demand variability, forecast demand, available procurement time, and desired service level.
   b. Cycle stocks are based on average (expected) consumption. Most of the parts on this category are held as work in process at the Assembly Plant.
   c. Other special cases are considered. Some part numbers have a minimum order quantity and need to be purchased in bulk.

7. All inventories are valued according to their respective standard costs.

8. An overall inventory cost is estimated for the whole operation. This cost represents the expected average cost that the Assembly Plant will need to hold to provide the desired order-to-shipment lead times at a given service level.

The inventory model was constructed using a periodic re-stocking scheme. Safety stocks are calculated based on the fundamental equation:

\[ SS = k \cdot \sigma_{L+R} \]

- \( k \): safety inventory relative to standard deviation of demand
- \( \sigma_{L+R} \): standard deviation of demand over the relevant period “L + R”

- \( L \): supplier lead time
- \( R \): review period (how often parts are ordered)

The main input parameters were:

- **Order-to-shipment lead time**: indirectly determines the amount of time that is available to procure spare parts once an order is placed. Depending on each supplier lead time, this parameter will require holding a safety stock of spare parts only for those part numbers
that have a lead time longer than the Parts Procurement parameter. Several scenarios were run, changing the length of this period from its original state to a

- **Service level**: determines the desired availability for individual components on the assembly floor.

- **Review period**: is defined by the frequency with which parts are ordered from a supplier.

- **Historical demand for engines**: was obtained from the records at the Assembly Plant. Data was collected for years 2007 through 2010.

- **Demand Forecast (for engines)**: was obtained from Caterpillar Logistics Services. It is based on estimates provided by Cat dealers around the world, as well as on actual orders placed by Cat dealers several months in advance.

- **Supplier lead times**: each part number has a supplier lead time associated to it. The MRP software used at the Assembly Plant contains this information for every single part number included in any of the bills of materials of the remanufactured engines.

- **Bills of materials**: describe all the components that go into each engine configuration. They include part numbers as well as quantities of each component. For this model, the necessary detail was the “assembly level” bill of materials.

- **Lot sizes**: some components can only be ordered in bulk or have a minimum order quantity. This parameter was used to estimate average inventories when part order sizes are larger than those required to fulfill the desired service levels because of suppliers’ ordering policies.

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30 Because the Assembly Plant continuously monitors its inventories, it is possible to identify problems ahead of time and to take corrective actions before a component is missing at the assembly line. This means the availability of a specific part can be greatly improved from its original value in those cases when a part would have been missing if nothing had been done in response to a potential shortage. Our model is concerned with point-of-use availability, which is not a parameter in the MRP software. To figure out a baseline service level, the historical total cost of inventories was used to estimate the point-of-use availability that the plant has experienced in the past. The model uses that same value in an attempt to guarantee service levels will remain constant even when the Parts Procurement period is reduced.
• **Standard cost:** the cost of each component was recorded according to current accounting practices. This cost determines the financial implications of different stocking policies (dollar amount of average inventories).

**Testing the model**

Once completed, the inventory model was tested in two different ways. First, the model was used to predict the most current value of all inventories at the Assembly Plant and the results were compared to the known cost of all parts held at the plant. Second, the results were compared to those of software that a vendor had developed to handle the parts ordering process in different business unit at Cat Reman; the results of both simulations were compared directly.

The results of the testing stage are not discussed in detail for confidentiality reasons, but the accuracy of the model was close to the benchmark in both tests. The results were reviewed by the key stakeholders and its output was deemed to be an appropriate reflection of the expected effects on working capital (parts inventories).