Study of the Role of Strategically Managed Inventory (SMI) in the Caterpillar Supply Chain

by

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B.S. Mechanical Engineering, Franklin W. Olin College of Engineering, 2007

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

Master of Business Administration
and
Master of Science in Mechanical Engineering

In conjunction with the Leaders for Global Operations Program at the Massachusetts Institute of Technology

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Abstract

Strategic Managed Inventory (SMI) is an inventory replenishment process deployed by Caterpillar that blends elements of Vendor Managed Inventory (VMI) and Collaborative Planning, Forecasting, and Replenishment (CPFR). The SMI process calls for Caterpillar's suppliers to control the material replenishment process and hold inventory in strategic locations. SMI is designed such that Caterpillar and the supplier collaborate on replenishment plans and forecasts to ensure that material moves efficiently through the supply chain. The process is aimed at increasing supply chain flexibility, responsiveness and performance.

This paper examines the current deployment of the SMI process in Caterpillar's supply chain in an effort to determine how the company can go about better leveraging this capability. It proposes potential frameworks for the identification of future SMI opportunities and part suitability. It also looks at the drivers behind SMI in cost evaluation.

While there are some challenges identified with the process by the study, the study concludes that the SMI process does lead to benefits for Caterpillar and its suppliers. It suggests that these benefits could be better leveraged by growing the capability slowly using the most proficient suppliers, establishing oversight for the SMI process, increasing supplier vetting, and crafting a way to gain visibility into current SMI usage.

Thesis Supervisor: Daniel Whitney
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I would also like to thank all of the people throughout Caterpillar’s various organizations (there are too many to name in a concise fashion) that provided support for this project. It was really a team effort to gather, analyze and distill all of the aspects of SMI at Caterpillar that are presented in this study.

Within the CPS division at Caterpillar I would like to thank Mark Ward, Steve Mahoney, Paul Strimaitis, and Siva Boppana for their guidance and supervision while I conducted this study. I would also like to thank Dan Shockley, Denise Johnson, and Erich Michelfelder for their efforts in strengthening the ties between the LGO program and Caterpillar.
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1 Introduction to Strategically Managed Inventory and Caterpillar

At the start of 2012 Caterpillar embarked on a company wide effort to implement a new supply chain strategy. Caterpillar’s previous supply chain strategy was executed between 2008 and 2011 and was focused on establishing the company’s fundamental supply chain processes and procedures. The new strategy, dubbed the Integrated Supply Chain (ISC) Strategy, is designed to move the supply chain from a series of processes that were standardized and executed in silos, to an integrated set of processes that are optimized for the entire company. The ISC is part of Caterpillar’s continuing emphasis on improving the efficiency of its operations to support increasing demand for its products. As the owner of Caterpillar’s production processes, the Caterpillar Production System (CPS) is at the center of the ISC strategy execution.

The ISC strategy was developed after an extensive evaluation of Caterpillar’s current supply chain capabilities and process implementation. A part of this evaluation was determining the role that current CPS supply chain processes will play after the ISC effort is completed. One of those processes governed the use of Strategically Managed Inventory (SMI). Caterpillar has used the SMI process for several years, but it has not achieved widespread use throughout the company’s supply chain. In order to help determine the extent to which SMI would continue to play a role in Caterpillar’s future state supply chain, a study of the process was conducted over a six-month period under the purview of the CPS division. The study had the following goals:

- Evaluate the current use and effectiveness of SMI in Caterpillar’s supply chain,
- Identify best practices for the deployment and sustainment of SMI and related supply chain strategies,
- Develop frameworks for the identification of SMI opportunities,
- Recommend the best way for Caterpillar to leverage the SMI process in the future.
These goals were all driven by a desire to determine if the SMI process was a good fit for Caterpillar, and if the observed challenges in the execution of the process could be overcome. The study concludes that even though there are significant challenges with the SMI process there are benefits to the process that the company has can realize. The study reached this conclusion using the following methods:

- Gathering best practices from industry and academic research on topics related to the fundamentals of SMI;
- Examining Caterpillar data sets (purchasing, transportation, and inventory) to determine the current impact of SMI, evaluate current prospects for the process, and aid in the development of an opportunity framework;
- Testing developed frameworks against the established process;
- Conducting internal assessments to determine the current state of the process, extract best practices, develop representative case studies, and develop recommendations for the future of the process.

1.1 Caterpillar’s Definition of SMI

Caterpillar defines SMI as an inventory management and replenishment model designed to streamline the company’s supply chain by optimally placing strategic inventory buffers. The primary goals of SMI are to increase overall supply chain efficiency and flexibility by increasing material availability at the point-of-use (POU), aiding the transition to a pull supply chain, and improving material flow. Implementation of the SMI process has the potential to increase Caterpillar’s inventory turns, improve Caterpillar’s customer delivery performance, reduce the amount of working capital Caterpillar needs to maintain inventories, reduce overall supply chain inventory, reduce response times, and improve supplier on-time delivery performance. SMI process accomplishes these goals by centralizing replenishment decisions, actively sharing forecast and demand information with suppliers, and developing supplier relationships. Under the SMI process, suppliers often retain material ownership until Caterpillar pulls the material from the
strategic stock. SMI is closely related in form and function to Vendor Managed Inventory (VMI) models with elements added from Collaborative, Planning, Forecasting and Replenishment (CPFR) processes.¹

1.2 Caterpillar Company Background

Caterpillar Incorporated is a multinational company with over 85 years of history in producing a wide range of products including construction equipment, earthmoving equipment, mining equipment, engines, locomotives, and power systems. In addition to its role as an original equipment manufacturer (OEM) Caterpillar is also a provider of financial, remanufacturing, and logistics services. Caterpillar posted record revenues of over $60 billion for the fiscal year ending in 2011. These results represent a profit of approximately $4.9 billion, an 83% increase over 2010.² Caterpillar invested over $2.2 billion in research and development in 2011.²

1.2.1 Products

Caterpillar sells products under many different brands, with the most widely known being the CAT brand. Products produced under the CAT brand consist of much of the company’s construction, mining and earthmoving equipment, as well as many of its engines and power systems. Caterpillar also maintains a portfolio of products manufactured by subsidiaries and sold under various other brands. These brands produce everything from full machines, to machine attachments, to hydraulic and track components.

Products sold under the CAT brand are typically distributed through the company’s global dealer network. There are currently over 180 independent dealers that serve as the main point of contact for the company’s customers.³ CAT sets tight standards for its dealer network and collaborates with it extensively to ensure customer expectations are being met. The dealers are responsible for not only selling machines to the end customer, but also servicing machines that have already been sold. To support dealer service operations CAT operates a large service parts business that warehouses and distributes components to dealers and customers. CAT customers demand quick service to ensure that if their

¹ See Chapter 2 for a full description of Vendor Managed Inventory.
² Includes impacts related to the acquisition of Bucyrus International.
equipment needs repair they are able to get back into service as quickly as possible. As a result, CAT’s parts business maintains a large inventory of parts to maintain a high delivery service level to the field.

Over 60 percent of the company’s revenue comes from outside of the United States. Because of this, Caterpillar produces its products in facilities distributed around the globe. The company’s general strategy with regard to machine production is to produce its products on the continent where they are to be sold. However, some of its larger and more specialized products are produced in a single location because of the level of capital investment required.

Caterpillar is partially vertically integrated. Internally, the company generally produces components for its products that it feels contribute to the competitive edge of its products. Outside of these areas, the company relies on an extensive base of suppliers to support production. Given that the company’s products are designed to be high quality durable goods, the company requires that components meet stringent specifications for performance and construction. Because of these requirements, the number of suppliers capable of producing these components is limited. This means that often components must be sourced from a country different from where the product is produced. Given these limitations, it is understandable that some of the components that Caterpillar sources are in limited supply.

In addition to having to address the issue of limited capacity in certain segments, the global sourcing of material creates several other problems for Caterpillar. The most prevalent issues are those of material lead times and logistical challenges. Sourcing material from overseas generally increases the time and number of steps required to transport material from its source to its point of use (POU). Both of these items imply that the party organizing transportation has to monitor material for a longer period of time and through many more steps. Companies must also learn to work with companies and agents in countries that may have significantly different laws and customs. Global sourcing also makes companies more susceptible to fluctuations in exchange rates and regional political instabilities.
1.2.2 Services

Caterpillar operates a number of service businesses that provide financial, remanufacturing, rail, and logistics services to Caterpillar and external clients. The most important of these organizations in a supply chain context is CAT Logistics. This division offers logistics, warehousing, and transportation services for Caterpillar as well as for external buyers. Internally, CAT Logistics houses two groups dedicated to providing logistics for production and service material. These groups are the Manufacturing Logistics Services (MLS) group and the Caterpillar Distribution Services (CDS) group. MLS is responsible for handling the transportation, warehousing, and delivery of parts destined for use in production. MLS also operates the Inbound Logistics Center (ILC) network. The facilities in the ILC network are dedicated to consolidating incoming material from suppliers in central locations. Most of the parts handled by the ILC network are low cost components used in multiple locations. Manufacturing sites served by the ILC network use a kanban pull system to order material from the ILC facilities, which is delivered to production facilities through an established delivery schedule. ILC facilities are capable of repackaging incoming material into kanban quantities as required.

1.2.3 Corporate Strategy

Caterpillar’s corporate strategy is shown in Figure 1. The strategy outlines the key goals, operating principles, and values. SMI and the general ISC initiative are involved in the “Competitive Costs”, “Supplier Collaboration” and “Caterpillar Production System” operating principles. In addition to this strategy, Caterpillar has also defined its “Big 8” Imperatives. The two most important of these in the context of this project relate to the streamlining company’s cost structure and increasing cash pull through.
1.2.4 Organizational Structure

Caterpillar's organizational structure is centered on its main product and service offerings including: construction industries, resource industries, power systems, buyer and dealer support and corporate services. Each of these groups has a Group President that reports to the CEO. Under each Group President are several Vice Presidents that run the various product and service groups. Responsibility for product, production, and supply chain decisions lies with each of the individual product groups. Depending on the facility, products from several product groups may be manufactured in a single location. The Global Purchasing Organization is responsible for the execution of component and material purchasing at a corporate level.

1.3 Caterpillar Production System

The Caterpillar Production System (CPS) was established in 2006 to establish standard processes, metrics, and procedures for Caterpillar's operations. CPS is comprised of 17 defined processes established as the result of the extensive benchmarking of the production systems of other companies.
The CPS Division operates as a dedicated organization within Caterpillar, and owns all of the processes established in the development of CPS. The SMI process is a sub-process in the area of Supply Chain and Materials Management. It is governed by a separate sub-process manual that lays out the steps and considerations that should be taken when engaging suppliers in SMI arrangements.

1.4 Significance of the SMI Process for Caterpillar

SMI represents an important process for Caterpillar because of the current structure of the company’s supply chain. In many cases, Caterpillar assumes ownership of material at the supplier’s location, and CAT Logistics transports that material through their transportation network to the final POU. Figure 2 diagrams the typical condition of Caterpillar’s supply chain. This structure creates a situation in which there is a good deal of material in transit, which ties up a large amount of working capital, especially in the case of material that is sourced from foreign sources. In the current state, inventory pools are held at multiple stages in the Supply Chain: at the supplier (prior to shipment), in Caterpillar warehouses, and at the point of use (in some cases the last two pools are consolidated). The situation is exaggerated when multiple Caterpillar facilities use a single supplier because their inventory pools are typically not consolidated (except in the case of material that uses the ILC network). Replenishment is typically orchestrated through the use of MRP systems and purchase orders (POs). Decisions in this model are made in a decentralized fashion; both the supplier and Caterpillar make their own production plans and decisions with limited information sharing.
Caterpillar is looking to engage suppliers in the SMI process to help streamline the current state and drive additional efficiencies into the supply chain. Figure 3 shows how the SMI process changes the basic structure of the supply chain. Suppliers are responsible for transporting material to a central point close to Caterpillar's production. From this central inventory pool Caterpillar can pull material for production. In Caterpillar's SMI process suppliers typically own the inventory until it is shipped from the central inventory pool. It is at this point that Caterpillar pays for the inventory according to terms established with the supplier. In the current state, each factory maintains its own inventory buffer that is sized based on material lead-times and demand fluctuations. Under SMI all production that uses a common component or supplier from a region can pull from this central stock, virtually eliminating the need to maintain large buffer inventories at each facility. This central stock can be located in a supplier warehouse in the region or in a segregated area in a current Caterpillar facility. In exchange for providing this service suppliers typically charge an additional per unit fee to Caterpillar to offset their increased costs.

By creating central demand forecasts with their supplier, Caterpillar ensures that suppliers are aware of how much material is needed and when it is needed in plant. The active sharing of POU consumption
information allows suppliers to adjust production and shipments according to actual material usage. The additional communication between the two parties allows for exceptions and shifts in production to be addressed more quickly than in the status quo. This allows for more flexibility in the supply chain and a better working relationship between Caterpillar and its suppliers. The transition from MRP and PO based replenishment, combined with a more complete inventory picture under SMI allows suppliers to reduce production costs through better production planning. It is under SMI that central planning and coordination is used to ensure that the given supply chain functions more efficiently; thereby reducing overall inventory in the supply chain, reducing Caterpillar’s required working capital, and helping to strengthen relationships with suppliers.

Figure 3: Diagram of Caterpillar supplier chain with SMI.

1.5 Overview

Chapter 2 and Chapter 3 take a look at the supply chain concepts most closely related to SMI: VMI and CPFR. Chapter 2 examines the basics of VMI and how basic multi-echelon inventory theory can be used to show that VMI leads to a reduction in inventory compared to a traditionally planned supply chain. Chapter 3 builds on this by reviewing the current body of literature surrounding VMI and CPFR with
specific emphasis on how these processes are classified, implemented, their potential benefits, and
examining what challenges they typically encounter.

Chapter 4 through Chapter 6 develop the current state of the SMI process at Caterpillar, look at potential
frameworks for the identification of opportunities, and examine the evaluation process for SMI decisions.
Chapter 4 examines the current state of the Caterpillar supply chain using case studies and empirical
evidence to determine what issues currently exist. Chapter 5 looks at the process for identifying SMI
opportunities, and proposes a framework for identifying opportunities given a lack of pre-existing targets.
Chapter 6 looks at the evaluation process for SMI opportunities, and proposes additional supplier vetting
criteria. Chapter 7 provides a summary of the study’s findings and proposes several recommendations to
facilitate better process deployment.

NOTE: The data presented in this report have been modified to protect the integrity of internal company
data. The data points are for illustrative purposes only and should not be used in any non-academic
purpose.
2 Basics of Vendor Managed Inventory and CPFR

The Caterpillar SMI process is essentially a combination of two supply chain management concepts: VMI and collaborative planning, forecasting, and replenishment (CPFR). These initiatives share a common goal of improving integration and collaboration between their suppliers and their downstream customers. These processes are targeted towards increasing operational efficiency (improving production flow, material flow, reducing replenishment costs) and improving supply chain planning. Under the two processes decisions are centralized for a given supplier and supply lane. Leveraging the respective strengths of each process allows Caterpillar to realize the benefits of central replenishment planning and inventory control with suppliers, while still being highly engaged in the planning process. Under the SMI process Caterpillar still maintains overall discretion in deciding its machine production volume, but it can also adjust its production plans based on what suppliers have agreed they can provide.

2.1 Traditional Definitions of VMI and CPFR

Vendor Managed Inventory is typically defined as a process through which the vendor (supplier) assumes responsibility for material replenishment and inventory management for the downstream customer.[5] The precise structure of VMI varies a good deal depending on the level of risk and material ownership the supplier assumes. VMI typically involves the customer sharing point of use (POU) or point of sale (POS) information with the vendor. The vendor uses this information to centrally plan replenishment for their customer, and in many cases manages the inventory for their customer. With VMI vendors typically rely on a combination of POU data and customer projections to assist in the generation of production and sales forecasts for their own operations.

Under VMI the supplier decides on appropriate inventory levels for each of their products and establishes the appropriate inventory policies to maintain inventory at the defined levels. The inventory levels are established based upon negotiated service levels between the suppliers and their customers. In some cases, suppliers can be penalized for poor delivery performance through reductions in VMI service fees or
through a forfeiture of favorable payment terms. VMI is a part of a range of Retailer Supplier Partnerships (RSPs) that include Quick Response (QR), Continuous Replenishment (CR), and Advanced Continuous Replenishment (ACR). Each respective process represents an increase in supplier responsibility and capability ranging from basic forecasting to complete supply chain management.[5],[6]

The use of consignment stocks is common in many VMI instances, but is not necessarily required for successful use of the process. The question of inventory ownership is decoupled from the question of who is responsible for a customer’s inventory. However, inventory ownership often provides one of the necessary incentives to ensure that the vendor is working to set-up their replenishment strategy, so that they are not flooding the supply chain with excess inventory.[6] The desire of the vendor to hold as little inventory as possible is balanced by their having to meet service level and on-time delivery targets for their customer.

Like VMI, CPFR involves centralized replenishment planning, but instead of just the supplier coordinating replenishment both the customer and the supplier collaborate on the replenishment strategy. In this case CPFR requires that suppliers and customers work together to create and co-manage common demand forecasts and replenishment plans.[7] The process requires a supplier’s customers to share a good deal of information regarding sales trends, planned promotions, and other information that can affect production and sales numbers. The process is designed to operate continuously, requiring the supplier and the customer to communicate changes to forecasts and replenishment requirements as they arise. This allows both parties to adjust short-term and long-term requirements and ensure that all parties know what lies on the horizon.

2.2 Basic Goals of VMI and CPFR

VMI helps move both partners from a serially optimized supply chain to a globally optimized supply chain.[6] CPFR builds on top of the concept of a centrally planned and optimized supply chain by insuring that both the supplier and their customer are aligned in terms of forecasted demand, inventory
placement, and replenishment strategy. The implementation of both systems should lead to an overall consolidation of inventory in the supply chain.

For the supplier, VMI helps to smooth product demand by removing a link in the inventory management system. Instead of suppliers and customers managing their own inventory pools, the customer portion of the system is removed from the supply chain. This allows suppliers to monitor overall supply chain inventory levels, accurately stock their warehouses, and help reduce errant orders. By smoothing demand and reducing the potential for the bullwhip effect, VMI helps suppliers to plan their production and utilize assets more efficiently. POU demand information will also allow suppliers to be more flexible in how they use inventories to replenish customers. CPFR also helps to smooth demand fluctuations by tying the supplier and their customer together in the planning process. CPFR provides both parties a view into their partners’ operations allowing the companies to jointly address any impacts to future production.

If consignment stocks are considered under VMI the customers can expect to see a reduction in the working capital required to hold inventory, as well the costs associated with purchasing and managing inventory. The supplier, on the other hand, will see an increase in their required working capital, the cost of which can be offset with VMI service fees to the customer. Suppliers can also offset this increase in working capital by using the improved forecasts to better plan production and more efficiently use capital. The ability of the supplier to maintain VMI without charging exorbitant fees to the customer will be dependent on the size of the supplier, their ability to access working capital, and the sophistication of their operations planning. VMI also allows suppliers to strengthen business ties with their customers.

2.3 Implementation of VMI and CPFR

The implementation of VMI partnerships and development of CPFR capabilities create several challenges when it comes to their deployment. For a supplier to be a good fit for either process they have to be sophisticated enough to handle the added responsibility of inventory and replenishment management. Under a VMI regime the cost of poor supplier performance is much higher than when the customers
managing their own inventory. Customers also have the potential to lose some visibility into the performance of their supply chain, making it harder for them to predict problems unless the supplier communicates them.

Adequate investment must be made in the development of common processes and IT systems to ensure that information can be shared and viewed by both parties in a reliable and timely fashion. This typically involves the development and deployment of common software processes or platforms that both parties can understand and use proficiently. The success of CPFR requires additional investment above and beyond basic VMI. For CPFR to be successful it requires a good deal of organizational alignment and confidence between parties.[9] Both parties must be able and willing to openly share and discuss sales forecasts, perceived industry trends, and product plans.

The Sarbanes-Oxley Act of 2002 (SOX) presents another challenge when it comes to implementing VMI. Section 401 of SOX requires companies to “disclose all material off-balance sheet transactions, arrangements, obligations (including contingent obligations) and other relationships” that have the potential to affect a company’s financial condition or financial reporting.[10] Off-balance sheet transactions and obligations include long-term volume purchase agreements, guaranteed purchase contracts, and VMI. Companies engaging in VMI arrangements need to ensure, under Section 404 of SOX, that adequate certified internal controls and records are maintained.[11] This is especially true if there is an obligation to purchase inventory under a VMI agreement when suppliers maintain ownership of material. SOX also poses particular challenges when the VMI and CPFR concepts are combined. Because both parties are collaborating on forecasts and inventory plans it is hard to determine the party that is actually making decisions, leading to confusion as to whether or not inventories count as off-balance sheet obligations for customers. Clear controls need to be in place to ensure that inventories are adequately controlled and accounted for in accordance with SOX.
2.4 The Role of 3rd Party Logistics Providers in VMI

3rd Party Logistics Providers (3PLs) are often involved in VMI arrangements. They act as an intermediary between suppliers and their customers providing transportation, warehousing, and inventory management services on behalf of the supplier. 3PLs are useful in that they can effectively augment a supplier's capabilities as long as the supplier knows how to interact and manage them. In some cases 3PLs can assist suppliers in maintaining the service levels required by their VMI arrangement by providing analysts to monitor inventory levels and ensure that the supplier has enough inventory in the pipeline.

The costs of 3PL service vary depending on the items being handled and transported, as well as the value added services being provided. Many 3PLs can provide value added services to customers and suppliers including quality inspection, receiving inspection, and in some cases defect rework. In some cases 3PLs can actually assume ownership of the material on behalf of the supplier and manage it (known as asset owning 3PLs).[6] This can be beneficial for VMI in the event that a foreign supplier cannot import material on their own or does not have access to the capital required by VMI.

2.5 Application of Multi-Echelon Inventory Theory to VMI

In this section multi-echelon inventory theory is applied to VMI with the goal of demonstrating how implementing VMI will lead to a reduction of inventory in the entire supply chain. Four examples will be examined: the traditional Caterpillar supply chain, the VMI Caterpillar supply chain, the VMI supply chain with CPFR, and the mixed supply chain. In all of these examples the following assumptions are made:

3

- Both Caterpillar and its supplier use a continuous review (s,S) inventory policy,
- The supply chain is operating at steady-state,
- Ordering is done on a weekly basis,

---

3 The two examples presented are simplifications of a much more complex system of distribution and are used to illustrate the potential benefits of VMI only.
• Desired service level for both parties is 98% (implies a z value of approximately 2),
• No correlation exists between the variation in product demand across Caterpillar’s sites (i.e. the demand for the products produced from one facility is independent from the demand for products produced in another)\(^4\),
• There is no mechanism for inventory transfer between Caterpillar facilities.

For each warehouse facility Safety Stock levels are established such that \( SS = z\sigma\sqrt{L} \), where \( L \) is the lead-time for the product (including review period) and \( \sigma \) is the standard deviation of demand.[6]

2.5.1 Traditional Supply Chain Example

The traditional replenishment model for the Caterpillar supply is shown in Figure 4. In this model a single supplier provides material to Caterpillar production facilities located in two geographic regions. Stocks in this example are maintained at each Caterpillar facility and at the supplier. The Caterpillar Distribution node in this example acts as a cross-dock only. The lead-time to each facility incorporates the total time it takes to transport material from the supplier through this network (including cross-dock time). In this model all material is pushed to its final stocking point, and there is no push-pull boundary.

Total safety stock (SS) for each of Caterpillar’s regions can be calculated as \( Region \ SS = \sum_{i=1}^{i=N} z\sigma_i\sqrt{L_i} \),

where \( N \) is the number of facilities in a region. This reduces to \( Region \ SS = Nz\sigma\sqrt{L} \), assuming that the demand variation and lead-times are similar within a given region. The total safety stock for Caterpillar across all of its regions is \( \sum_{j=1}^{j=R} n_j z\sigma\sqrt{L_j} \), where \( R \) is the number of geographic regions.

Average Stock is simply the sum of average demand and safety stock.

For the supplier, its safety stock can be assumed to be similar to that of a single location except for the uncertainty that the supplier faces. Since it is assumed that there is no correlation between the

\(^4\) In reality, the demand for all related products in a given product segment will be correlated to some degree. Given the complicated product portfolio of the company this assumption is made to simplify the analysis.
demand requirements of each of the Caterpillar sites, the supplier’s standard deviation of demand can be expressed as $\sigma_s = \sqrt{\sum_{j=1}^{J} \sum_{i=1}^{N} \sigma_{i,j}^2}$.

The parameters used in this example and the results of the safety stock calculations are shown in Table 1. Demand is set to model a high throughput item with 10% standard deviation in demand. Including Caterpillar’s stocks and the suppliers stocks the entire system has a total safety stock of 62,811 units.
Table 1: Parameters and stock levels for the traditional supply chain example.

<table>
<thead>
<tr>
<th>Location</th>
<th>Demand (μ)</th>
<th>Standard Deviation (σ)</th>
<th>Lead Time (L)</th>
<th>Safety Stock (SS)</th>
<th>Average Stock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Units</td>
<td>items/week</td>
<td>weeks</td>
<td>units</td>
<td>units</td>
<td>units</td>
</tr>
<tr>
<td><strong>Caterpillar Region 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Site A</td>
<td>10,000</td>
<td>1,000</td>
<td>5</td>
<td>4,472</td>
<td>9,472</td>
</tr>
<tr>
<td>Site B</td>
<td>10,000</td>
<td>1,000</td>
<td>5</td>
<td>4,472</td>
<td>9,472</td>
</tr>
<tr>
<td>Site C</td>
<td>10,000</td>
<td>1,000</td>
<td>5</td>
<td>4,472</td>
<td>9,472</td>
</tr>
<tr>
<td><strong>Caterpillar Region 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Site D</td>
<td>25,000</td>
<td>2,500</td>
<td>6</td>
<td>12,247</td>
<td>24,747</td>
</tr>
<tr>
<td>Site E</td>
<td>25,000</td>
<td>2,500</td>
<td>6</td>
<td>12,247</td>
<td>24,747</td>
</tr>
<tr>
<td><strong>Supplier</strong></td>
<td>80,000</td>
<td>3,937</td>
<td>10</td>
<td>24,900</td>
<td>64,900</td>
</tr>
<tr>
<td><strong>Supply Chain Total</strong></td>
<td></td>
<td></td>
<td></td>
<td>62,811</td>
<td>142,811</td>
</tr>
</tbody>
</table>

2.5.2 VMI Supply Chain Example

The VMI supply chain model is shown in Figure 5. In this model the supplier operates two regional warehouses from which the Caterpillar sites can replenish. Each warehouse maintains the central safety stock for the region. It is assumed that each Caterpillar facility maintains a small inventory and is replenished on a weekly basis. The supplier is assumed to carry a minimum amount of inventory at their production facility (enough to fill desired transportation mode economically), have full control over the stock in its regional warehouses, and carry inventory under consignment. It is also assumed that Caterpillar has “right-sized” its inventories to reflect the new respective lead-times. In this model the push-pull boundary is clearly established between the supplier and Caterpillar. Lead times for the Caterpillar sites are determined to be approximately two days (this could represent onsite or in-region processing and transit time).

For the supplier, safety stock is similar to that in the previous example except that they are maintaining stocks in two regions. Supplier safety stock for the region can therefore be determined to be

\[ \text{Regional SS} = \sum_{j=1}^{n} n_j z \sigma_j \sqrt{L_j}, \]

where \( \sigma_j \) is the standard deviation of demand across a region. The parameters and results of this example are shown in Figure 5. Total supply chain inventory is shown to be 51,820 units in this example.
Figure 5: Simplified illustration of supply chain structure under ideal Caterpillar VMI structure. Supplier warehouses in each region provide central inventory pools for the sites in that region to pull from.

Table 2: Parameters and stock levels for the VMI example.

<table>
<thead>
<tr>
<th>Location</th>
<th>Demand ($\mu$)</th>
<th>Standard Deviation ($\sigma$)</th>
<th>Lead Time ($L$)</th>
<th>Safety Stock (SS)</th>
<th>Average Stock</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Units</td>
<td>items/week</td>
<td>weeks</td>
<td>units</td>
<td>units</td>
</tr>
<tr>
<td><strong>Caterpillar Region 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Site A</td>
<td>10,000</td>
<td>1,000</td>
<td>0.40</td>
<td>1,265</td>
<td>6,265</td>
</tr>
<tr>
<td>Site B</td>
<td>10,000</td>
<td>1,000</td>
<td>0.40</td>
<td>1,265</td>
<td>6,265</td>
</tr>
<tr>
<td>Site C</td>
<td>10,000</td>
<td>1,000</td>
<td>0.40</td>
<td>1,265</td>
<td>6,265</td>
</tr>
<tr>
<td><strong>Caterpillar Region 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Site D</td>
<td>25,000</td>
<td>2,500</td>
<td>0.40</td>
<td>3,162</td>
<td>15,662</td>
</tr>
<tr>
<td>Site E</td>
<td>25,000</td>
<td>2,500</td>
<td>0.40</td>
<td>3,162</td>
<td>15,662</td>
</tr>
<tr>
<td><strong>Supplier VMI Warehouse</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Region 1</td>
<td>30,000</td>
<td>1,732</td>
<td>15</td>
<td>13,416</td>
<td>28,416</td>
</tr>
<tr>
<td>Region 2</td>
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<td>3,536</td>
<td>16</td>
<td>28,284</td>
<td>53,284</td>
</tr>
<tr>
<td><strong>Supply Chain Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>51,820</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>131,820</td>
</tr>
</tbody>
</table>
2.5.3 Addition of CPFR to VMI Supply Chain

In this example the impact of CPFR on supply chain inventory levels is examined. The utilization of CPFR in the supply chain allows for the development of common forecasts between Caterpillar and the supplier. In this example, the standard deviation of demand for the supplier’s VMI warehouses is reduced by 25% compared to the basic VMI supply chain example from the previous section. This reduction in variation between the supplier and Caterpillar is the result of the harmonization forecasts and the continuous sharing of changes to planned production between the two parties. The structure of the supply chain in this example is the same as that discussed in the previous section (Figure 5). Table 3 shows the results of this scenario. Total network safety stock is further reduced to 41,395 units (down from 62,811 in the traditional supply chain example).

<table>
<thead>
<tr>
<th>Location</th>
<th>Demand (μ)</th>
<th>Standard Deviation (σ)</th>
<th>Lead Time (L)</th>
<th>Safety Stock (SS)</th>
<th>Average Stock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Units</td>
<td>Items/week</td>
<td>weeks</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Caterpillar Region 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Site A</td>
<td>10,000</td>
<td>1,000</td>
<td>0.40</td>
<td>1,265</td>
<td>6,265</td>
</tr>
<tr>
<td>Site B</td>
<td>10,000</td>
<td>1,000</td>
<td>0.40</td>
<td>1,265</td>
<td>6,265</td>
</tr>
<tr>
<td>Site C</td>
<td>10,000</td>
<td>1,000</td>
<td>0.40</td>
<td>1,265</td>
<td>6,265</td>
</tr>
<tr>
<td><strong>Caterpillar Region 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Site D</td>
<td>25,000</td>
<td>2,500</td>
<td>0.40</td>
<td>3,162</td>
<td>15,662</td>
</tr>
<tr>
<td>Site E</td>
<td>25,000</td>
<td>2,500</td>
<td>0.40</td>
<td>3,162</td>
<td>15,662</td>
</tr>
<tr>
<td><strong>Supplier VMI Warehouse</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Region 1</strong></td>
<td>30,000</td>
<td>1,299</td>
<td>15</td>
<td>10,062</td>
<td>25,062</td>
</tr>
<tr>
<td><strong>Region 2</strong></td>
<td>50,000</td>
<td>2,652</td>
<td>16</td>
<td>21,213</td>
<td>46,213</td>
</tr>
<tr>
<td><strong>Supply Chain Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>41,395</td>
</tr>
</tbody>
</table>

2.5.4 Mixed Supply Chain Example

In this example one region is supplied by traditional methods, while another region is supplied by VMI. This example is designed to simulate what happens when the entire supply chain does not transition to VMI for a given supplier/product pairing. This example, shown in Figure 6, assumes that Region 1 is closer to the supplier’s production than Region 2 and as such is being replenished directly from the supplier. Using the methods described in Sections 2.5.1 and 2.5.2 the same analysis can be completed for
the mixed supply chain. Table 4 shows the results of this analysis. Total Safety Stock in this case is approximately 64,067 units.

![Figure 6: Simplified illustration of the mixed supply chain. The supplier replenishes Caterpillar using transitional inventory positioning and VMI.](image)

Table 4: Parameters and results for mixed supply chain example.

<table>
<thead>
<tr>
<th>Location</th>
<th>Demand (μ)</th>
<th>Standard Deviation (σ)</th>
<th>Lead Time (L)</th>
<th>Safety Stock (SS)</th>
<th>Average Stock</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Units</strong></td>
<td>items/week</td>
<td>weeks</td>
<td>weeks</td>
<td>units</td>
<td>units</td>
</tr>
<tr>
<td><strong>Caterpillar Region 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Site A</td>
<td>10,000</td>
<td>1,000</td>
<td>0.40</td>
<td>1,265</td>
<td>6,265</td>
</tr>
<tr>
<td>Site B</td>
<td>10,000</td>
<td>1,000</td>
<td>0.40</td>
<td>1,265</td>
<td>6,265</td>
</tr>
<tr>
<td>Site C</td>
<td>10,000</td>
<td>1,000</td>
<td>0.40</td>
<td>1,265</td>
<td>6,265</td>
</tr>
<tr>
<td><strong>Caterpillar Region 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Site D</td>
<td>25,000</td>
<td>2,500</td>
<td>6</td>
<td>12,247</td>
<td>24,747</td>
</tr>
<tr>
<td>Site E</td>
<td>25,000</td>
<td>2,500</td>
<td>6</td>
<td>12,247</td>
<td>24,747</td>
</tr>
<tr>
<td><strong>Supplier</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VMI Warehouse</td>
<td>30,000</td>
<td>1,732</td>
<td>15</td>
<td>13,416</td>
<td>28,416</td>
</tr>
<tr>
<td>Production Facility</td>
<td>50,000</td>
<td>3,536</td>
<td>10</td>
<td>22,361</td>
<td>47,361</td>
</tr>
<tr>
<td><strong>Supply Chain Total</strong></td>
<td>64,067</td>
<td>144,067</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.5.5 Analysis of Examples

These four examples illustrate how changing the structure of the supply chain affects the overall level of inventory in the supply chain. Switching between the traditional model and the VMI model results in the
removal of just short of 11,000 units from the overall supply chain. This level of inventory reduction will decrease in the presence of higher demand uncertainty or as lead-times increase for products. As expected with VMI the supplier’s total inventory levels increase (by about 16,800 units). This shows the importance of the supplier being able to handle this increased level of inventory in a practical sense and a financial sense. It also shows that suppliers must be able to find some benefit in holding this extra inventory. The basic VMI example does not take into account the collaborative benefits of CPFR. The third example shows how a reduction in order variation between Caterpillar and the supplier through the use of CPFR nets additional inventory reductions (10,425 units of safety stock). When multiple replenishment methods are used in the supply chain the total amount of inventory in the supply chain actually increases (in this example by 1,256 units) because the supplier has to maintain adequate safety stock in both a regional distribution center and at its production center. This highlights the importance of having a cohesive strategy for a given supplier and product combination.

2.6 Chapter Summary

This chapter covers the basic processes behind Caterpillar’s SMI capability: Vendor Managed Inventory (VMI) and Collaborative Planning, Forecasting and Replenishment (CPFR). Under VMI vendors take control of the replenishment process using customer demand information to plan replenishment. With CPFR both the supplier and their customer collaborate to develop forecasts and replenishment plans. Both processes have the ultimate goal of centralizing replenishment decision-making in the supply chain. This helps to smooth product demand by removing the barriers that exist between organizations, thereby creating a more responsive supply chain with better material flow. Consignment stocks can be used to help align supplier interests with these goals. Using basic Multi-Echelon Inventory concepts it is shown that centrally stocking material leads to a reduction in overall inventory levels in the supply chain provided that a cohesive strategy is implemented. The lowest levels of inventory in the supply chain are shown to be when a combination of VMI and CPFR is employed.
3 Literature Review

A key part of the evaluation of the use of SMI at Caterpillar involved looking at how the SMI process was defined in the spectrum of collaborative processes and ensuring that the process addressed potential pitfalls that had previously been identified in the literature on the topic. Since SMI is a process germane to Caterpillar the most relevant external information is contained within the body of literature pertaining to Vendor Managed Inventory and CPFR. There are several particular areas of focus for the body of work surrounding VMI. These areas of focus include the position of VMI amongst other replenishment collaboration types, methods for evaluating VMI collaborations, the benefits of VMI, the issues inherent with VMI, determinants of VMI success, and product suitability for VMI.

Given that VMI was pioneered and popularized in the retail and consumer goods spaces many different terms are used in reference to the channel partners. For the purposes of this literature review the upstream partner will be referred to as the supplier and the downstream partner will be referred to as the buyer. It is also important to note that references to the incorporation of Point of Sale (POS) data will be taken to be Point of Use (POU) or Point of Consumption (POC) information in the context of manufacturing.

Looking at the basics of the VMI process it is important to first address the question of inventory ownership. Since the party owning the inventory the channel is in inherently in a riskier position than the party not owning inventory it is important to answer this question at the start of any VMI arrangement. Biyalogorsky and Koenigsberg determine in their study of channel ownership that unless there is high demand uncertainty both parties generally prefer that the supplier own the inventory. When there is high market uncertainty both parties prefer to own the material because they are better able to respond to the needs of downstream parties. The authors conclude that when there is not a high level of market uncertainty the parties are more indifferent to who owns the material, and that under intermediate market uncertainty the profit of the supply channel is maximized when the supplier owns the material.[12]
3.1 Positioning of VMI

The first thing that must be established is how VMI fits in amongst comparable initiatives. Olson and Xie establish a spectrum of coordination amongst various processes including Efficient Consumer Response (ECR), VMI, Continuous Replenishment, and Collaborative Planning Forecasting and Replenishment (CPFR). They present VMI as a middle step between the processes of ECR (simple information sharing) and CPFR, and CPFR as the highest level of coordination involving continuous complete information sharing.[13] Sari shows that the differences in performance and functionality between CPFR and VMI can be minimal in situations where the supplier’s capacity is limited or where product lead-times are short. However, the collaborative elements of CPFR are more beneficial in situations where there is a good deal of uncertainty.[9]

3.1.1 Defining and Evaluating VMI Systems

Since VMI systems can display a variety of traits in their development and deployment it is important that a common language be used to characterize them. Kauremaa et al. divide VMI systems into three major categories defined by the agents driving the initiative [14]:

- **Basic**: Replenishment responsibility is transferred from buyer to supplier and is driven by the buyer,

- **Cooperative**: Bilateral interest in improving supply chain performance (including better material flow and alignment of forecasts between parties),

- **Synchronized**: Driven primarily by the supplier’s desire to increase its internal efficiency in production and reducing order fulfillment costs.

Sarpola develops a more detailed method by defining VMI systems using six categories. These categories include inventory location, the methods used to distribute inventory, methods used to monitor inventory and demand, the role of information systems, responsibility of the inventory decision, and inventory
ownership. Sarpola positioned the purest VMI system as one with real time inventory monitoring, real-time demand visibility, distributed inventory, supplier distribution, suppliers responsible for replenishment, suppliers responsible for inventory, and where information systems play an important role. These traits are typically seen as being interdependent.[5] Elvander et al. expand upon this by adding inventory ownership, control limits, the horizontal integration of buyers, the horizontal integration of items, and the level of vertical integration of the supplier as additional criteria with which to evaluate VMI systems.[15] These criteria can be used to characterize and understand VMI systems and help manage their implementation.

3.2 Benefits of VMI

The benefits of VMI are likely the most documented part of the concept of VMI. Disney and Towill show that VMI can reduce the impact of the bullwhip effect by almost half.[16] Claassen et al. state that VMI supports reduced inventory, reduced costs, and increases supplier service level.[17] On a more basic level Valentini and Zavanella describe the benefits of VMI to be the consistent availability of material for the buyer, buyer paying for material upon use, and that the reinforced links between the supplier and the buyer.[18] Yao at al. show with an analysis of various supply chain parameters on VMI that replenishment frequency always increases under a VMI arrangement.[19] Dong and Xu show that VMI may increase short-term costs for suppliers, but long-run profit will increase as supplier realizes VMI benefits. They also show that VMI will push the purchase price of material higher unless there exists a large mismatch in ordering cost between buyer and supplier in the status quo.[19]

A key trait of VMI when compared to traditional MRP based inventory strategies is the increased level of information sharing between buyers and suppliers. Sari explores the effect of VMI under varied levels of information, and determines that although buyer uncertainty in demand decreases the effectiveness of VMI, better information sharing can mitigate this effect. [20]
Nyen et al. determine that buyers typically always favor VMI. They also show that suppliers have a range of prices that they can charge for VMI that will allow the buyer to continue to benefit while allowing the supplier to offset their higher inventory management costs. They add that the benefits are clearest when there exists a high service level expectation between buyers and suppliers, or when most of a supplier’s capacity is utilized.[21] Savaşaneril and Erkip demonstrate that suppliers also see a good number of benefits under VMI, but that these benefits may not extend beyond those of simple information sharing. They state that the primary benefits for suppliers are flexibility in timing replenishment and quantity of shipments. The potential benefits include increased flexibility and support the potential for increased benefits in tight capacity situations because the supplier is able to match production to demand and plan for customer needs.[22]

In a global environment, Lee and Ren show that in the presence of exchange rate uncertainty between a supplier and a buyer supply chain cost reductions are greater under VMI because the supplier is not bound by a fixed replenishment policy. Instead, the supplier is able to choose their order quantities, reorder points, and order-up to levels based on current exchange rates.[23]

3.3 Conditions for VMI Success

With VMI being used in a wide variety of industries it is important to understand what common traits drive suppliers and buyers to establish successful VMI partnerships. Waller et al. determine that success with VMI is highly dependent on interpersonal relationships, and that trust between chain partners is critical.[24] James et al. surveyed a variety of actors involved with VMI and determined that the following dimensions were important drivers for VMI: the buyer’s inability to control stock, item importance, range of items, nature of demand, buyer’s ability to use information, supplier’s ability to take advantage of additional information from VMI, and supplier’s ability to manage buyer demand information.[8] Claaseen et al. state that information sharing and quality information systems are important factors for successful VMI.[17]
In a study of the establishment of a VMI partnership between Boeing and Alcoa for wing spar materials, Micheau concludes that the following were important in helping the partnership to succeed: successful integration of information, real-time information sharing, accurate demand information, awareness of the benefits of blanket purchase orders versus purchase order releases, integrated information systems, and high levels of cooperation and trust. Micheau also adds that it was useful to have a buffer warehouse that could be used to house incoming material from the supplier for the purposes of inventory tracking.[25]

Niragjan at al. developed criteria to evaluate VMI decisions that included buyer and supplier related elements. They determined that buyers should have stable revenues, high purchasing transaction costs, good information and communication systems, and no issues sharing demand and forecast information. They also determined that suppliers must have high levels of trust with buyers, long-term relationships with buyers, that VMI benefits should be apparent to a company and its suppliers, that suppliers are willing to cooperate, and that the information systems of the buyers and suppliers can be integrated.[26]

Fry et al. establish that when it comes to executing VMI minimum and maximum stock levels need to be set according to product variance. They also demonstrate that penalties for poor performance have to be set in such a way that the benefits of VMI are not eroded due to higher costs, and that poor execution of VMI will harm suppliers.[27]

3.4 Challenges with VMI

VMI and related processes represent a challenge when it comes to their successful integration into current business processes. Both processes represent dramatic changes in the way a buyer and supplier define their relationship. Valentini and Zavanella detail how differing motivations can lead to complications when setting inventory boundaries. Suppliers want to have the widest gap between minimum and maximum stock levels so they have the options to maximize production flexibility or keep capital investment at a minimum. Buyers on the other hand want to keep the gap as small as possible to get the benefit of having a high safety stock (for which the cost is the responsibility of the supplier), while
maintaining a minimal amount of space for supplier inventory (assuming VMI inventory is stored in the buyer’s facility). [18] Dong and Zu as well as Yao et al. show that the benefits of VMI are not always evenly distributed and in many situations tend to favor the buyer. Yao et al. also show that this inequality is present even when the supplier increases purchase price to offset the additional costs of VMI.[19], [28]

Despite the amount of literature debating the benefits of VMI and the challenges associated with attaining those benefits, there is little written about the important step of determining what products are suitable for VMI. Valentini and Zavanella contend that the best items for a consignment stock or VMI regime are those where supply chain performance is critical to the buyer (parts of strategic value or critical to assembly tasks). The ideal VMI item is also one that is characterized by constant consumption.[18] Niranjan et al. ascertain that VMI products should be standardized as sold from the supplier (i.e. minimal customization between buyers), prone to infrequent changes in product specification, possess a standard product identification throughout the supply chain, low demand variance, forecasted demand and monitored stock levels.[26]

3.5 Literature Summary

This chapter analyzes the literature behind VMI and CPFR. The two processes are viewed as part of a larger continuum of collaborative supply chain processes with CPFR representing the highest level of coordination. Previous work has shown that market uncertainty has an impact on the preference of material ownership in the supply chain. VMI has been shown to have many benefits if implemented properly in the supply chain. These benefits include increasing overall supply chain profit, helping to mitigate difficulties encountered in capacity restricted production, and protection from currency fluctuations. The benefits of VMI have also been shown to be highly dependent on the relationship between a supplier and their customer, the capabilities of the individual suppliers, and the sophistication of the systems supporting collaboration. Challenges occur with VMI and CPFR when supplier and buyer motivations are misaligned, and when the benefits of the process are not understood or properly distributed.
4 Current SMI Process Use

One of the primary goals of this study was to determine the current state of the SMI process as it is deployed within Caterpillar. This chapter reviews the current state of the process at Caterpillar. In most instances, the process is currently deployed in a fashion similar to that depicted in Figure 3. In this model, suppliers replenish a central pool of inventory that is located at a regional warehouse or a segregated section of a current Caterpillar warehouse. From this inventory pool, production facilities can pull inventory as required for production. Replenishment planning in this model is coordinated between the supplier and Caterpillar through collaborative forecasts and exception handling.

The following sections provide a detailed explanation of the benefits that Caterpillar is hoping to gain from deploying SMI, an overview of the current SMI deployment process, several case study analyses, and a comparison of Caterpillar’s current ability with the entire spectrum of VMI.

4.1 Caterpillar’s Perceived SMI Benefit

The CPS process manual outlines several targeted benefits that can be realized from deploying the SMI process. These benefits can be divided into those the supplier will realize and those that Caterpillar will realize. The benefits identified for Caterpillar include the following:

- Improved/expanded collaboration with suppliers which reduces costs,

- Increased service level to POU,

- Improved inventory velocity/Increased cash pull-through,

- Improved overall supply chain inventory velocity and flexibility with reduced supply chain response time,

- Reduction in interruptions to production,

- Reduction in cost of controlling inventory,
• Reduction in material handling time/costs,

• Quicker responses to shifting demand,

• Improved surplus inventory management,

• Opportunity to have other value added service performed.

While suppliers often receive a fee for inventory management and other services provided as a part of an SMI arrangement, it is important that they also realize the other potential benefits of SMI for suppliers.

The SMI process manual identifies the following as potential benefits for suppliers:

• Direct access to buyer “real” consumption information,

• Better forecasting through collaboration,

• More efficient production through use of optimal production lot sizes,

• Improved buyers satisfaction through increased service level to Caterpillar facilities,

• Improved/expanded relationships with Caterpillar,

• Increased sales revenue through improved relationships and better service level,

• Reduced fulfillment costs,

• Reductions in inventory (driven by less uncertainty and better data from buyer),

• Reduction of administration costs,

• Improved response time,

• Improved buyer satisfaction by fewer production interruptions.
4.2 Current Deployment Process

The SMI deployment process prescribed by Caterpillar is divided into three distinct phases according to six-sigma methodology: define/measure, analyze/improve, and control. The first phase, the design/measure step, is designed to identify SMI opportunities (parts and suppliers) and to begin team preparations for engaging suppliers. The process manual sets several guidelines for the identification of SMI opportunities. These guidelines include the following:

- Transit time between supplier and Caterpillar should be greater than two days,
- Products selected have a high level of forecast accuracy,
- Products should be subject to infrequent design changes,
- Suppliers should be able to understand and work with pull signals (operationally and in IT infrastructure),
- Suppliers should have previous SMI experience.

Once potential SMI suppliers and part numbers have been identified, the analyze/improve phase can begin. In this phase the justifications for moving to SMI are established, and supplier capabilities are verified. The following steps should be taken during this phase to ensure the viability of SMI implementation:

- The current state of the supply chain should be evaluated to ensure that any current problems can be addressed under an SMI agreement,
- The scope and requirements of an SMI arrangement are negotiated with the supplier,
- Caterpillar should verify that the supplier is capable of legally importing material, inventory management, and transportation management,
- Common systems need to be developed between the supplier and Caterpillar for the communication of demand information, forecasts, and pull triggers,
- Target service levels are established and communicated between parties,
• Kanban container lot sizes are established with supplier,

• The supplier must obtain quotes for transportation (from CAT Logistics or 3rd Party), as well as costs for any 3PL services,

• The Supplier communicates SMI costs to Caterpillar,

• Caterpillar completes a Total Cost of Ownership (TCO) model and determines if SMI project is viable,

• A Memorandum Understanding (MOU) must be signed between Caterpillar and the supplier. In the MOU the supplier assumes responsibly and ownership of inventory until the pull signal is received and the material is transferred to Caterpillar.

The control phase is where the measurement and monitoring of the established SMI process occurs. Supplier delivery performance should be monitored, and unacceptable deviations addressed. Caterpillar shares long term forecast and actual usage information with the supplier, and both parties monitor total supply chain inventory to ensure that the system is performing properly.

4.3 Case Studies

In an effort to understand the current state of SMI at Caterpillar many individuals involved the process were surveyed. These conversations helped shed light on many instances where SMI was deployed, the challenges with deploying it, and the best practices/lessons learned to date. In addition to this, external benchmarking was conducted to determine how other companies have deployed similar processes (like VMI). These efforts resulted in the cases presented in the following sections.

4.3.1 Internal Deployments

The following case studies describe the state of collaborative planning within the Caterpillar supply chain. The first two cases describe suppliers that are engaged in SMI partnerships with Caterpillar, while the third supplier is engaged in a proactive centralized replenishment processes similar to CPFR with
Caterpillar. These studies were chosen because of their illustrative nature and are not intended to be exhaustive examples of the status of collaborative planning in the supply chain.

4.3.1.1 Foreign Supplier of Structural Components (Supplier A)

Background: Supplier A was initially developed to supply structural components to Caterpillar manufacturing facilities in the supplier’s home country. During the economic downturn of 2008 Caterpillar lost some of its domestic suppliers that produced structural components. In an effort to reduce costs and shore up supply, additional components were sourced from Supplier A under a SMI arrangement. These new components were meant for use some of Caterpillar’s larger products and were more complex than the ones the supplier was providing for Caterpillar.

From the start the increased complexity of the new components caused quality issues for Supplier A. In addition to this, Supplier A had trouble meeting staffing levels for its facility. In recent months the supplier has missed a targeted production increase. This targeted production rate was above the supplier’s demonstrated capacity.

The supplier had a SMI agreement with Caterpillar, under which it was supposed to be maintaining stock at a warehouse in the continental United States to meet Caterpillar’s domestic demand. Because the supplier was currently capacity constrained they depleted their current inventory in the U.S. and are unable to replenish their warehouse to meet production requirements.

For Caterpillar to maintain production levels the components have been sent via expedited means in recent months. This stopgap measure costs Caterpillar a good deal of money (due to the number, size, and weight of the parts). Because the supplier ran into cash flow issues stemming from not being able to meet production targets and significant rework, Caterpillar significantly reduced its payment term length for this supplier to ensure that they have the necessary capital to maintain production.

Caterpillar has engaged another supplier as an alternate source of parts to offset the issues Supplier A is having meeting its capacity ramp. Supplier A anticipates that they will be able to meet production targets
and begin restocking their U.S. warehouse by the middle of 2012, allowing for the resumption of SMI activities.

*Lessons Learned:* This case demonstrates how important it is to clearly understand a supplier’s capabilities and ensure that they have the required excess capacity when establishing SMI arrangements. While these areas should be considered before engaging a supplier in any sort of supply chain arrangement, SMI suppliers compel extra scrutiny because of the additional responsibility required by the process. Despite the fact that these areas are covered in the supplier evaluation portion of Caterpillar’s SMI process manual they were not given adequate weight when evaluating this supplier.

In this case the issue of supplier capability centers on manufacturing ability. While the supplier had the knowledge and knowhow to meet the requirements of the less complex components it was producing, it did not have the capability at the outset to produce the larger and more complicated components at an increasing rate. The second aspect of supplier capability that is important to note here is ensuring that the supplier can meet personnel requirements and has the required level of working capital (especially when the supplier is expected to increase output).

While in this case it is hard to differentiate the impact of quality issues from the supplier’s capacity constraints, this case demonstrates the importance of ensuring supplier capacity when it comes to establishing SMI arrangements. Capacity in excess of forecasted demand is required to implement a SMI arrangement, as inventory must be established at the central location for facilities to begin to pull from it. In this case the supplier was never able to reach a steady state with its SMI operations because of its production restrictions. Especially important is that the supplier has solid plans for increasing output, or that they have demonstrated the ability in the past.

In addition, this case shows the potential importance of active and ongoing supplier collaboration. In the event that problems do develop with a supplier on SMI both parties need to proactively address the issues. Had Supplier A and Caterpillar used the collaborative elements of the SMI process the supplier’s issues...
could have been addressed more readily. The companies could have made adjustments to production schedules or negotiated better terms on expedited transportation to minimize the impact of Supplier A’s issues. In this case, the lack of communication from Supplier A to Caterpillar strained the relationship between the two parties and forced Caterpillar to seek out another supplier.

4.3.1.2 Forged Component Supplier (Supplier B)

Background: Supplier B is a provider of forged components to Caterpillar. Based in Asia, the supplier provides components to facilities located in the United States and Europe. Supplier B is currently partnered with Caterpillar on a SMI agreement, and has a long-term agreement with Caterpillar to provide material for a defined set of part numbers and lanes. The supplier provides Caterpillar a breakdown of its SMI charges for freight, warehousing, and importation so that SMI costs can be easily evaluated. The supplier is currently maintaining regional warehouses within a 100-150 mile radius of the Caterpillar plants it serves.

Initially, there were issues in the SMI process when engineering changes were put into effect. The changes were not communicated in a timely manner forcing the supplier to adjust production quickly. The supplier also did not evaluate its on-hand inventory leading to a situation were some of the material might be unusable for production. Another issue with the SMI implementation had to do with the frequency with which Caterpillar was pulling material from the supplier. Initially, Caterpillar’s facilities were pulling small amounts of material on nearly a daily basis from the supplier. Given that there is a fixed cost associated with a pull, this practice cost the supplier more than they originally anticipated when the agreement was set-up. Caterpillar and the supplier negotiating a set replenishment schedule alleviated this issue.

In setting up the SMI process with Supplier B there was an additional issue with the supplier’s foreign status when it came to importing material. Caterpillar cannot be the importer of record for material entering the United States under a SMI agreement due to customs and SOX requirements. To solve this
issue the supplier created a domestic subsidiary that buys material from the parent company and operates the SMI process in the United States.

*Lessons Learned:* In this case the primary issues with the SMI process stemmed from the handling of engineering changes. This case highlights the importance of communicating engineering changes on a timely fashion. Suppliers also need to evaluate the effect of the proposed engineering changes and drawdown inventory accordingly once a change is received.

The supplier's willingness to provide SMI price information is also worth noting. In many cases suppliers simply provide an end cost as a fixed value or percentage of part cost. Having this information helps Caterpillar evaluate its sourcing strategy and ensure that SMI continues to be a cost effective strategy.

This case also illustrates the importance of setting standards and expectations when a SMI arrangement is negotiated. Expectations such as pull frequency and service level should be established at the outset of the arrangement.

### 4.3.1.3 Rotational Components Supplier (Supplier C)

*Background:* Supply C is a company based in the United States that provides rotational components for transmissions, drivetrains, engines, and attachments. Supplier C produces components in its U.S. factories as well as its international facilities for Caterpillar. While Supplier C does not technically provide Caterpillar with SMI services, they do work closely with Caterpillar to develop forecasts and handle deviations in a manner very similar to a CPFR process. This relationship was established because the supplier has a very centralized planning process for its own operations. Supplier C works with all of its buyers to develop demand forecasts, and combines these with its own industry projections to develop its production plan. Because many of their products use similar production methods they are able to use this process to shift production between facilities as necessary.

By design Supplier C's manufacturing plants are not set-up for shipping product to buyers. Instead the plants send their output to central distribution centers from which the buyer orders are dispatched. In
some cases Supplier C has specialized parts that must be sourced from overseas. In these cases they import the material that is to be consumed by U.S. buyers into the country and store it in a similar fashion to their other production material. While this process closely mirrors the structure of an SMI arrangement, Supplier C does not treat it as such. This operational structure is driven mainly by the supplier’s own desire to effectively manage their own production.

*Lessons Learned:* Even though this example is not strictly an example of an SMI arrangement it is still an example of the benefits of strong supplier collaboration. Because of the structure of this relationship the supplier maintains low inventory levels and is able to level out its production. For Caterpillar, the positioning of the material provides benefits close to that of SMI because transit times are shorter for material (in the U.S.). Collaborative forecasting and exception management also ensure that Supplier C is aware of Caterpillar’s needs and ensures that shortfalls in material availability can quickly be communicated throughout the supply chain.

### 4.3.2 External Deployments – Company X

The final case study presented is of a company that recently established a VMI capability with its suppliers. This example is included because it illustrates how a company can successfully grow its collaborative capabilities with suppliers.

*Background:* Company X manufactures large components for companies in the aerospace industry. The company began using VMI after it was divested from its parent company. The primary driver in its supply chain evaluation during this transition period was the company’s need of free cash to support operations. The company was successful at developing the capability and currently has approximately 75% of its annual component spend on VMI.

To facilitate its VMI implementation the company partnered its suppliers with a 3PL. The 3PL manages inventory onsite for Company X’s supplier in a segregated warehouse. The 3PL receives material from suppliers, kits it if necessary, and distributes it to the POU. Minimum and maximum levels for inventory
are set with input from Company X as a function of component size, value, and the geographic location of the supplier. The company and the 3PL actively monitor inventory levels so that issues can be addressed with the supplier.

*Lessons Learned:* While Company X had an advantage in that the bulk of its production is in a central location and not distributed like Caterpillar’s, it is still possible to garner several takeaways from the company. As Company X selected suppliers for VMI, they targeted those that could provide the greatest impact on improving cash flow. By setting this target they were able to sort through their supply base and make their initial selections for supply partners. Company X also set targets for part selection. They targeted their highest moving parts, parts that were used across multiple product configurations, and parts with stable demand. This combination of targets allowed Company X to put 75% of its material spend on VMI with only 20% of its part numbers. Placing such a large percentage of its material on VMI helped Company X successfully navigate its divestiture and establish its own operations by freeing up desperately needed working capital. The company’s suppliers also credit the process for allowing them to level-load their own production.

### 4.4 Current Challenges with SMI Process

Implementing any collaborative planning process presents a significant challenge requiring the development of common systems, processes, and relationships. Deploying SMI represents a particular challenge for Caterpillar because it involves a good deal of collaboration across internal functional groups, as well as an increased reliance on supplier capabilities. The CPS process manual identifies some potential pitfalls/areas of concern with regard to SMI. These include issues with unclear roles and responsibilities, potential SOX compliance issues, and the need for detailed cost analysis to prevent simply pushing inventory on to the supplier.

The case studies presented in the previous section as well as discussions with many of the current stakeholders in the SMI process generated a good deal of information about the current state SMI process.
While there have been successes with the process, there are also some opportunities for improving the way in which the process is deployed. The areas where the deployment of the process can be improved are summarized as follows:

- **Highly fragmented deployments** – The individual product groups currently drive the deployment of SMI. This decentralized method of deploying the process creates a situation where multiple methods of replenishment may exist between a given supplier and Caterpillar. Suppliers that serve one Caterpillar plant using SMI may serve another with a traditional purchase order based system. This creates a confusing situation for the suppliers to work within. Also, as was demonstrated in Chapter 2, multiple replenishment methods may lead to an overall increase in supply chain inventory if the supplier is not able to rationalize inventory.

- **Mixed process adherence** – Despite having a clearly documented process for SMI implementation, not all deployments are fully aligned with the process. This issue is partially attributable to limited process awareness and variations in process interpretation.

- **Lack of clear expectations, responsibilities, and process guidance** – The roles of the various parties both internal and external to Caterpillar could be better defined. As it stands now there is a process owner, but no central authority providing guidance on the implementation of SMI. The various stakeholders in the process have addressed issues relating to their respective competencies (trade compliance, transportation, purchasing), but there has been no centralized incorporation of this knowledge to improve process deployments.

- **No Clear Picture of SMI Usage** – Currently a centralized method for determining which Caterpillar facilities and suppliers are utilizing SMI does not exist. The SMI process calls for changing the Incoterm code for SMI to DDP in the Caterpillar purchasing system.5

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5 Incoterms – International Commerce Terms established by the International Chamber of Commerce. DDP stands for Delivered Duty Paid. This is the term that places the maximum amount of responsibility on the seller to deliver goods to a named place with all associated cost paid. DDP is the term that should be used for SMI shipments to Caterpillar.
Theoretically, changing the INCO terms code in the system should allow the company to track SMI instances by querying purchase orders. However, the code is not always updated in the system. This means that SMI is tracked separately by each facility and that there is currently no central way to aggregate the information.

- **Part Selection Issues** – In the current state there are few guidelines for what components are suitable for SMI. As a result many high value components that are critical to assembly are currently on SMI. These pieces are being chosen because they create large impacts on inventory dollars when placed on SMI (covered in Chapter 6). However, the suppliers that produce these components may lack some of the capabilities that SMI requires, and as such partnering with these suppliers has led to some issues with SMI implementation.

- **Multiple Implementation Methods** – As it currently stands there are a variety of methods for implementing SMI across the company. Suppliers are currently using a variety of 3PLs, as well as solutions from CAT Logistics, and some are directly handling the SMI process. While the process allows for some flexibility in implementation methods to accommodate specific circumstances, the lack of centralized organization has led to there being no common way to implement the process.

- **Supplier Selection Issues** – Some of the issues with deploying the SMI process can be traced back to the suppliers selected to participate in the process. Shortcomings have been identified in the capabilities of some of the selected suppliers including lack of import/export control, lack of material management, and little available capacity. Some of the suppliers currently on SMI are relatively small foreign firms that cannot be expected to have the necessary capabilities without assistance. In the traditional Caterpillar supply chain model these suppliers have not had to perform many of the functions required of them under SMI; Caterpillar handled material for
them. Even with assistance under SMI these suppliers still need more resources than they previously required.

- **Lack of relationship building with suppliers** – A key tenet of the SMI process is the establishment of strong relationships with suppliers. The construction of supplier relationships is one of the key enablers of CPFR. As it stands now, there is room for Caterpillar to place more emphasis on supplier relationships with SMI. While inventory reduction is a key result of the SMI process, the goals of making a more responsive supply chain are tied closely with the information sharing and relationship building aspects of SMI.

- **Incentives Unaligned with SMI Process** – Under the SMI process suppliers charge Caterpillar a fee that is typically based as a fixed cost per part or a percentage of total cost. Therefore under SMI the piece part cost actually increases. In the standard replenishment process transportation managed by Caterpillar is billed as a separate item from the part. This creates a disincentive to Caterpillar for implementing SMI in cases where piece part cost is the driving decision factor. The increase in cost should be balanced against the increased availability of working capital and reductions in inventory costs (see Chapter 6).

### 4.5 Realized SMI Benefits

The issues with the current deployment of the SMI process identified in the previous section indicate that there may be some issues with Caterpillar and its suppliers realizing the full range of targeted SMI benefits (outlined in Section 4.1). Currently, there is no central way of tracking the impact of the SMI process on Caterpillar or its suppliers because of the fragmented way in which the process is deployed. However, it is clear that efforts in deploying and utilizing the process are meeting with success given proper process implementation. Comparing inventory and purchasing data between suppliers on SMI and those that are not, it is clear that some of the inventory related benefits are being realized. In comparing some suppliers from similar geographic regions that supply similar parts to the same facilities, it is clear
in many cases that parts from suppliers that are on SMI show higher inventory turns and lower on-hand inventory levels in Caterpillar facilities. This indicates that SMI may have allowed those facilities to increase inventory velocity, reduce costs associated with inventory, and increase cash pull-through. Without information on the state of these supply chains prior to SMI the overall impact cannot be quantified. In a few cases, Caterpillar is also using the SMI process as an opportunity to have additional quality checks put into place to insure that sub-standard material is not shipped for production.

On the supplier side it is equally difficult to determine if the process has led to any of the targeted supplier benefits. The extent to which the collaborative elements of the process have led to improvements in supplier production is unclear. However, with the exception of the suppliers that are having difficulty with the process, many of the suppliers on SMI have been able to maintain satisfactory delivery performance.

### 4.6 CAT Logistics and the SMI Process

In the traditional Caterpillar supply chain CAT Logistics was responsible for transporting most of the company’s production material from the supplier to the POU. With suppliers taking responsibility for this under SMI the job of CAT Logistics is to transport material between the central supplier stock and the POU. Overtime, as SMI becomes more prevalent in the enterprise, this reduction in material volume has the potential to erode the transportation buying power of CAT Logistics. In the traditional supply chain model CAT Logistics tracked material in-transit, allowing the company to gain insight into the exact location of its shipments, work to proactively address potential problems, and mitigate production impacts by shifting schedules or expediting material. With suppliers taking control, Caterpillar has the potential to lose this visibility, and must rely on suppliers to stay on top of shipments to ensure that central stocks have adequate levels of inventory to support production. CAT Logistics does also provide SMI solutions for suppliers, but the systems used in these solutions are sandboxed to comply with SOX requirements. As such, individual facilities cannot easily monitor material movements. While the impact of a loss of visibility can be mitigated through the development of monitoring mechanisms and frequent
communication with the supplier, Caterpillar does relinquish the ability to take proactive action. This highlights the importance of selecting capable suppliers to participate in SMI. As it currently stands, there is no reason to believe that this is an issue given a stable operating relationship with a supplier, but this issue becomes a problem with underperforming suppliers on SMI.

4.7 Evaluation of Caterpillar’s Current SMI Capability

Many of the areas identified as challenges with the SMI process in Section 4.4 have led to instances where the process has not delivered the full range of expected benefits. It is important to note that while the identified issues represent challenges for the SMI process, they do not indicate that the process simply will not work for Caterpillar. Addressing these items will clear up many of the issues surrounding the process, and allow for the process to mature within Caterpillar.

Given the opportunities for improvement identified in Section 4.4 it is important to look at the difficulties faced by Caterpillar with its SMI process on the wider band of VMI capabilities. The spectrum employed is based on the criteria employed by Kauremaa et al. as well as Sarpola with some added parameters specific to Caterpillar’s prescription, and is shown in Figure 7.[5],[14] As it stands Caterpillar is closer to a “Basic” level of VMI capability than companies that have been employing processes similar to SMI for a long period of time. The list of previously identified challenges provides several reasons for the location of Caterpillar’s SMI process on the spectrum.

This spectrum of capability shows traits of VMI at various stages, however it does not suggest that Caterpillar needs to necessarily progress all the way to the “Advanced” level. Moving that far down the spectrum requires a major level of investment in modifying the structure behind Caterpillar’s operations. Such a move would take a long period of time and substantial resources. However, Caterpillar will likely borrow elements from each category as they fit the recipe for the SMI process.
4.8 Chapter Summary

This chapter establishes the current state of the SMI process at Caterpillar. The targeted benefits of the process for Caterpillar and its suppliers are explored. Through an examination of the current process deployment several case studies were examined that illustrate the current state of the process and identify lessons that can be learned from current deployments. These case studies were combined with empirical evidence to show that there are opportunities for improving the deployment of the process. These challenges include fragmented SMI deployment, mixed process adherence, part selection issues, supplier selection issues, and a lack of relationship building with suppliers. A comparison of Caterpillar’s SMI capability against a spectrum of collaborative processes shows that the company’s current use of the SMI process progressing away from a basic level.
5 SMI Opportunity Identification Process

One of the primary goals for the SMI study was to establish a method to identify opportunities for SMI implementation. Currently, SMI deployment is driven by a situation where a targeted group of components is selected by a product group or production facility based solely on cost or a need to increase replenishment frequency. An emphasis on cost will place only high value components on SMI, while an emphasis on improving low performing suppliers will lead to partnering with suppliers with minimal supply management capabilities. There currently is no way of identifying good candidates for SMI without a preexisting notion of what parts are to be targeted.

SMI opportunities can be looked at through two lenses: impact and suitability. For SMI to work properly suitable components and suppliers must be selected; for the process to be adopted by the company and its suppliers there must be an impact on supply chain performance and cost. When target components and suppliers are known prior to starting the SMI process, they only need to be evaluated for suitability through the SMI process.

There are two steps that are typically taken when considering an SMI partnership: identification of opportunities and evaluation of opportunities. This chapter looks at a framework to identify opportunities through the impact lens, and identifies the traits that should be present in components to ensure they are suitable for SMI. The framework proposed is based on analyzing the information available within Caterpillar to determine the key indicators that should be utilized when identifying SMI opportunities. Chapter 6 addresses the question of how to evaluate the identified opportunities to ensure that the impact can be attained using the SMI process.

5.1 Framework for Identification

SMI impact can be measured inline with the basic goals of the process: improving supply chain flexibility, reducing total supply chain inventory, optimally placing inventory in the supply chain, and
increasing material availability. The challenge with developing this framework was to determine how to align basic supply chain indicators with each of these goals.

The framework is presented in Figure 8, and a summary of the major indicators along with their area of impact is presented in Table 5. It consists of six major criteria that can be evaluated to determine if a group of components or a supplier is a good fit for SMI. These criteria are as follows:

- **Supplier/Commodity Spend** – This is primarily geared at determining the potential financial impact for SMI. Larger levels of spend with a supplier or commodity indicate greater potential impacts when implementing a SMI program (provided there is improvement that can be made in the current handling of material). High levels of spend indicate either high levels of material flow, or expensive components. It also is an indicator of the amount of working capital required to maintain inventories of that commodity.

- **Inventory Levels** – Current inventory levels are a good indicator of where large material buffers are being held. This information can be broken down to determine which suppliers have the highest levels of inventory throughout the supply chain. These buffers can be held for a variety of reasons, but this metric provides a good indicator of the suppliers, facilities, and parts involved. Inventory levels are an indicator of potential reductions in working capital, and the need for a strategic inventory buffer.

- **Transportation Information** – This typically consists of ocean, rail, air, and motor shipping information. The relevant data points for shipments are origin point, destination point, mode, container size (ocean shipments), contents, the Caterpillar facility responsible, and the material supplier. Other details that are worth noting include consolidation and deconsolidation points. This information helps paint a picture of the transportation steps material has to go through before it reaches its final POU. The more complex the chain or the farther away the origin and destination the more opportunity there is to hold material in a centralized buffer. This data
combined with transportation lead times (described below) indicates how much inventory is in-transit at a given time.

- **Transportation Lead Times** – Transportation lead-times are an important metric as they inform how long (in a non-expedited case) it takes for material to move from one region or another. The larger the lead-time the more material that must be held by Caterpillar to buffer for fluctuations in production and material shortages. This information is commonly available in a facility’s MRP system or can be calculated from the transportation information.

- **Inventory Turns** – This is a good measure of how quickly material is moving in the supply chain. Parts for which inventory turns are low are those where an increase in replenishment frequency would be beneficial. Low turns also indicate that working capital is tied up for a longer period of time.

- **Number of Caterpillar Facilities Served by Supplier** – This is simply a count of the number of Caterpillar facilities that an SMI supplier would serve. Good SMI candidate suppliers would replenish several facilities, and thus by putting them on SMI inventory would be able to be pooled across those facilities. This metric is closely tied to the product variety metric as a way to evaluate inventory pooling potential.

- **Supplier Product Variety** – Ideally, SMI suppliers would have a low number of high volume part numbers that they supply to Caterpillar. The fewer part number supplied by a given supplier the more able they will be to aggregate inventory. Responsibility for a few part numbers also places fewer requirements on suppliers under SMI.
Combining these measures provides a picture of where the greatest inflexibilities and inventory levels are in the supply chain, and adds the dimension of potential impact. This framework provides a rough guideline for what to look for, but in many instances the identification of opportunities is going to involve a good deal of contextual interpretation. Part of this contextual interpretation is looking at how suitable the identified components are for SMI.
5.2 Suitability of Identified Components for SMI

The question of component suitability is an important one when considering the SMI process. Unless a supplier has a proven track record of providing SMI or similar services to its buyers, it is a very risky proposition to give the supplier responsibility for critical or high value components. The framework presented in the previous section provides guidance for identifying potential opportunities. This section describes how the characteristics of the parts identified using that framework should be looked at to determine if SMI is an appropriate replenishment process. It highlights the need to look beyond the potential for SMI impact and balance it with an understanding of where and how the components are used.

Figure 9 shows a chart of the part characteristics for SMI divided into four primary categories: general, use, manufacturing, and movement. These characteristics have been gathered from empirical information, as well as work done by Valentini and Zavanella, and Niranjan et al.[18], [26] The chart makes a distinction between basic SMI capability and Advanced SMI (reference Figure 7) employed with high capability suppliers. This distinction is made because supplier ability plays a large role in the performance of the process, and as such it is important to match supplier capability with the complexity of the process. The more complexity the process is expected to handle, the greater level of supplier capability that is required.

The general category includes general characteristics related to part demand and cost. As cost tends to scale with how important a purchased component is to the assembly of the final product it is recommended that High Cost/critical parts be only used in a partnership with high SMI competency suppliers. Parts with Moderate Demand Variability and Basic Differentiation between POUs should be used also be used only with high competency SMI suppliers.

The use category contains most of the characteristics related to the identified part’s role in operations. The selected parts should be Finished Components; any additional processing done on the components should
be done in house by Caterpillar. This means that the selected part should not be part of a value chain that requires additional finishing or processing (finish machining, surface treatment, painting, etc.) by an extra party prior to being consumed by Caterpillar. In addition, parts selected for SMI should be primarily used in the production of new machines. Caterpillar sources components from suppliers for both the production of new machines and the service of exiting machines through its dealers. Those components sourced solely for dealers are not fits for SMI. These components are purchased by Caterpillar to maintain inventory levels that allow the company to maintain a high service level to dealers and suppliers.

Material on SMI has a higher value (unit cost and SMI charge) than the same material not on SMI. Having parts subject to external processing or whose primary demand stream is for service parts on SMI places a higher value item on Caterpillar's books for a longer period than higher velocity parts that are to be consumed as a part of production. This ties up additional working capital, complicates the supply chain, and rarely proves to be worth the added expense. Currently, this is not a major issue with the SMI process, but there are isolated cases were service level parts have been placed on SMI because the parts were used in both production and service. It is important to account for the impact of the different parts models when evaluating SMI.

The manufacturing category contains most of the traits related to part manufacture at the supplier in question. This category centers on the supplier's ability to retain value from the SMI process, and the ease with which employing the process will produce results for them. Short Manufacturing Cycle Times and Small Optimal Production Batch Sizes contribute to a supplier more readily being able to adjust their production to more easily take advantage of the supplier side benefits of SMI. Minimizing Quality Issues and Mature Production Processes ensure that the supplier will not have any outstanding issues that will make it difficult to operate and take advantage of an SMI process.

The movement category addresses the steps required to get the part from the supplier to its final POU. This category seeks to identify parts that will lead to an overall increase in material flow for Caterpillar.
Having *Small Delivery Lot Sizes* allows the supplier to adjust its replenishment on a more granular level. This means that the supplier will be able to more closely match the quantity needed by Caterpillar without having to ship extra material to meet lot size minimums. This allows for the desired reductions in Caterpillar’s inventory.[14] Choosing parts with *Minimal Import Restrictions* and *Straightforward Taxes And Tariffs* lowers the management and capital burden on international suppliers. *Standard Packaging* between Caterpillar facilities allows the supplier to serve multiple facilities with the same part without having to repack components to meet individual facility specifications.

![Figure 9: Categorized chart of ideal SMI part parameters.](image)

These characteristics are guidelines for how part characteristics should be incorporated into the identification of SMI opportunities. Certain criteria can be relaxed depending on supplier abilities and the impact the component may have on SMI. It is important to note that even if the framework and part
characteristics analysis identify a potential area for utilizing the SMI process, the opportunity should still be vetted using cost analysis and supplier capability analysis.

5.3 Chapter Summary

This chapter presents a framework for the identification of SMI opportunities based on information readily available at Caterpillar. This framework can help address the process identifying suppliers and components for SMI when there is not a targeted supplier or component family. A series of material selection criteria is also presented to help narrow the identified opportunities to material that is suitable for SMI. Chapter 6 looks at how these opportunities can be evaluated to ensure that implementing SMI will yield positive results.
6 SMI Opportunity Evaluation

The evaluation of potential parts and suppliers to ensure that the benefits of SMI can be attained can be divided into three steps. The first step is to ensure that the additional cost of SMI is outweighed by the benefits of improved material availability and the current cost of inventory. The second step is to ensure that suppliers possess the required skillset to manage collaborative replenishment. The third step is to perform a contextual analysis of the implementation of SMI. This chapter examines the methodology required to review potential SMI instances. This examination evaluates the current process that is in place for cost and supplier evaluations, as well as looking at the potential improvements to all processes.

6.1 Basics of Total Cost of Ownership Evaluation

One of the main goals of supply chain strategy is to minimize the total landed cost of a procured item. Total landed cost, commonly referred to Total Acquisition Cost (TAC) or Total Cost of Ownership (TCO), consists of not only the unit cost of the item, but all of the costs associated with getting that item to the POU. These costs typically include transportation expenses, inventory holding cost, handling costs, duties, taxes, and financing costs.[6] Caterpillar evaluates SMI sourcing decisions based on the results of discounted cash-flow (DCF) analysis incorporating TCO. Decisions are made based on a fixed time horizon using the Caterpillar Weighted Average Cost of Capital (WACC). The goal of this methodology is to select the option that has the lowest overall NPV of expenditures over the time horizon.

Currently, Caterpillar uses a very robust Microsoft Excel based tool to perform its cost analysis. The tool is designed to provide a comparison between possible sourcing scenarios to aid in decision-making. It is capable of providing cost estimates for impacts to production that result from quality deficits, missing material, or rework. The TCO model requires a variety of inputs for each scenario. These inputs include:

- Unit cost and demand,
- Transportation cost (broken down by transportation segment),
- Taxes and duties,
• Warehousing and handling costs,
• Cost for any additional value added services,
• Current and expected inventory turns,
• Fixed costs (supplier set-up, IT investment, tooling for new suppliers, etc.),
• Costs of non-conformance (unacceptable part quality and late delivery).

The cost structure of the TCO model changes slightly between traditional replenishment methods and SMI. Under traditional replenishment, Caterpillar is responsible in most cases for all legs of transportation; as such it pays all costs associated with transportation and handling. Under SMI, suppliers are responsible for paying all transportation and handling costs until the material reaches the location of the strategic buffer. The cost of transportation, handling, warehousing, taxes, and tariffs is then passed back to Caterpillar in the form of an additional charge per part. These charges can be broken down into individual charges for transportation and inventory management, or just billed as a flat percentage of the part cost.

An example of the inputs to and outcomes of the TCO model is shown in Table 6. The table shows two sample parts, a casting and a forging, whose parameters have been run through the TCO model. The output shows that the example casting family of parts has the potential to save $18.6M over the 10-year period of the analysis. This is compared to the forging family of parts that proves not to be a viable product for SMI given its cost structure ($6.1M in additional costs over 10 years). Working capital is reduced in both circumstances, but the value of this is outweighed by the cost of SMI in the case of the forging. These results highlight the need to perform cost analysis on a case-by-case basis. TCO analysis helps to determine if the increased cost of SMI is offset by the benefits of the process. The TCO analysis presented here is for a single set of part numbers delivered to a single location. More complex analyses are required for multiple part numbers and points of use.
Table 6: Example inputs and outputs of TCO model.

<table>
<thead>
<tr>
<th>Caterpillar Inputs</th>
<th>Casting</th>
<th>Forging</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit Cost</td>
<td>$10.00</td>
<td>$975.00</td>
</tr>
<tr>
<td>Demand</td>
<td>2,363,994</td>
<td>65,622</td>
</tr>
<tr>
<td>Yearly Increase in Demand</td>
<td>2%</td>
<td>2%</td>
</tr>
<tr>
<td>Current Transportation Costs (Non-Expedited)</td>
<td>$3.23</td>
<td>$57.40</td>
</tr>
<tr>
<td>Transit Time - Current (days)</td>
<td>40</td>
<td>30</td>
</tr>
<tr>
<td>Current Transportation Costs (Expedited Airfreight)</td>
<td>$5.47</td>
<td>N/A</td>
</tr>
<tr>
<td>Yearly Percent of Parts Expedited (Current)</td>
<td>14%</td>
<td>14.00%</td>
</tr>
<tr>
<td>Inventory Turns (Current)</td>
<td>5.67</td>
<td>9</td>
</tr>
<tr>
<td>Inventory Turns (SMI-Target)</td>
<td>14</td>
<td>31</td>
</tr>
<tr>
<td>Supplier Inputs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SMI Charge (Percent Unit Cost)</td>
<td>26%</td>
<td>10%</td>
</tr>
<tr>
<td>Transit Time - SMI (days)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Results</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Reduction in Working Capital (millions)</td>
<td>$5.1</td>
<td>$12.0</td>
</tr>
<tr>
<td>10 Year NPV (millions)</td>
<td>$18.6</td>
<td>$56.1</td>
</tr>
</tbody>
</table>

6.2 Supplier Evaluation

The second half of the SMI evaluation process centers on the vetting of supplier capabilities. Currently, the Caterpillar process highlights suppliers that have previous SMI/VMI experience, transportation management experience, have available capacity, export/import experience, be electronic data interchange (EDI) capable, and not have a record of major quality issues. Current Caterpillar suppliers that are being considered for the SMI process should have a proven track record of satisfactory shipping and delivery performance.

After evaluating the current state of the process (reference Chapter 4) the following elements were identified as additional supplier vetting criteria to increase the effectiveness of the process:

- **Suppliers should be able to realize the benefits of SMI** – Selected suppliers must possess the sophistication to be able to participate in collaborative forecasting. They must also be able to take advantage of having access to Caterpillar’s POU information to better plan their production. Without the realization of the benefits of collaboration, suppliers are less likely to see benefits in the SMI partnership beyond the service charge.[8]
• **Caterpillar should partner with suppliers for which they are a major buyer** – Suppliers for which Caterpillar is a major buyer are going to be more willing to invest in a collaborative relationship and will likely be able to realize the benefits of the arrangement. Suppliers to which Caterpillar is a small buyer are less likely to see the benefits of implementing the SMI process and are less likely to invest in developing the relationship.[14]

• **Suppliers should be in sound financial positions** – Suppliers need to have adequate working capital to support holding additional inventory under the SMI process. This is likely less of an issue for larger suppliers. However, it could pose an issue for smaller suppliers or those in countries with tight credit markets.

• **International Suppliers should be certified as a part of C-TPAT** – C-TPAT is the Customs-Trade Partnership Against Terrorism. Members of the partnership are subject to less frequent inspections and reduced border wait times.[29] If an event leading to heightened border security occurs the importation activities (into the U.S.) of member companies are subject to fewer disruptions.

• **Suppliers that partner with 3PLs should be able to manage them** – Should a supplier choose to engage a 3PL to handle material on their behalf in the SMI partnership, they should be capable of managing the relationship with the 3PL and monitoring its activities to ensure that it meets performance requirements.

These elements are designed to assist in the identification of suppliers that can easily participate in the process and that can successfully take advantage of the benefits that it affords them. For the SMI process to be successful the most capable suppliers must be engaged. The elements should be used in conjunction with better supplier vetting to ensure that the best suppliers are selected for this partnership.
### 6.3 Contextual Evaluation Elements

There are several other contextual considerations that must be taken into account before the decision to pursue SMI is made in a given situation. Implementing SMI involves a major change to the structure of the supply chain, and as such there is the potential that implementing SMI can lead to unforeseen consequences. One of those consequences is the potential for Caterpillar to lose some of the benefits it sees from having economies of scale in procuring material transport. Caterpillar currently has transportation responsibility for the bulk of its material. Under SMI that transportation responsibility is shifted to the supplier. With every supplier that Caterpillar shifts onto SMI, material is removed from the Caterpillar transportation network. The effect of this is the potential for rates to increase for Caterpillar’s remaining material. As it stands now there is no way to capture this cost in the TCO methodology, as the

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**Figure 10: Chart of the major criteria for use in evaluating suppliers for SMI.**

<table>
<thead>
<tr>
<th>Current Suppliers</th>
<th>All Suppliers</th>
<th>New Suppliers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good Delivery Performance</td>
<td>Logistics / Transportation</td>
<td>EDI Capable</td>
</tr>
<tr>
<td>Previous SMI Experience with CAT</td>
<td>Demonstrated Import/Export Experience</td>
<td>Available Demonstrated Capacity for SMI</td>
</tr>
<tr>
<td>Limited/ Mitigable Impacts to Current Transportation Network</td>
<td>Domestic Subsidiaries or Non-Resident Importer License</td>
<td>Order Management</td>
</tr>
<tr>
<td></td>
<td>Demonstrated Exception Handling</td>
<td>Financial Resources for SMI</td>
</tr>
<tr>
<td></td>
<td>Demonstrated Exception Handling</td>
<td>Cost Transparency</td>
</tr>
<tr>
<td>CTPAT Certified</td>
<td>Supplier Collaboration System (MRC Connect or Similar)</td>
<td>Demonstrated Exception 3PL facilities Handling</td>
</tr>
</tbody>
</table>

**No 3PL**
- Transportation Management Capability
- 10+2 Import Requirements
- Demonstrated Exception Handling

**3PL Involved**
- Selected 3PL has international experience
- Experience Managing 3PLs
- 3PL facilities within 2 days

**New Suppliers**
- Previous SMI Experience
- Track record for good delivery performance
- Demonstrated Exception 3PL facilities Handling

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impact is hard to quantify. However, it is an impact that needs to be evaluated and balanced against the potential benefits of SMI.

Regulatory compliance is also another issue to be considered. The use of the SMI process poses potential risks when it comes to accurately accounting for inventory obligations and as such poses risks with SOX compliance. In the way the company has currently structured the process, it has sought to minimize this risk to the best of its ability. This risk minimization does place some limitations on the benefits that SMI has the potential to realize as the transfer of inventory ownership is currently defined at a point that is not the final point of use. However, given the current state of the process, this risk-apposed stance is likely justified until the company has more experience with deploying the process.

Other considerations include the loss of material visibility and the impacts that supplier performance shortcomings can have on production. With the supplier assuming responsibility for managing inventory and transportation under SMI the potential for Caterpillar to lose sight of the performance of the overall supply chain does exist. Caterpillar is currently using or developing a number of systems and processes that allow them to track material to a very fine level of detail. This allows the company to intervene should issues occur. If the supplier and Caterpillar do not have a high level of collaboration set up, these impacts have a greater chance of disrupting production.

6.4 Chapter Summary

This chapter addresses the process of validating SMI opportunities through financial analysis and supplier capability vetting. TCO methodology should be used to ensure that the use of SMI in a given situation would not lead to an adverse financial situation. Supplier vetting should be used to ensure that suppliers have the correct capabilities before Caterpillar partners with them. Several additional criteria for supplier vetting are also proposed to ensure success with SMI. Contextual elements should also be evaluated to ensure that the implementation of SMI does not impact other aspects of Caterpillar’s operations.
7 Future SMI Implementation

Through the use of the SMI process Caterpillar seeks to transform the supply chain by centralizing replenishment decisions and building collaborative planning capabilities with suppliers. The process strives to enable increases in material velocity, increases in material availability, aid the increased use of pull in the supply chain, and reductions in overall inventory levels in the entire supply chain. This study was completed in conjunction with a company wide supply chain initiative to help determine if this process was functioning as intended, and if it could be used more extensively in the current supply chain.

The study’s three primary mandates were to evaluate the current use and effectiveness of SMI in the supply chain, identify best practices from literature and empirical evidence, and develop frameworks to help determine how to move the process forward by identifying opportunities for SMI. The study was capped with a set of recommendations, presented in this chapter, targeted towards further developing the process for Caterpillar.

7.1 Study Conclusions

After an evaluation of the current state of SMI deployment the study found that while the process was meeting some of its goals, there were several areas were the deployment of the process could be improved. There is an opportunity to improve the current fragmentation of the process as many product groups and facilities are deploying the process on a small-scale basis utilizing several different methods with suppliers. There is also no central way of determining which facilities and suppliers are currently using SMI. Changing these factors can help increase information sharing between the major process stakeholders, and address situations were suppliers could have multiple replenishment methods for Caterpillar. There are also opportunities to centralize guidance for the process and clarify the roles and responsibilities of those involved.

In addition, there is an opportunity to emphasize the collaborative and relationship based elements of the SMI process. The literature has shown that success with processes like SMI is tied to building and
sustaining relationships with the suppliers chosen for the process. As such, it is important that this part of the process is given sufficient weight. Caterpillar can also better utilize the process by adding additional criteria to its supplier vetting procedure. This will help alleviate issues associated with having suppliers participate in the process that do not possess the necessary competencies to handle the additional responsibilities of SMI.

7.2 Recommendations to Address Current Challenges with SMI Process

The conclusions reached by the study highlight several areas where the current SMI process could be strengthened. However, given the benefits that have and can be realized from implementing the SMI process it is not recommended that Caterpillar stop employing the process. There are several steps that better leverage the potential of the process:

1. **Build SMI capability gradually by starting with high-competency suppliers and low to medium value (non-critical) commodities/components.**

   As with any learning process it is important to build capability gradually. As it stands now Caterpillar has placed a large number of high value/critical components on VMI. While this practice is not without its benefits, it is also risky for a company seeking to establish this capability with its suppliers. The implementation of a new supply chain strategy is the perfect occasion to continue building this competency with the suppliers, but it should be done in stages using the most competent suppliers as initial partners.

2. **Establish oversight for SMI execution.**

   Currently there is no central oversight for the SMI process. This leads to a lack of information on where the process is currently deployed, sparse knowledge sharing, and no central channel of communication between vested parties. Establishing a central method of oversight will help insure that knowledge and best practices are shared. It will also ensure that the process is deployed in a way that is more centrally coordinated. Caterpillar will also be able to more readily track the benefits that the process is providing them and their suppliers.
3. **Increase vetting of supplier capabilities (especially for international suppliers)**
   according to best practices and CPS processes.

As it stands now some suppliers that are involved in the SMI process lack some of the skills or characteristics that would make them good fits for the process. Increasing the vetting of suppliers will allow Caterpillar to select the best partners for this process. Vetting should be done according to the parameters called for in the CPS manual as well as those identified in Chapter 6.

4. **Improve visibility to current suppliers and facilities utilizing SMI.**

While this is closely related to the establishment of central oversight for the SMI process, it is recommended that a central way of identifying current SMI usage be developed. This central method will help in identifying suppliers that are currently engaged in SMI instead of simply relying on anecdotal information. It will also allow product groups to better coordinate which suppliers to approach regarding the implementation of the process.

While these recommendations only begin to address some of the issues inherent with any process that is dependent on relationships, trust, cross-organizational collaboration, and which fundamentally changes the decision structure of the supply chain; they do provide a basis for the company to continue gaining experience with the process. These recommendations are designed to help Caterpillar further leverage the SMI process in the future.

7.3 **Additional Challenges**

While the recommendations outlined in the previous section will help to alleviate many of the current issues identified with the SMI process there are several other items that will also need to be addressed to insure that the process is successful. A major issue involves the current perception of the SMI process. Examples of challenging processes implementations have contributed to the somewhat negative impression of the process. This negative perception can partially be overcome through education on the benefits of the process (especially the results of TCO analysis), but it will take several solid successes to
help the process gain traction amongst its detractors. Changing this image will also require that the company embrace the collaborative aspects of the process, and show how it can contribute to better overall supplier performance.

One of the major recommendations presented in the previous section was to establish central oversight for the SMI process. By allowing for some centralization of the process and aligning the way it is deployed, Caterpillar will be better able to leverage the benefits of the SMI process. However, given that the ultimate responsibility for the deployment of the process lies with the product groups this recommendation will be challenging to implement. Establishing central oversight and standardization of the process will require the involvement of the various stakeholders throughout the company so that the company can determine how prescriptive the process should be. This is especially true when it comes to the question of what 3PLs should be involved in the process. While the company cannot tell suppliers how to manage their new responsibilities under SMI; it can provide recommendations as to what provider the supplier might see the best results with (especially if this is the supplier’s first attempt). Since CAT Logistics provides its own SMI solution for suppliers this area of process specification must be carefully considered.

Supplier benefit realization is also a major challenge. Many studies have shown how the benefits of SMI (and related processes) tend to favor the buyer.[19], [28] Caterpillar needs work with its suppliers to ensure that SMI is set-up in such a way that the supplier can realize the benefits of participating over time.

7.4 Recommended Areas for Future Work

There are several areas that still need to be examined as the process is further deployed within Caterpillar. Many of these were issues or topics touched upon in this study that require a more in-depth look. One potential topic includes finding a ways to analyze the effect of deploying SMI on existing transportation networks. Another area is looking at way with which the process can be deployed in a more flexible fashion (line side replenishment by suppliers), while still maintaining the current level of inventory.
accountability risk of the current process. Since, according to much of the prior research, a major component of the success of SMI and related processes is driven by the IT infrastructure supporting collaboration and material management, an analysis of the current systems employed and their effectiveness would be beneficial in ensuring that the right systems are being deployed.

In addition to these topics there is also the question of how to set up ways of enforcing supplier performance. As it stands now there is not a good procedural way of establishing an incentives structure for supplier performance with the company's suppliers. This topic also poses several challenges when it comes to balancing enforcement with building supplier relationships.
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8 References


[29] U.S. Customs and Border Patrol, “Securing the Global Supply Chain: Customs-Trade Partnership Against Terrorism (C-TPAT) Strategic Plan.”