Analysis and Reduction of Excess Inventory at a Heavy Equipment Manufacturing Facility

by

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ABSTRACT

The research presented in this thesis explores two hypotheses focused on excess inventory at a heavy equipment manufacturing facility. The scope of the thesis includes inventory in the form of raw materials, purchased components, and work in process parts found at the facility and in the off-site storage warehouse. The first hypothesis proposes that excess inventory at the facility has several key root causes, and that their elimination drastically reduces the accumulation rate of excess inventory. The second hypothesis proposes that a basic material review process could be effective in identifying and reducing excess inventory at the facility in a six-month timeframe. The hypotheses were tested over a six-month period at a Caterpillar Global Mining facility. The first hypothesis was not confirmed. More than twenty root causes of excess inventory accumulation were identified and no evidence was discovered that would suggest that certain root causes are dominant. The second hypothesis was supported by the findings at the facility. The organization was able to formulate a basic material review process, apply the process to the facility's inventory, and reduce excess inventory by roughly 35% over a three-month time span.

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Learning from thought leaders, collaborating with fantastically motivated and supportive classmates, and conducting research at one of the most respected companies in the world is a dream of mine that has been fulfilled by the LGO program. The program has been pivotal in my transformation and personal growth, and I am most grateful to the program staff, research advisors, sponsor companies, Caterpillar, and the Institute.

The research underlying this thesis is derived from a six-month project conducted at the Caterpillar Global Mining facility located in Denison Texas. The facility's staff members, including Matt Arel, Robert Pearson, and Amanda Traweek, as well as Caterpillar Production System experts Brian Tebrock, Lou Hawley, and Marcos Cabada have been instrumental in all phases of the project. Their knowledge, support, and guidance have propelled my work.

As I discovered quite early in the project, research is challenging, and the course to discovery is uncharted; however, I was fortunate to have two advisors who guided my journey. The insights and enthusiasm of Dr. Deborah Nightingale and Dr. Charles Fine helped me achieve the project goals.

Finally, I would like to thank my parents and relatives; without their support and personal examples of academic achievement, I would never have set foot on the Institute's campus. You have inspired me to learn and question the world around me; for this, I am grateful.

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1 Introduction

1.1 Foreword

This thesis analyzes the problem of excess inventory at a heavy equipment manufacturing facility. While the problem's context is rooted in a heavy equipment manufacturing environment, the problem can be observed and insights from the thesis can be applied at a wide range of manufacturing facilities.

1.2 Problem Formulation

Although the problem experienced by the manufacturing facility is hidden in the enterprise resource planning (ERP) system, it is clear as day at the facility's inventory yard and off-site storage warehouse: excess inventory is abundant, and it is negatively impacting production, quality, and most importantly the facility's bottom line. Thus, the challenge for the materials group is to drastically reduce the amount of excess material and stop creation of new excess inventory. The thesis examines the problem faced by the materials group and attempts to answer two questions: one, how to best identify and reduce excess inventory, and two, how to stop the creation of new excess material.

1.3 Scope

This thesis analyzes inventory in the form of raw materials, purchased components, and work in process (WIP) parts found at the sponsor facility and in the off-site storage warehouse. The thesis does not examine the finished goods component of the inventory.

1.4 Hypothesis

The thesis explores two hypotheses that focus on the reduction of excess inventory and the elimination of root causes of excess inventory accumulation.

- The majority of excess inventory at a heavy equipment manufacturing facility is caused by several key factors, and elimination of these factors drastically reduces the accumulation rate of excess inventory.

- A basic material review process can be used effectively to identify and reduce excess inventory at a heavy equipment manufacturing facility, even in a compressed six-month timeframe.

1.5 Research Methodology

The research behind this thesis is rooted in an excess inventory analysis and reduction project carried out by a Leaders for Global Operations (LGO) Fellow at a recently acquired heavy equipment manufacturing facility. The facility is undergoing a major transformation: the sales, engineering, planning, procurement, materials, production, and logistics processes are being introduced or converted to Caterpillar's standard processes.

Caterpillar Production System (CPS) internal consultants manage the transformation projects using a standardized Define-Measure-Analyze-Improve-Control (DMAIC) methodology. In order to receive support from the CPS consultants and use a process familiar to facility employees, the excess inventory project is also structured based on the DMAIC methodology.

In the Define phase of the project, the excess inventory problem is characterized and researched. The research conducted in this phase of the project uncovers the best practices for defining excess inventory, identifying and reducing excess inventory, and eliminating the root causes of excess inventory.

The Measure phase is used to collect data on the excess material within the facility, interview key personnel on their opinions concerning the root causes of the problem, and create a tailored excess inventory review process for the facility.

In the Analyze phase, the collected inventory data is reviewed to evaluate the excess inventory reduction opportunities and formulate the root cause mitigation strategy.

Next, in the Improve phase of the project, the excess inventory identification and reduction method is applied to the facility's inventory. Also, the root cause elimination strategies are piloted to reduce key sources of excess inventory.

Finally, in the Control phase of the project, the excess inventory reduction and root cause elimination processes are handed over to the facility process owner.

1.6 Thesis Outline

The thesis is divided into seven chapters that lead the reader through problem formulation and the hypothesis, relevant literature review and company context, solution formulation and project results, and finally improvement recommendations and thesis conclusions.

The first chapter of this thesis introduces the reader to the two problems faced by management at a recently purchased heavy equipment manufacturing facility, the proposed solutions to the identified problems, and the research approach used to uncover the findings presented.

The second chapter provides an overview of literature that analyzes the topics of inventory management, excess inventory, root causes of excess inventory accumulation, and excess inventory reduction techniques.

The third chapter details the project context, and does so in four steps. First, the chapter familiarizes the reader with the company and the acquisition that brought the facility into the company's production network. Second, the chapter provides an overview of the facility and its products. Third, the chapter talks about the materials group and the state of the inventory management processes at the start of the project. Finally, the chapter discusses the motivation behind the project.

The fourth chapter focuses on the causes of excess inventory accumulation at Caterpillar Denison, and tests the first hypothesis. The chapter discusses the root causes existing at the facility, the methods of addressing the identified root causes, the selection of root causes targeted for elimination, and the expected outcomes based on the elimination of the specified root causes.

The fifth chapter examines excess inventory reduction. First, the chapter describes the formulation of the excess inventory review process. Second, the chapter analyzes the facility's inventory position. Finally, the chapter discusses the realized inventory reduction and the implications of the results on the validity of the second hypothesis.

The sixth chapter appraises the Fellow's recommendations for Caterpillar Denison management. Specifically, the chapter examines recommendations pertaining both to the excess inventory reduction effort, as well as the elimination of excess inventory accumulation root causes. Also, the chapter delves into future research opportunities connected to the area of data collection for root cause effect quantification.

The seventh chapter provides a conclusion to the thesis, and assesses the validity of the presented hypotheses.

2 Literature Review

2.1 Summary

This literature review section first takes a look at the broad topic of inventory management, its origins, and its evolution. Next, the review examines literary works dedicated to the topic of excess inventory. There then follows a discussion of literature focused on the root causes of excess inventory accumulation and methods of eliminating said causes. Finally, the section covers literature dedicated to the methods and techniques aimed at reducing excess inventory.

2.2 Inventory Management

Inventory management is a well-discussed topic; in fact, a search on Amazon.com results in 15,980 books that are immediately available for purchase, and a search on Google Scholar yields a whopping 1.97 million documents that contain the phrase "Inventory Management". The number of publications hints at the importance and popularity of the subject. Not surprisingly, there is a myriad of definitions of inventory management; however, one of the more concise and clear ones comes from a financial encyclopedic website. *"Inventory management can be defined as overseeing and controlling of the ordering, storage and use of components that a company will use in the production of the items it will sell as well as the overseeing and controlling of quantities of finished products for sale."* (*Inventory management.*2013)

While the practice of inventory management most likely predates written records, archaeological discoveries in ancient Egypt document the emergence of basic inventory management 5,300 years ago. Specifically, Dr. Deyer discovered bone labels attached to bags of oil and linen at the tomb of King Scorpion I at Abydos, Egypt, that date back 5,300 years, and that document material owners, amounts, and suppliers (Dolinsky, 2013).

The first professional publications on inventory control can be traced to the 1913 article "How Many Parts to Make at Once" by F.W. Harris in *Factory, the Magazine of Management* (Silver, 2008). The article analyzes and lays out the principle of economic order quantity. Research and publication activity surrounding inventory management accelerate in earnest after WWII, and the first textbooks on inventory management appear in the 1960s (Silver, 2008). Since then, dozens of universities around the world have developed academic programs focused on supply chains and logistics, and cover inventory management in great detail.

However, although the topic of inventory management is well discussed, a gap exists between the supply chain theorists and practitioners, which limits the application of the latest research methodologies. While theorists are primarily concerned with optimization, which often requires a long time span in the real world, practitioners, on the other hand, are concerned with shorter-term improvements and not necessarily optimization (Juran & Dershin, 2002). Furthermore, the majority of research is applied to steady-state conditions, while practitioners often face transient states. Researchers mostly ignore behavioral aspects of inventory management, while for practitioners, this is one of the most challenging factors in an underperforming inventory management system (Silver, 2008). Hence, while the topic receives a good deal of attention, academics need to understand the existing gap between theory and application and focus on closing this divide.

2.3 Excess Inventory

The concept of inventory is universal, and humans probably began thinking about inventory with the emergence of farming. The word inventory appears in 26,000 Amazon.com book searches and 2.3 million Google Scholar searches. The definition of inventory on investopedia.com makes it clear that inventory is absolutely critical to the existence of a modern day business: *"Inventory is the raw materials, work-in-process goods and completely finished goods that are considered to be the portion of a business's assets that are ready or will be ready for sale. Inventory represents one of the most important assets that* *most businesses possess, because the turnover of inventory represents one of the primary sources of revenue generation and subsequent earnings for the company's shareholders/owners."* (*Inventory.*2013)

However, while in the past, a large inventory gave an advantage and was viewed positively, with the passage of time and the development of advanced inventory management strategies, inventory has come to be viewed as a necessary evil due to the carrying costs associated with its ownership. The research on this topic suggests that annual inventory holding costs can range between 20% and 40% of material costs (Thummalapalli, 2010). Therefore, most companies try to minimize/optimize their inventories, and some even outsource inventory management and its ownership in vendor-managed inventory (VMI) schemes.

For the purposes of this paper, excess, surplus, or obsolete inventory are treated as synonyms. However, choosing a definition for excess inventory is not simple. For instance, even the US military community does not have one single definition of excess inventory. The Navy's definition is any stock that is above the combination of war reserves, safety level, expected demand during administrative and production lead times, economic order quantity (EOQ), and the reorder point, plus eight years of demand at current consumption rates (Kang, 1998). The Defense Logistics Agency's definition, on the other hand, is any stock that is above six years of demand at current consumption rates (Kang, 1998). Therefore, it is not surprising that the manufacturing facility hosting the Fellow had its own excess inventory definition, which will be discussed later.

Furthermore, in addition to the carrying costs that companies must sustain due to inventory, Grant, et al. make an observation that points out additional burdens associated with excess inventory. The authors state that since surplus stock is an asset on the firm's books, it therefore inflates assets, reduces return on investment, and distorts stock turns (Grant, Karagianni, & Li, 2006). Overall, it is clear that excess inventory is problematic and should be avoided. However, even as inventory management techniques have advanced, excess inventory issues continue to plague companies small and large. In July

2000, a report by AMR Research projected that excess consumer goods would top $60 billion in the US and $120 billion globally (Crandall & Crandall, 2003). In 2001, Cisco had to write off $2.25 billion of excess inventory (Hult, Ketchen, & Arrfelt, 2007). In fact, companies that have reported excess inventory positions to their shareholders have been historically penalized by the stock markets (Hendricks & Singhal, 2009). Moreover, the problem of excess inventory can be traced even to national levels. For instance, in 2001, France blamed slow growth on excess inventory write-offs (Crandall & Crandall, 2003). However, excess inventory problems be can mitigated if management understands the root causes of this problem, and systemically eliminates them.

2.4 Root Causes of Excess Inventory

Over the years, the problem of inventory management has interested both practitioners and theorists; thousands of research papers and articles on this topic highlight this fact. However, fewer works have identified or analyzed the root causes of excess inventory, and even fewer works have focused their attention on methodology for the elimination of excess inventory causes.

For instance, several LGO theses have looked at ways of reducing inventories at partner company factories and supply chains, thus indirectly lowering excess inventory. In a 1993 thesis, Stephen R. Bylciw looks at the positive effect of introducing a modified inventory management policy that is based on the study of the stochastic characteristics of the manufacturing process and customer demand on inventory levels at an aluminum can manufacturing facility (Bylciw, 1993). In a 2004 thesis, Amber J. Chesborough analyzes possible inventory reductions at an aerospace parts distribution company through the introduction of a two-bin kanban refill system (Chesborough, 2004). In a 2011 thesis, Brian Robert Masse outlines a system for an optimal safety stock management strategy for an aerospace supply chain, which would result in lower inventory level (Masse, 2011). However, although the theses mentioned target inventory reduction, they do not analyze the root causes leading to accumulation of excess inventories, or quantify the root cause effects.

A number of publications from the military community has identified top-level reasons for excess inventory; however, none of these publications provides in-depth analysis of the effects of the identified causes. For example, Quintero and Valadares discuss surplus inventory in the context of an international arms sales program, and state that the most common causes of surplus inventory are over-procurement, uncontrolled production, and general inefficiency. Also, they mention that planners tend to acquire excess material due to cultural preferences. Finally, they list engineering changes as yet another contributor of surplus inventory (Quintero & Valadares, 1994). Interestingly enough, they conclude that excess inventory is an inherent characteristic of any logistic support method.

Steven C. Thorne also talks about excess inventory in a military supply chain context. His analysis provides a perspective on excess inventory and the potential reduction of the Department of Defense's inventory levels based on a transition to modern commercial inventory management principles. In his discussion, he points out differences between the military and commercial worlds such as unpredictable demand, lack of suitable substitutes, and high stock out costs, which would prevent the military from operating at similar efficiencies as commercial companies, even if the DOD were to embrace modern inventory management principles (Thorne, 1999). However, this publication omits any notable analysis of the root causes of excess inventory. Thus, the analyses provided by the military community provide a discussion of the problem, yet overall, the discussion is too high-level to be useful in the context of a manufacturing facility.

Another viewpoint is provided by Dr. Sami Sboui based on his experience in the textile and clothing distribution sector. Dr. Sboui identifies the following reasons for excess inventory: features of the textile supply, management of inventory points, client assets and product development, and the mass distribution mode. The reasons mentioned in this paper stand out, because they do not correspond to the factors identified in the papers from the military community (Sboui, 2006). However, the paper does not characterize the effects of any of the root causes of excess stock, and the paper's hypothesis therefore stands unproven.

Another group of researchers discusses the connection between inventory record inaccuracy and excess inventory. The paper focuses on use of the radio frequency identification (RFID) tags for continuous inventory tracking in a hospital environment. Specifically, the publication discusses RFID technology as the next step after the bar-coding technology that is widely used in hospitals; the outcome of using RFID technology is improved inventory record accuracy and lower excess inventory (Jones & Garza). The problem of low inventory record accuracy is acute at the facility sponsoring the thesis project, and inventory record accuracy becomes one of the key improvement targets for the materials group.

An influential practitioner, R. Pay expresses his viewpoint on surplus inventory in an article in *Industry Week* magazine. He asserts that the main cause of excess inventory is uncertainty in both supply and demand. He then proceeds with three recommendations to solve the problem, which include creation of a sales and operations planning (S&OP) process, auto-replenishment systems, and a ramp-up/ramp-down discipline (Pay, 2010). While the article does not provide any quantitative support for the recommendations, it does provide a good example of simple heuristics that is appealing to practitioners. However, the sponsor facility already has an S&OP process, and the auto-replenishment system exists, but only for low-dollar/high-moving items such as fasteners. The ramp-up/ramp-down discipline assessment is difficult to make. Therefore, once again it cannot be determined whether the researcher's recommendations are all-encompassing and would result in the required improvement.

Patrick Bower provides one more practitioner's viewpoint on inventory reduction that also affects surplus inventory (Bower, 2011). The article presents six common solutions that supply chain consultants focus on in order to reduce inventory: Reduction of Demand Variability, Examination of the Components and Parameters That Drive Inventory, Management of Capacity Relative to Inventory, Structural Changes in the Distribution and Production Network, Finished-Good SKU Rationalization, and Lean/Just in Time/Theory of Constraints. While the article acknowledges the validity of the common solutions, it also points out the long setup times required to achieve results with the solutions under discussion, and goes on to provide several recommendations for actions that yield results quickly and build up the confidence required for the implementation of the long term solutions. The first action that Bower recommends is the improvement of inventory quality through the removal of junk inventory. This recommendation influences the strategy of the underlying project and becomes one of the foci for this thesis. Also, Bower acknowledges the large number of potential sources of surplus inventory, and insightfully recommends examining the raw, pack, and component inventory in favor of finished goods. Finally, he urges practitioners to make an effort to truly understand the sources of excess inventory, and states that in some of his professional engagements, he has seen excess inventory in the range of 25% to 50%. Thus, the paper is valuable because it points out a sequence of improvement actions to be taken by a supply chain organization. However, the paper does not provide a root cause/effect analysis.

In an article on supply chain assessment and improvement, D. Juran and H. Dershin list a number of factors that lead to surplus stock (Juran & Dershin, 2002). The authors identify two broad categories of root causes of surplus stock: overproduction and lack of control over field inventory. Next, they develop this assertion into a cause–effect diagram of surplus stock and backorders. The diagram can be reviewed in Figure 1, and it contains 14 factors, some of which were observed at the sponsor facility. Furthermore, the authors hypothesize that deficiencies in the production process and in the management of inventory at distribution points feed back into each other, creating a cycle that creates both product backorders and surplus inventory. However, the article does not provide any quantitative evidence in support of the hypothesis.

Richard and William Crandall provide a thorough analysis of excess inventories and prevention techniques in an article on managing excess inventories (Crandall & Crandall, 2003).

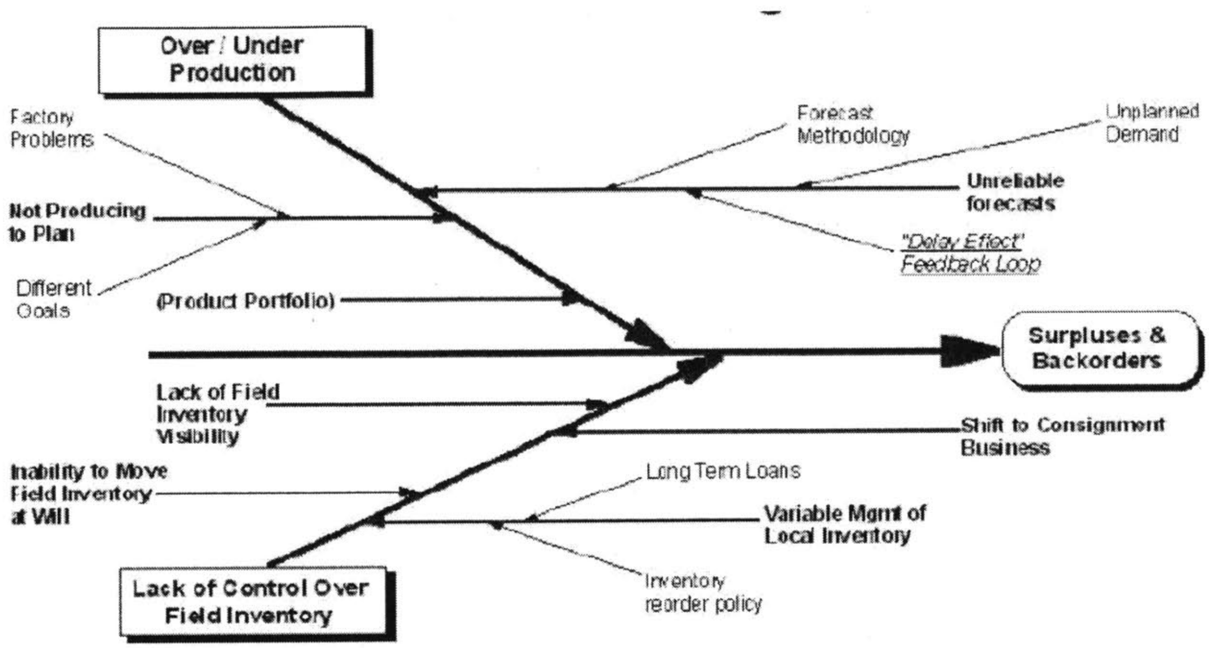

Figure 1: Cause and effect diagram of Surpluses and Backorders

Similar to D. Juran and H. Dershin, the Crandalls also develop an Ishikawa-style cause and effect diagram that explains the creation of excess inventory; the diagram is presented below in Figure 2. However, the Crandalls' diagram is dedicated solely to excess inventory. The authors group root causes of excess inventory into the following six greater categories: Demand Forecasting, Supply Planning, Strategic Planning, Economy, Competitors, and Customers. Each category houses three causes that directly contribute to the proliferation of surplus material. However, they recommend that each company create its own cause and effect diagram, since the actual conditions of the supply chain, and hence the causes of excess inventories, vary from one company to another.

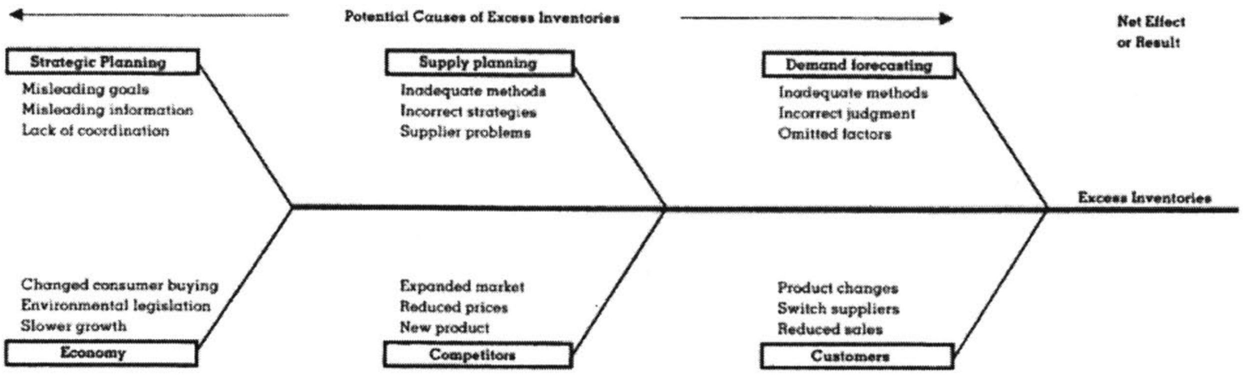

Figure 2: Excess inventory cause and effect diagram

The idea of creating a cause and effect diagram to investigate the root cause of excess inventory at the sponsor facility was influenced by the Crandalls. Further sections will present the cause and effect diagrams specific to the facility.

In addition to the abovementioned categories of excess inventory root causes, the authors provide another diagnostic tool for determining the sources of surplus inventory accumulation. The questionnaire presented below can be used to identify the functional groups whose actions contribute to the creation of surplus inventory.

Diagnosing Problem Areas in Excess Inventory Control

Focus Area	Analysis
1. Is it a marketing problem?	☐ Does marketing want products built before there is a firm sale or customer commitment? ☐ Does marketing try too hard to "guess" what the customer will buy without adequately communicating with the customer?
2. Is it a forecasting problem?	☐ Do the excess inventories occur because the demand forecasting methodology is inadequate? ☐ Do the forecasters need more knowledge and training, or do they need better input data?
3. Is it an engineering problem?	☐ Does engineering make too many engineering changes without considering the impact on existing inventories? ☐ Do they fail to consider the benefit of standardized, or modular, components?
4. Is it a production problem?	☐ Is the production group building to the schedule, or are they attempting to build ahead and thereby reduce setups? ☐ Are they sacrificing quality or customer service to achieve labor efficiency and equipment utilization?
5. Is it a purchasing problem?	☐ Are large purchasing orders taken for discounts without considering their impact on excess inventory control? ☐ Are we able to negotiate a smooth, dependable flow of goods, or are we the victim of our suppliers' capabilities or caprices?
6. Is it a production-planning problem?	☐ Will changes in basic decision rules, such as when to phase in engineering changes, alleviate the excess inventory build-up? ☐ Does the production schedule reflect the marketing forecast or the production comfort zone?
7. Is it an accounting problem?	☐ Will a change in the accounting system provide the information necessary to identify excess inventories faster? ☐ Are they assigning unrealistic values, either too high or too low, to the excess inventories?
8. Is it a performance-measurement problem?	☐ Are the performance measures focused on local primary measures (labor efficiencies) rather than global measures (EVA)? ☐ Is the intangible value of customer service considered more important than the tangible cost of excess inventories?
9. Is it a cross-functional coordination problem?	☐ Would the use of cross-functional teams reduce the magnitude of the excess-inventory problem? ☐ Would greater communication and coordination among the functional areas reduce excess inventories?
10. Is it a cross-functional organization problem?	☐ Has the responsibility for excess inventory been assigned to a specific function or is it "everyone's" responsibility? ☐ Would a specific continuous improvement program, such as Six Sigma or CPFR, help reduce excess inventories?

Figure 3: Excess inventory questionnaire

Also of interest is the discussion on possible causes of inventory excesses that result from the well-intentioned actions of functional groups. This discussion highlights the difficulty in avoiding excess inventory, since some actions resulting in excess inventory may seem proper to functional employees, who only see a subsection of the supply chain processes. In the second half of the publication, the authors come to the conclusion that excess inventory is an inherent part of business. They write that to eliminate excess inventory, all process and demand variances would need to be eliminated first, and since this is impossible, excess inventories will always be created and need to be managed. Next, they propose a heuristic system for managing excess inventory. The authors develop a lifecycle model that helps managers understand the decisions that lead to the creation of inventory and excess inventory. Also, the model implies that excess inventory accumulation is an inherent process in any business, and must be managed systemically.

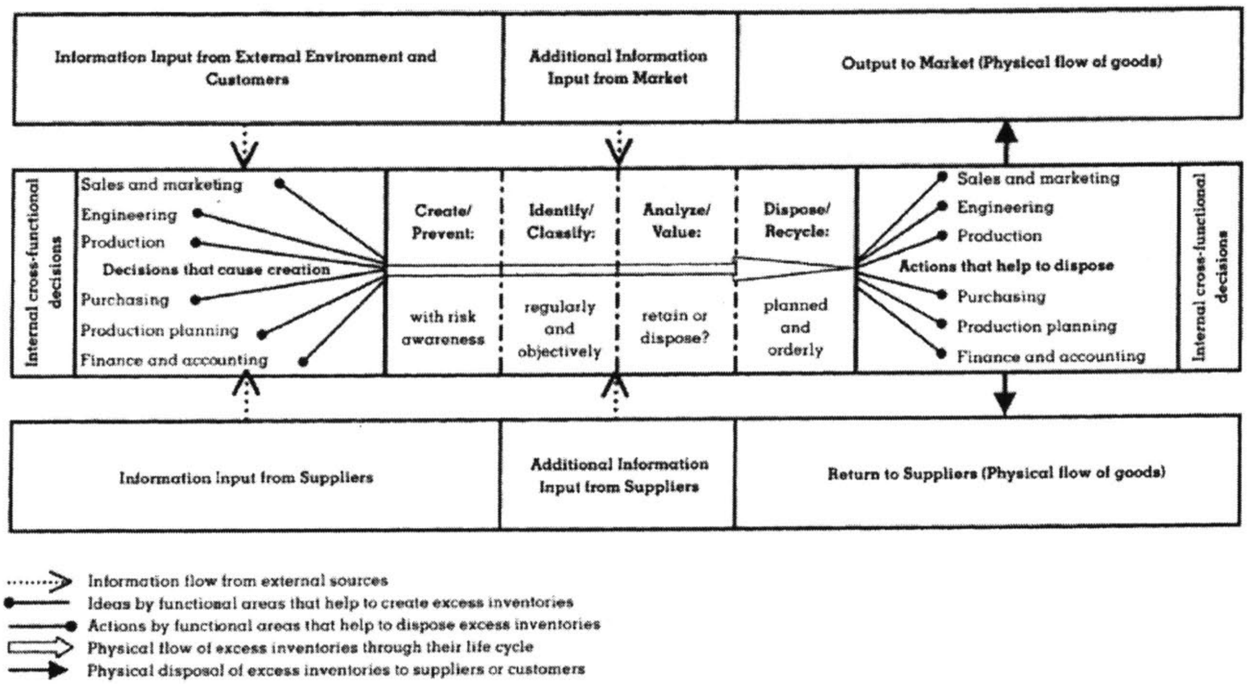

Figure 4: Lifecycle model for the control of excess inventory

Overall, the article by Richard and William Crandall provides the most comprehensive discussion on the causes of excess stock, along with a few points on excess stock disposition. Some of their recommendations were applied at the sponsor facility to identify and eliminate the root causes of excess inventory accumulation.

In conclusion, the publications referenced above all identify excess inventory root causes; however, each publication provides its own list, rather then referring to a commonly accepted list of factors. This leads one to believe that every supply chain system has its own excess inventory causes, and that the numbers of these causes can vary. Furthermore, none of the publications provide thorough, quantitatively based analyses of the root cause effects on excess inventory, which leaves practitioners with no root cause prioritization strategy. Based on this fact, the sponsor facility chiefly relied on its own root cause identification effort and prioritization strategy.

2.5 Methods of Identifying and Reducing Excess Inventory

The majority of the discussion that covers identification and reduction of excess inventory is found in publications focused on the broader subject of inventory management. This makes sense, since inventory management is primarily concerned with maintaining a proper inventory position to satisfy customer demand at an acceptable service level and at minimal cost. At the core of inventory theory are the concepts of economic order quantity (EOQ), buffer-stock principles, and reorder point, which together form inventory policy.

Specifically, inventory policy dictates the frequency of orders, order sizes, and safety stock. Furthermore, inventory policies can be divided into three classes: continuous review, periodic review, and base stock. Within the first two classes, the policies are split between order quantity or order-up-to level. However, central to the discussion is the fact that by setting an inventory policy, one also defines the desired inventory level, and thus identifies excess inventory held by the facility. However, at the time of the project, the sponsor facility did not have an inventory policy, was not using EOQ for reorder decisions, and did not have a set safety stock; therefore, it was unclear what the desired level of inventory was and what constituted excess inventory.

An alternative method of identifying excess inventory is based on a "red tag" program that requires facility employees to periodically review inventory and red-tag material in cases in which they think that the material is surplus. The red tags include: date of tagging, the name of the reviewer, and a deadline for material use. Once tagged, the material is moved to a quarantine location, where it is kept either until it is used in production or until the deadline date, at which point it is disposed of. Literature suggests that the "red tag" programs originated with Japanese automakers, and have gained in popularity with other manufacturers (Thummalapalli, 2010). The "red tag" method's simplicity and effectiveness are the reasons why this technique was included in the excess inventory identification and reduction process at the sponsor facility.

Thinking about the purpose of any excess inventory reduction process, it becomes apparent that organizations aim to maximize the net present value, and thus have to balance the revenue from the potential sale of the inventory minus the holding cost over the predicted period until the sale against the revenue from immediate disposal of the material. Several works have covered this topic, and have proposed solutions for dealing with this problem. An often-cited paper in the field of inventory reduction, written by D. Rosenfield, provides organizations with a numerical formula to determine when to salvage items and when to keep them in stock for later use (Rosenfield, 1989). However, this formulation only applies to finished goods, and requires the knowledge of the average number of units demanded per unit time, the average ultimate sales value of a single unit as a percentage of its current value, and the salvage value. Since the excess inventory project at the sponsor facility focused on raw materials, purchased components, and WIP, and as the facility had severely limited historical material demand information, Rosenfield's formulation was not applicable. In fact, due to the data limitations at the sponsor facility, a numerical formulation was not very useful, and a heuristic was necessary. This finding supported the decision to create a material review process to identify and reduce excess inventory.

Given that an organization can identify excess inventory and determine to reduce it, there are several options available for disposing of the material. In his article on inventory reduction, P. Bower provides a nearly exhaustive list of options that deal with excess material: return to supplier, rework for use in another product, use as spare parts, sell to third party, donate, and scrap (Bower, 2011). According to P. Bower, the list of options ranges from the highest monetary return to the lowest monetary return. Furthermore, P. Bower specifies that all options require the cooperation of suppliers, customers, and the internal functions of the business. In the context of a manufacturing organization, the list of options provided above misses the option of transferring material to a different facility. However, all of the specified options framed the discussion of the inventory reduction approaches at the sponsor facility.

An article by P. Deis and G. Miller provides a simple process for dealing with excess inventory that the two practitioners have utilized in their careers (Deis & Miller, 2006). The process sequence is based on their experience rather than a numeric optimization. The practitioners recommend first selling excess inventory at full price/cost, if possible. The second step is reworking the material or substituting it in place of other parts. The third step is salvaging material for cash at a reduced rate. The fourth step is scrapping the material, because the tax write-off and the lower holding costs will cover any benefit that could be gained from holding on to the material. Due to the simplicity of the approach and its proven record, the system proposed by P. Deis and G. Miller formed a starting point for the reduction methodology at the sponsor facility.

One particularly interesting option for dealing with excess inventory is discussed by Dennis-Escoffier in his article on the benefits of donating excess inventory. Dennis-Escoffier states that in some cases, a corporation may be eligible for an enhanced tax deduction of up to twice the inventory's base value if the material is donated (Dennis-Escoffier, 1993). Furthermore, the National Association for the Exchange of Industrial Resources states that over 7,000 businesses have used the organization's services to donate inventory to non-profit organizations (Zavada, 2000). The difficulty of using donation as an excess inventory reduction technique at the sponsor facility is related to the fact that the majority of the excess inventory is purchased components specific to the machines made at the facility, which would therefore not be of interest to non-profit organizations.

In their discussion of surplus inventory, E. Crandall and W. Crandall conclude that firms should approach excess material disposition as a standard business process. Furthermore, the Crandalls state that the disposal phase requires the collaboration of internal cross-functional teams that partner with customers and suppliers to define disposal methods. Also, the authors point out that the status quo in most corporations is such that excess material disposal is viewed as one-off event rather than a regularly scheduled activity. While this assessment was true for the sponsor facility as well, the parent organization had a well-defined excess inventory process, and had plans to implement it at the sponsor facility.

Overall, the review of literature dedicated to the topic of excess inventory reduction pointed out the need for the sponsor facility to develop an inventory reduction process that would rely on the stakeholders of the materials value chain making the disposition decisions rather than a numerical algorithm. Also, the publications reviewed described several ways of reducing excess inventory while recouping some of the material costs. These two findings established the groundwork for the formulation of the excess inventory review and reduction process at the sponsor facility.

3 The Company

3.1 Summary

The following section will introduce the reader to Caterpillar Inc. and its acquisition of Bucyrus International; it will describe the history of the Denison, Texas, facility and its product line; and finally, it will discuss the material value chain at the facility and the motivation behind the project. Overall, the section will help the reader develop an understanding of the facility where research for the thesis was conducted.

3.2 Caterpillar Inc.

This section of the text will familiarize the reader with the company that hosted the LGO Fellow and the project. Caterpillar Inc. is an American corporation that designs, manufactures, sells, and finances heavy equipment to customers all over the world via a global network of dealers. The company's portfolio of products includes equipment for the construction, mining, and power generation industries, and it is the market leader in the heavy equipment industry. Furthermore, the company is a member of the Dow Jones Industrial Index; it holds the 46th position on the Fortune 50 list, and the 19th spot on the Fortune's list of the most admired companies. (*Caterpillar Inc.* 2013)

Caterpillar Inc. traces its roots to the merger of Holt Manufacturing Company and the C. L. Best Tractor Company in 1925, which joined two leading tractor manufacturers. The company grew through the late 20s and 30s; during WWII, its equipment became iconic. Post-WWII, Caterpillar Inc. continued its expansion, and it launched its first international venture during the 1950s. Since the 1950s, the company has a continued to grow, both organically and through strategic acquisitions. In 2013, Caterpillar was manufacturing its equipment in 110 facilities, 59 of which were located outside of the US. The company's equipment can be bought in nearly 200 countries through one of the 220 dealers. (*Caterpillar Inc.* 2013)

Over the course of its existence, Caterpillar Inc. has made a series of strategic acquisitions that have helped the company gain the market leader position in its traditional markets, and also diversify into other markets, such as rail transport and power generation. In late 2010, Caterpillar broke the news that it was moving ahead with the acquisition of Bucyrus International, one of the leading manufacturers of mining equipment. The deal was valued at $8.6 B and was the largest acquisition in the construction and mining machinery industry in a five-year time span (Carter, 2010).

3.3 Acquisition of Bucyrus International

The following section discusses the acquisition of Bucyrus International by Caterpillar; this information is relevant because the project took place at a former Bucyrus facility, where most of the supply chain processes had been carried over from the previous owner. In late 2010, Caterpillar offered a broad portfolio of mining equipment; however, its portfolio was not exhaustive, meaning that mining companies still needed to purchase machines from other manufacturers to run operations. Furthermore, mining activity around the world had recovered quickly after the 2008 economic crisis, and mine operators were making significant purchases of capital equipment. Specifically, the global commodities demand, primarily supported by China's rapid economic growth, kept commodity prices elevated and spelled out a positive future for mining investments. Based on this industry outlook, Caterpillar decided to broaden its portfolio of products offered to the mining industry, and acquired a large competitor based in Wisconsin: Bucyrus International. The original Caterpillar product types made for the mining industry can be seen in the figure below.

Figure 5: Caterpillar portfolio of products for the mining industry prior to Bucyrus acquisition

The illustration below presents the additional equipment that was added to the portfolio through the Bucyrus acquisition.

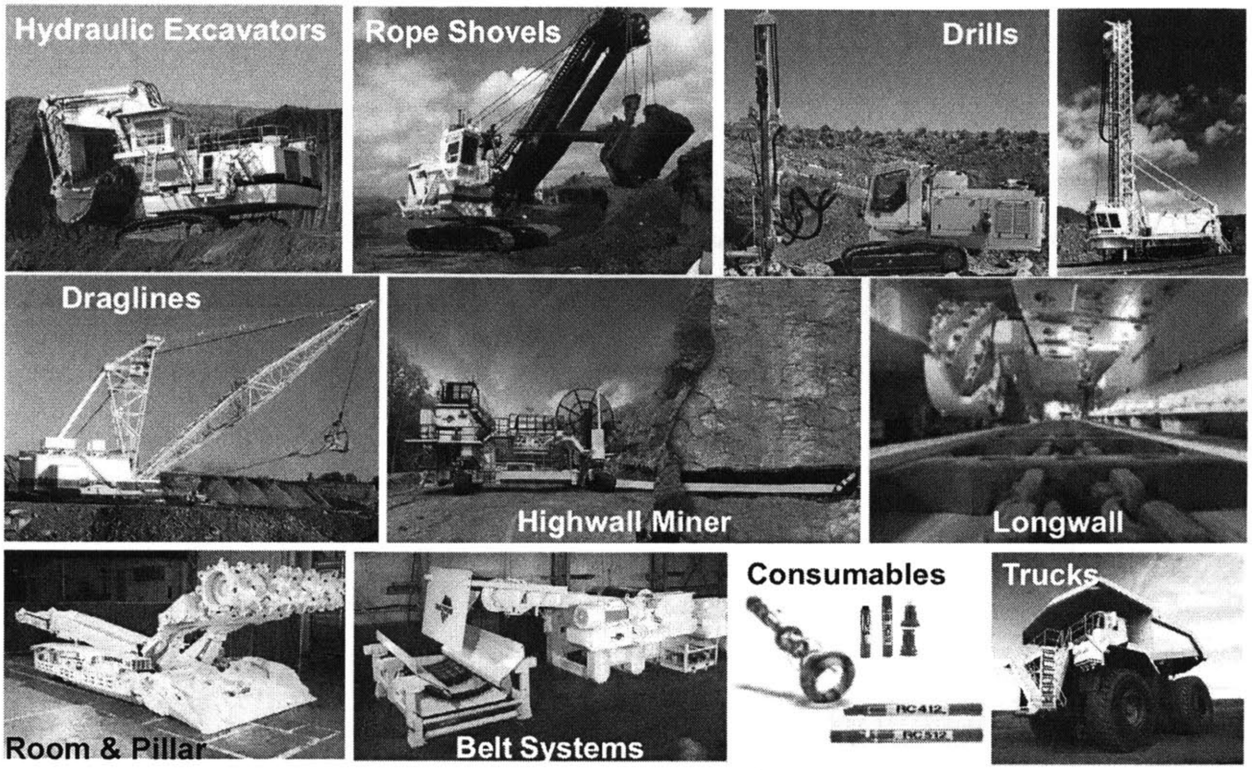

Figure 6: Bucyrus product portfolio prior to its acquisition

When the deal was announced in late 2010, the investment community greeted it favorably. Investment analysts stated that "the deal fills an important portion in Caterpillar's portfolio", and that "Bucyrus gives Caterpillar an opportunity to gain from growth in emerging markets and tap a business with extensive after-market parts and services opportunities". Caterpillar's CEO, Doug Oberhelman, said, "The mining industry is very attractive to us for the long term" (Singh, 2010).

By July 2011, Caterpillar had completed the purchase of Bucyrus International and assumed control over Bucyrus' manufacturing facilities. The acquisition expanded Caterpillar's product offering and provided mining companies with the opportunity to purchase all of their equipment from a single source. In order to effectively control and grow this part of the business, Caterpillar consolidated and moved its Global Mining Division to former Bucyrus offices in Oak Creek, Wisconsin.

3.4 Caterpillar Denison

In this section, the reader will be introduced to the products and history of the Denison facility, which hosted the excess inventory project. Also, the reader will learn key information about the global drill market and the improvements made to the plant in 2011 and 2012. The Denison, Texas, factory was one of the facilities included in the Bucyrus International acquisition. The facility manufactures drills for the surface mining and quarry industry. The factory went through four ownership transitions in the span of 10 years: Svedala to Metso in 2001, Metso to Terex in 2004, Terex to Buycyrus in 2010, and finally Bucyrus to Caterpillar in 2011. Regardless of ownership, the facility continued to design, manufacture, sell, and service drills for its customers.

However, by joining Caterpillar, the factory gained access to that company's global network of dealers, which offered a significant increase in the bandwidth of the sales channel. The drill product managers predicted that the global demand for the factory's drills was several times greater than the 2010 factory output of 62 units.

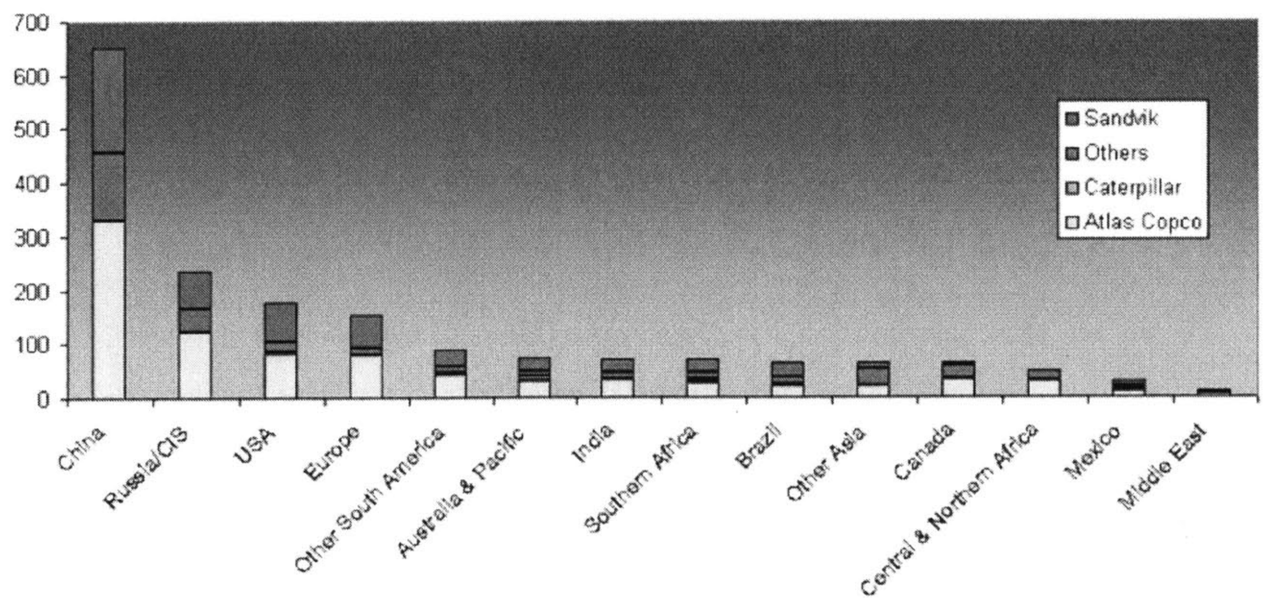

Figure 7: Global demand for Track drills

Figure 7 and Figure 8 display the global demand for drills in two categories: track and rotary. They also indicate that Caterpillar is a minor player in the smaller and cheaper track segment, and is the third-place company in the larger and pricier rotary segment. Therefore, the product group managers believed that Caterpillar had significant opportunities to grow its sales.

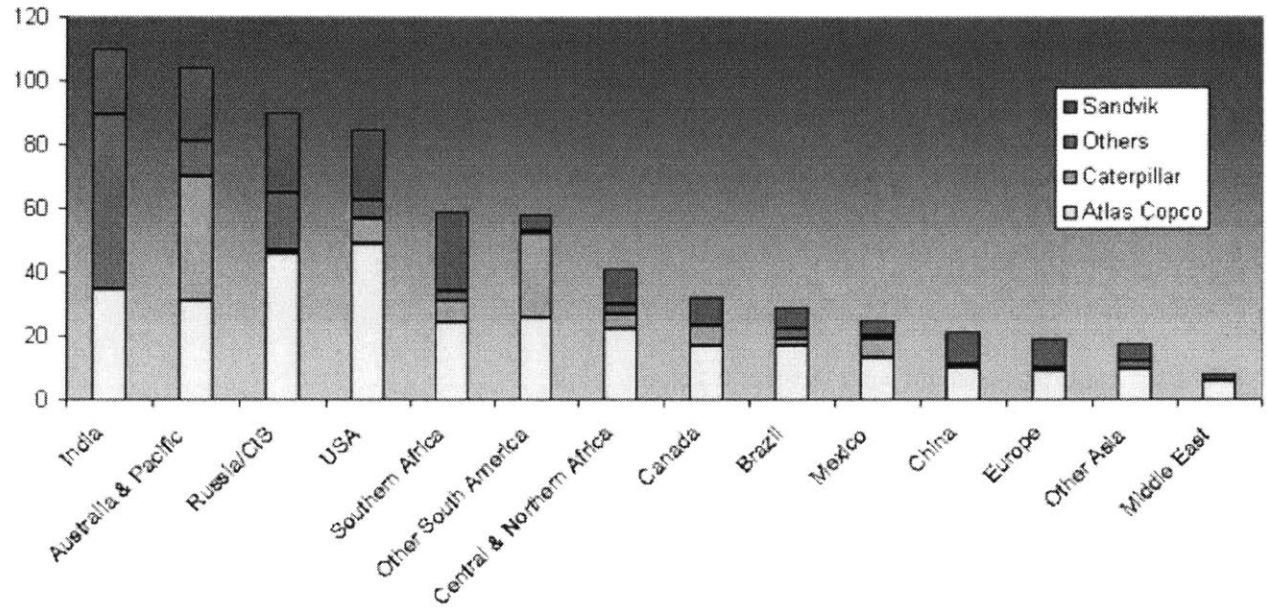

Figure 8: Global demand for rotary Blasthole drills

Based on the global drill demand estimates and market analysis, Caterpillar Global Mining management approved capital investments in facility improvement projects in order to increase production output. Thus, starting in late 2011, the Caterpillar Denison facility began seeing a steady stream of improvement projects. By August 2012, the improvements included: construction of three product line lanes, installment of more than ten lift cranes, replacement of outdated machine shop equipment, refurbishment of the paint shop and construction of a primer booth, installment of AC and of a new pneumatic system, creation of an off-site inventory storage facility, and reorganization of the storage yard.

Furthermore, since the acquisition, the facility staff had been augmented by a contingent of Caterpillar Production System (CPS) internal improvement experts. Caterpillar used the CPS experts to lead process improvement projects and value stream transformations.

3.5 State of Materials Management at Project Start

Next, the reader will be introduced to the Caterpillar Denison materials value chain, its key stakeholders, and the state of materials management at project start. Although Caterpillar has plans to transform the value chain, at the start of the project, the materials value chain remained largely unchanged from the time of the Bucyrus acquisition. The material acquisition decision-making process remained with the facility. At the time of the project, the facility was utilizing a supplier base of roughly 670 suppliers, the majority of which were located in Texas.

The individuals who were involved in the materials value chain are presented next. Most of these individuals were new to Caterpillar and were not familiar with Caterpillar standards, processes, or tools. This factor complicated the facility transformation process, since oftentimes stakeholders had to learn Caterpillar processes while leading the transformation efforts.

Job Function	Denison Experience/Caterpillar Experience/Supply Chain Experience
Supply Chain Manager	New to Denison facility/Experienced Caterpillar employee/Familiar with supply chain processes
Purchasing Manager	Experienced Denison facility employee/New Caterpillar employee/Familiar with supply chain processes
Demand Manager	Experienced Denison facility employee/New Caterpillar employee/Familiar with supply chain processes

Engineering Manager	Experienced Denison facility employee/New Caterpillar employee/Familiar with supply chain processes
Suppliers	Experienced in supplying Denison facility/Not experienced in supplying Caterpillar/Low supply chain processes exposure
Off-Site Warehouse Manager	New to Denison facility/Experienced Caterpillar employee/Low supply chain processes exposure
Quality Manager	Experienced Denison facility employee/New Caterpillar employee/Familiar with supply chain processes
Production Manager	New to Denison facility/Experienced Caterpillar employee/Familiar with supply chain processes
Materials Planning Manager	New to Denison facility/New Caterpillar employee/Familiar with supply chain processes

Table 1: Caterpillar Denison materials value chain stakeholders

Next, the discussion will describe the state of the materials management processes at Caterpillar Denison at the beginning of the project. The text utilizes the CPS supply chain assessment questionnaire; the answers to the questionnaire paint a picture of the amount of work that had to be completed to transform the facility into a Caterpillar production plant.

CPS Questionnaire	Current State of Facility
We have a Logistics Planning Process (LPP) with a Plan for Every Part (PFEP). Standard lot sizing, lead-time, response time, and	No PFEP established, no standard lot size, no standard lead time, no

exception parameters are managed consistently and agreed upon by suppliers for every part.	standard response time
Part numbers are planned to Point of Use (POU). Part numbers are moved from receipt at facility dock to first POU (machine or assembly) per plan with the smallest number of handling opportunities possible.	No plan for part movement, handling opportunities have not been analyzed
Point-of-usage inventory in production is managed using formal inventory management principles. Inventory record accuracy (wall to wall – counted in every location) measurements and cycle counting procedures are used in production, much like they are used in the stockroom.	Inventory management principles are only being introduced to the facility. Inventory record accuracy is not measured in production
MRC Connect is used to communicate replenishment requirements, including pull signals with external suppliers.	Electronic systems are not being used to communicate with suppliers
More than 80 percent of direct inbound material is on pull.	Less than 10% of inbound material is on pull
Roles are clearly separated between operations and supply chain personnel. The supply chain team or suppliers provide all required materials to the POU.	Roles are separated
Workplace layouts support continuous flow, pull replenishment, capacity planning, and the future-state value stream map.	Layouts are not complete, as production lines are being added
A documented process exists to support First In First Out (FIFO)	No documented FIFO process

inventory management in all operations.	exists
Internal pull replenishment processes are implemented to manage material flow within a facility.	Internal pull processes are being introduced to the facility
A future-state map outlines the ideal state of pull replenishment from customer through supplier.	Unclear whether a future-state map exists
Process variability within the factory and supply chain is measured. The variability in these processes is the driver for all inventory and buffers.	Only some of the variability is measured
Accountability for inbound direct material delivery performance is clearly established, with an overall goal of 98% or greater on-time conformance consistently being demonstrated.	Not clear whether accountability is established. Performance is not being monitored

Table 2: CPS questionnaire for supply chain

The completed CPS questionnaire presents the gap between the facility's state of materials management and Caterpillar standards. The Supply Chain Manager was aware of this gap, and was sponsoring several CPS projects that addressed some of the issues. Specifically, the enterprise resource system was being tailored to match the facility needs, metrics were being implemented to monitor inventory record accuracy across the material storage areas, and workplace layouts were being designed.

3.6 Project Motivation

The following section will explain the motivation for the project. After the acquisition of Bucyrus International in July of 2011, Caterpillar sent teams of operations experts to examine former Bucyrus facilities and assess the operations at each plant. One of the recommendations for the Denison facility's supply chain organization was to review its inventory position and reduce excess stock. However, this recommendation was one among many other recommendations for the materials team, and was not at the top of the priority list for the Supply Chain Manager in 2011. When the Supply Chain Manager learned that the facility would be hosting an LGO project in 2012, he proposed that the LGO project be focused on analysis and reduction of excess inventory. Therefore, the project to analyze and reduce excess inventory at Caterpillar Denison can be traced to the recommendation made by the acquisition synergy committee that reviewed the facility's operations in 2011.

4 Root Causes of Excess Inventory

4.1 Summary

The following section of the thesis will focus on the first hypothesis, which asserts that the accumulation of surplus inventory can be traced to several key root causes, and that their elimination will significantly slow the creation of new surplus inventory. First, the text discusses the root cause discovery process at Caterpillar Denison. Then, the text identifies and analyzes the root causes discovered. Next, the text presents an analysis of three selected root causes and their effects on excess inventory. Finally, the thesis discusses the implications of the findings made at Caterpillar Denison for the validity of the hypothesis.

4.2 Root Cause Identification

The text in this section will describe the process used to identify the root causes of surplus material at the facility. A common approach used to solve problems starts with cause identification. Therefore, if an organization wants to reduce the accumulation of surplus material, it first has to acknowledge that surplus material is only a symptom, and then identify the causes of this symptom. The Supply Chain Manager at Caterpillar Denison firmly believed that surplus material was in fact only a symptom of the problem, and supported the discovery of root causes as the first step to stopping surplus material accumulation.

Numerous publications list sources of excess material in supply chains. For instance, one could start with the cause and effect diagram developed by the Crandalls that is presented in Figure 2, and apply it to the Caterpillar Denison facility. However, the authors state that a more accurate and complete picture of the root causes will be derived if the facility investigates its operations and creates its own cause and effect diagram (Crandall & Crandall, 2003). In view of this recommendation, the LGO Fellow set out to identify the sources of excess material at Caterpillar Denison by examining the materials value chain. To complete this goal, the LGO Fellow interviewed managers of every functional group that participated in the materials value chain: demand management, engineering, planning, purchasing, off-site materials warehouse, production, and quality. Based on the interviews, the LGO Fellow created a process map of the materials value chain, and then located the factors leading to the creation of surplus material. The analysis of the value chain processes yielded over twenty factors responsible for the creation of surplus material. Hence, the LGO Fellow grouped sources of surplus material by category, and created a cause and effect diagram loosely based on the principles of system dynamics. The resulting cause and effect diagram can be found in the appendix section of the thesis.

However, while the cause and effect diagram was helpful in identifying the causal relationships of the primary and secondary root causes, the efficacy of the cause and effect diagram was limited because it did not prioritize the root causes or connect them with specific functional groups. Complicating the situation was the fact that the facility did not possess quantitative data that could be used to characterize the effect of the majority of the root causes.

To address the fact that the cause and effect diagram did not connect root causes with functional groups, the LGO Fellow converted the diagram into a root cause spreadsheet, which can also be found in the appendix. The spreadsheet tied each root cause to the behaviors of the functional group, which was interviewed using a set of questions similar to the questionnaire developed by the Crandalls and presented in Figure 3 (Crandall & Crandall, 2003).

4.3 Root Causes of Excess Inventory Accumulation

The following section of the text will present the factors discovered to affect excess inventory accumulation. The analysis of the materials management processes at Caterpillar Denison yielded a significant number of causes of surplus inventory. Nearly all of these could be attributed to the actions or decisions of functional groups within the facility. What follows is a list of the identified factors, organized by functional group.

Functional Group	Root Causes of Excess Inventory
Sales	Special customer requests such as hardware modifications are accepted, even after the machine design has been frozen and parts are ordered. Thus, ordered parts have a high probability of becoming obsolete.
	The machine lead time quoted to customers is shorter than the lead time for some of the materials required to build the machine. This causes the purchasing group to order materials to forecasts, which means that some of the material will go unused and become surplus.
Engineering	The Bill of Material (BOM) is not always updated with engineering changes; therefore, Purchasing may order the wrong number of parts or parts to the wrong design specification. This means that ordered parts may be unnecessary or of the wrong design, in which case there is a high probability that they will become obsolete.
	The facility operates with duplicate part numbers for the same part; which implies that in some cases, engineering changes are not applied to all of the parts; hence, parts may be ordered to the wrong specification.
	Engineering change notices become effective immediately upon release, and the old revision material often becomes surplus.
	Part commonality among machines is low; therefore, if extra parts are ordered or a machine order is canceled, there is a small probability that the surplus parts can be used on a different machine.
	Accurate material routings are not established, and therefore, the MRP system is used

	ineffectively.
	The facility does not have a machine configurator, meaning that the design is translated from a written description to a bill of materials manually. This creates a significant opportunity for manual error in which a design engineer specifies an incorrect part, Purchasing buys the incorrect part, and the incorrect part becomes excess inventory.
Planning	Planners use a conservative material due date of several weeks prior to start of build. Therefore, the facility holds excess material, incurring unnecessary holding costs over this period.
	Planners use a single need date for all of the material used throughout the machine build, even if the cycle time is nearly three months. This means that the facility incurs extra holding costs on material that is waiting to be used.
	The MRP system is not configured with correct production data, and therefore, all of the material need dates are set manually. This creates opportunities for manual errors and ordering of excess material.
Purchasing	The facility has no electronic forecasting system set up between itself and the suppliers. Therefore, the suppliers have no visibility into the facility's future needs; hence, they quote longer lead times to provide for needed flexibility. This turns into longer lead time for the facility and more conservative materials delivery requirements used by planners, which translates into earlier delivery dates, greater holding costs, and higher levels of excess inventory.
	Suppliers are not incentivized or penalized for their performance. Hence, sometimes suppliers deliver materials early; this increases holding costs and excess inventory. Also,

	often suppliers deliver nonconforming materials that cannot be used in production, and in some cases end up as excess inventory if enough time has elapsed since the material receipt date.
	In some cases, Purchasing does not send the required engineering changes to the suppliers, and as a result, the suppliers deliver non-conforming materials, which end up as excess inventory.
Quality	Some of the quality-rejected material is stored outside of the rejected material storage area, is never tracked, and is forgotten. Over time, this rejected material becomes excess inventory.
Materials	The facility storage yard is treated by the system as a single storage location, and therefore material is sometimes lost and becomes surplus; in the best case, finding material in the yard is time-consuming.
	Parts are often damaged during transfer, rejected, and forgotten.
	Parts are often misplaced prior to machine ship-out, and become surplus inventory.
	First in first out (FIFO) is not implemented. Hence, parts are more likely to be damaged by the elements, rejected, and forgotten.
	The enterprise resource planning system has glitches which lead to misplaced and lost items in the material storage warehouse.
	There is no standard for material labeling in the storage yard and the warehouse. Hence, often the material handlers simply do not know which part number corresponds to which physical part. Therefore, the physical parts languish in inventory and ultimately become

	surplus.
	Parts are not visible to the system after they enter the manufacturing facility; this leads to frequent loss of parts and, ultimately, excess inventory.
Production	Parts are removed from finished machines to be used on the production line (machine cannibalization). This leads to inventory record inaccuracy and excess inventory.
	Parts are modified on the line without proper changes being made to the engineering drawings. This means that incorrect parts are ordered in the future, and excess inventory is created.
	Kits are partially used, and then the remaining parts are returned to the warehouse and classified as a complete kit. Since the kit is incomplete, it cannot be used in production, and is excess inventory.

Table 3: Root causes of excess inventory observed at Caterpillar Denison

Table 3 presents more than twenty root causes of excess inventory observed by the LGO Fellow at the facility. This large number of identified causes falls in line with the findings presented in the reviewed literature. For instance, the Crandalls identify 18 root causes, which they organize into six groups (Crandall & Crandall, 2003). D. Juran and H. Dershin list 14 contributing causes grouped into two broad categories (Juran & Dershin, 2002). Interestingly enough, some of the practitioners believe that there are only a few key root causes behind the excess inventory problem. For instance, P. Bower specifies just six areas that are typically reviewed by supply chain improvement consultants (Bower, 2011), while R. Pay focuses on just three areas for improvement (Pay, 2010).

However, the discovery of a large number of root causes does not immediately rule out the first hypothesis, as it is possible that only a few causes generate the majority of excess inventory. Unfortunately, most heavy equipment manufacturing facilities, including Caterpillar Denison, do not collect data that could be used to characterize the effect of each root cause. These data would be helpful in determining how dominant the effects of each root cause are, and this, in turn, would help to determine whether, in fact, a handful of causes are driving most of the excess inventory, or whether each factor contributes to the problem more or less equally.

4.4 Excess Inventory Root Cause Elimination

Once the root causes are determined, an organization must eliminate these underlying issues in order to solve the problem. However, since there was no data available to quantify the majority of the root causes identified at Caterpillar Denison, it was not clear how to prioritize the improvement efforts. In fact, D. Juran and H. Dershin state that there is no single "silver bullet" that will solve the problem of excess inventory, and that all of the critical "bones" in the cause–effect diagram need to be addressed (Juran & Dershin, 2002).

Conversely, several authors recommend specific, limited actions that, in their experience, yield significant results and thus claim higher priority over other possible root cause elimination efforts. For instance, P. Deis and G. Miller state that the most important factor affecting surplus inventory is product design. The authors state that "a product design that minimizes the number of parts, picks easily obtainable materials and components, lends itself to manufacturing with the simplest possible facilities and equipment will minimize inventory costs over the long pull" (Deis & Miller, 2006). While this statement may be true, this activity also takes years to implement, and therefore could not be tested in the scope of the six-month LGO project.

R. Pay makes another set of recommendations that consists of just three improvements: the introduction of S&OP, auto-replenishment systems, and a ramp-up/ramp-down process (Pay, 2010). However, Caterpillar Denison already had an established S&OP process, and ramp-up/ramp-down process were outside of the schedule scope for the project. The third recommendation of an auto-replenishment system was already in place for some of the low-dollar, high-consumption parts, such as fasteners. While creating an auto-replenishment system for other parts was an attractive option, the realities of the Denison facility, with its continuously changing part specifications and low part commonality, as well as the scope of the project's schedule, ruled out this option.

Furthermore, during the examination of material management at Caterpillar Denison, the LGO Fellow discovered that some of the root causes were already being addressed. The LGO project coincided with improvement activities associated with the assimilation of the facility into the Caterpillar production network; these improvements are listed below.

Functional Group	Improvement Activities Eliminating Root Causes of Excess Inventory
Engineering	Addition of temporary engineering staff to deal with BOM inaccuracies and updates, which will reduce instances of incorrectly ordered material.
	Efforts to improve/correct material routings that will empower the functionality of the MRP system and facilitate staggered material ordering.
	Plans to introduce an engineering change effectivity date, so that ECNs do not become effective upon release, and the quantity of material turned into surplus due to ECNs is reduced.
	Plans to introduce a machine configurator to eliminate the possibility of manual error during BOM creation, which will reduce the amount of material ordered incorrectly.
Purchasing	Hiring of a manager to oversee supplier tactical operations and improve supplier delivery performance accuracy and part quality. This should reduce the number of surplus parts generated due to quality defects, and reduce the excess inventory delivered to the facility early.

Materials	Plans to analyze and improve the ship-out process. This will reduce instances of materials getting lost during machine ship-out.
	Division of the material storage yard into quadrants with matching locations present in the system. This greatly reduces the chances of material getting lost.
	Adjustment of material dimensions and weights recorded in the system to reflect reality; this allows for material to be stored correctly in the warehouse, and reduces inventory record inaccuracy.
	Creation of a materials staging area for some of the machine types. This reduces chances of material being misplaced.
	Creation of a group to review unidentified/unknown material that is returned to the warehouse from the manufacturing facility. This will improve inventory record accuracy and highlight issues in production that are causing the return of material to storage.
	An expert group has been employed by the facility to work on the ERP system (SAP) implementation issues and glitches.
	Improvement of material handling practices through standard work and staff meetings. This reduces the number of parts that are damaged during handling.
Quality	Freezing of payment to suppliers in order to accelerate the return of quality-rejected material to suppliers. This solves the problem of rejected material lingering at the facility and getting lost.

Table 4: Caterpillar Denison initiatives targeting root causes of excess inventory

In assessing the options for eliminating the remaining causes of surplus material in the absence of a concrete prioritization methodology, the LGO Fellow followed two strategies: focusing on causes of surplus material accumulation identified by the Supply Chain Manager, and continuing the search for dominant root causes.

The first strategy resulted in the selection of two causes of surplus inventory: first, purchasing group employees ordering all material needed for one machine to a single date one month ahead of the build start; and second, the suppliers consistently shipping material early. The analysis of these two root causes can be found in the following section of the text.

The second strategy resulted in the creation of a survey. Initially, the LGO Fellow considered different methods of prioritization of the root causes without relying on quantitative data. Ultimately, the Fellow decided to elicit the "wisdom of the crowd" and survey the stakeholders in the materials value chain to determine what they considered to be the pivotal root causes. The survey pointed out inventory record inaccuracy as the single largest contributing root cause of excess inventory accumulation.

4.5 Solution feasibility and Analysis of Expected Results

The following analysis estimates how much money Caterpillar Denison could save by staggering material delivery dates, thus eliminating one of the root causes of excess inventory. At the time of the project, the purchasing group at Caterpillar Denison ordered all material required to build a machine to a single date, one month ahead of the machine's build start. Considering that the largest and most complicated machines take nearly three months to assemble, the delivered material was held at the facility for a long period of time without being used, and was considered excess inventory. The time that material spends at the facility without being used translates into holding costs for the company. The Supply Chain Manager wanted to find out how much money the facility could save by staggering the material delivery dates such that the material was delivered to the facility one week prior to its expected use date.

To estimate the impact of such a policy change on the facility's bottom line, the LGO Fellow decided to analyze the Ultras, Caterpillar Denison's most expensive line of machines, which have material costs in the range of several million dollars. These machines have eight assembly stations in the build process, and the work at each station takes nine days to complete, for a total of 72 days. While operations experts estimate annual holding costs to range between 20% and 40% of inventory value (Thummalapalli, 2010), for the purposes of this analysis, the annual holding cost is estimated at a conservative 20% of inventory value. The low holding cost estimate of 20% is used to highlight the significant savings that could be realized by the facility even using the most conservative calculations. This means that the following analysis considers only the capital costs of holding inventory and ignores all other costs associated with storing material.

Furthermore, this analysis compares the cost savings that the facility could expect if it switched from a single delivery date for all material one month ahead of the build start to a staggered material delivery approach in which the material is delivered one week ahead of its actual use date. Finally, the analysis is based on the material cost data derived from the enterprise resource planning system.

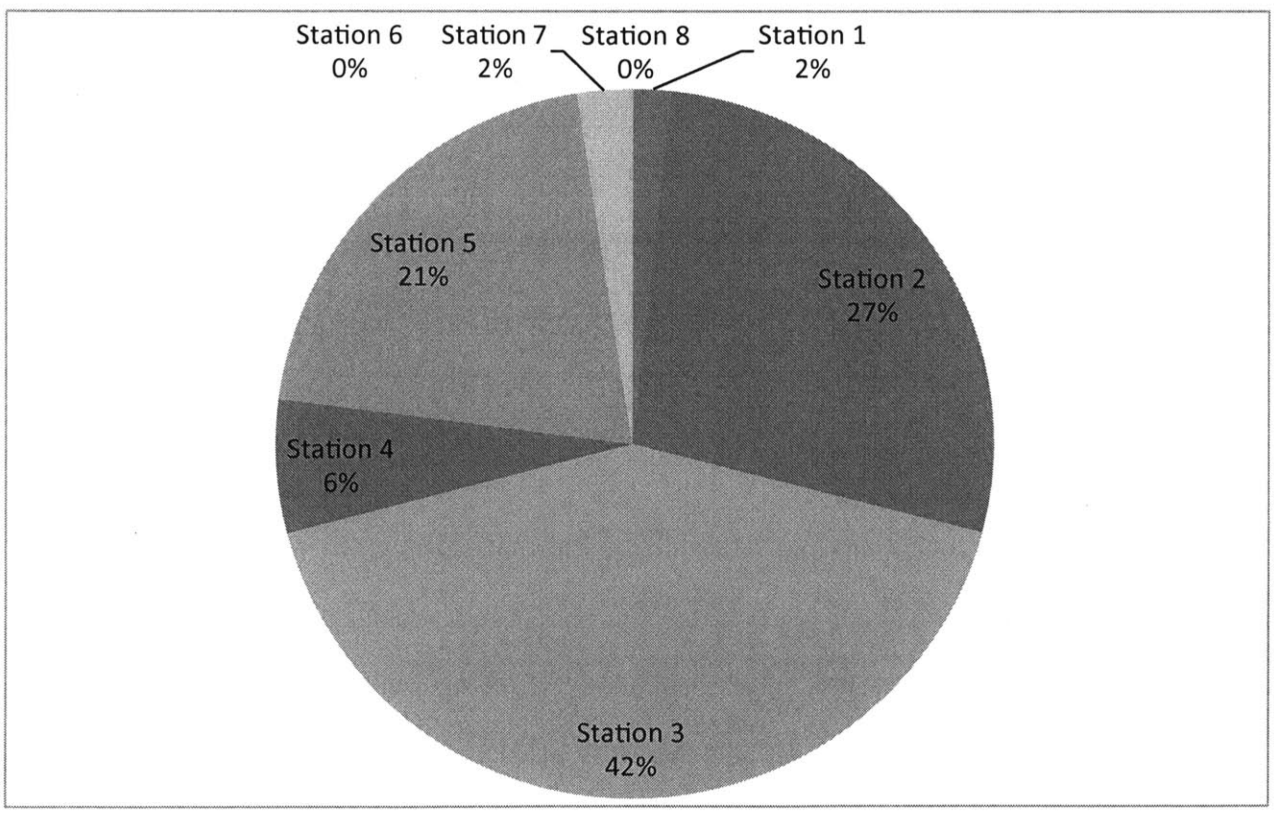

Figure 9: Ultra machine holding cost breakdown

The figure above documents the current holding cost expenditures incurred by the facility grouped by assembly station. The data suggests that the majority of expenditures fall on stations 2, 3, and 5; these are the stations that attach the most expensive parts to the machine.

The overall analysis suggests that Caterpillar Denison could save over $40,000 in inventory holding costs on each Ultra machine. The total conservative cost savings could amount to nearly a million dollars per year. These savings are significant, and would improve the profitability of the facility by several percentage points.

The same analysis methodology can be applied to the less expensive machines that take less time to build; the results would also be positive, and would improve profitability by several percentage points for each machine. However, this policy change requires accurate material routings, along with consistent supplier quality and delivery performance. While material routings are controlled by the facility and can be improved in the short term, supplier performance is an exogenous factor that is generally difficult to control. To account for possible supplier issues yet still reduce the holding costs, the facility could move to a conservative staggered delivery schedule. Materials could be delivered two weeks ahead of the actual need date instead of one week. If the more conservative policy is applied to the Ultra machines, the facility still conserves capital in the amount of well over $30,000 per machine, and well over $500,000 cumulative savings.

The second source of excess material accumulation that was analyzed by the LGO Fellow is supplier delivery performance. At the time of the project, Caterpillar Denison facility management did not have supplier delivery performance metrics; therefore, it was not clear whether the suppliers were in fact systematically delivering material ahead of schedule. If, in fact, the suppliers were delivering material early, that would mean that the facility was holding excess material and paying additional inventory holding costs. This source of excess material is examined by P. Bower and is classified as buy-side tolerance. P. Bower cites examples of companies carrying hundreds of thousands of dollars in excess inventory on a single class of product due to this issue, and he therefore recommends an investigation of this area of operations (Bower, 2011).

To analyze this potential problem, the LGO Fellow utilized system data organized by expected material delivery dates and the actual material delivery dates. The data came from supplier shipments completed from December 2011 through August 2012. In this time period, 675 suppliers shipped material to Caterpillar Denison. The following chart documents the distribution of the average delivery performance by each supplier. Based on the data, the average delivery is approximately six days late, which suggests that on the whole, the facility is not receiving material early.

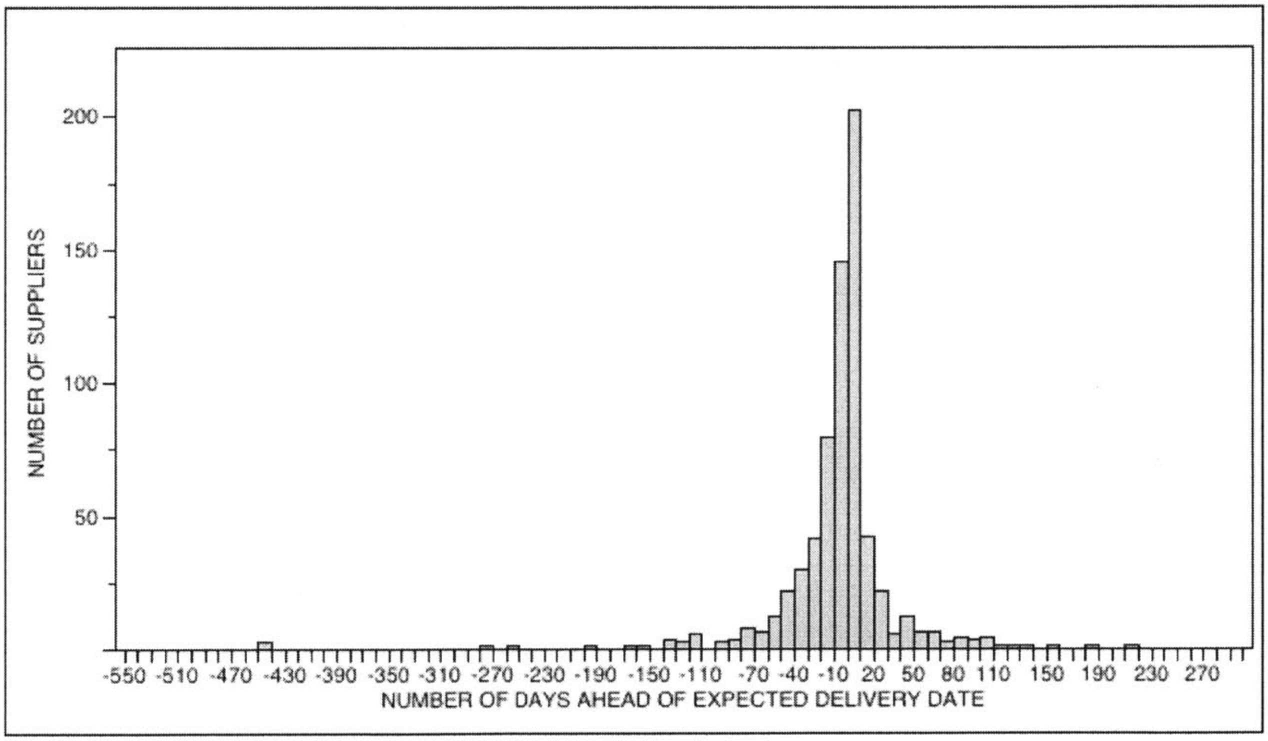

Figure 10: Distribution of supplier delivery performance

However, the question of whether any specific suppliers are systematically delivering materials early remains unanswered. Hence, the data is analyzed further. To identify suppliers with consistently early or late deliveries, the following filter can be applied. The absolute difference between the average actual delivery date and the expected delivery date must be greater than the standard deviation of the differences between the actual delivery date and the expected delivery date for each supplier. This filter eliminates suppliers who are inconsistent in delivery performance, and leaves 506 suppliers in question. Next, to filter out the non-consequential suppliers who have not had a sufficient number of transactions with the facility, all suppliers who have fulfilled fewer than ten purchase orders are also removed from the list. The second filter shrinks the list to 19 suppliers who deliver materials consistently early, and 149 who deliver late. Their performance can be examined in the chart below.

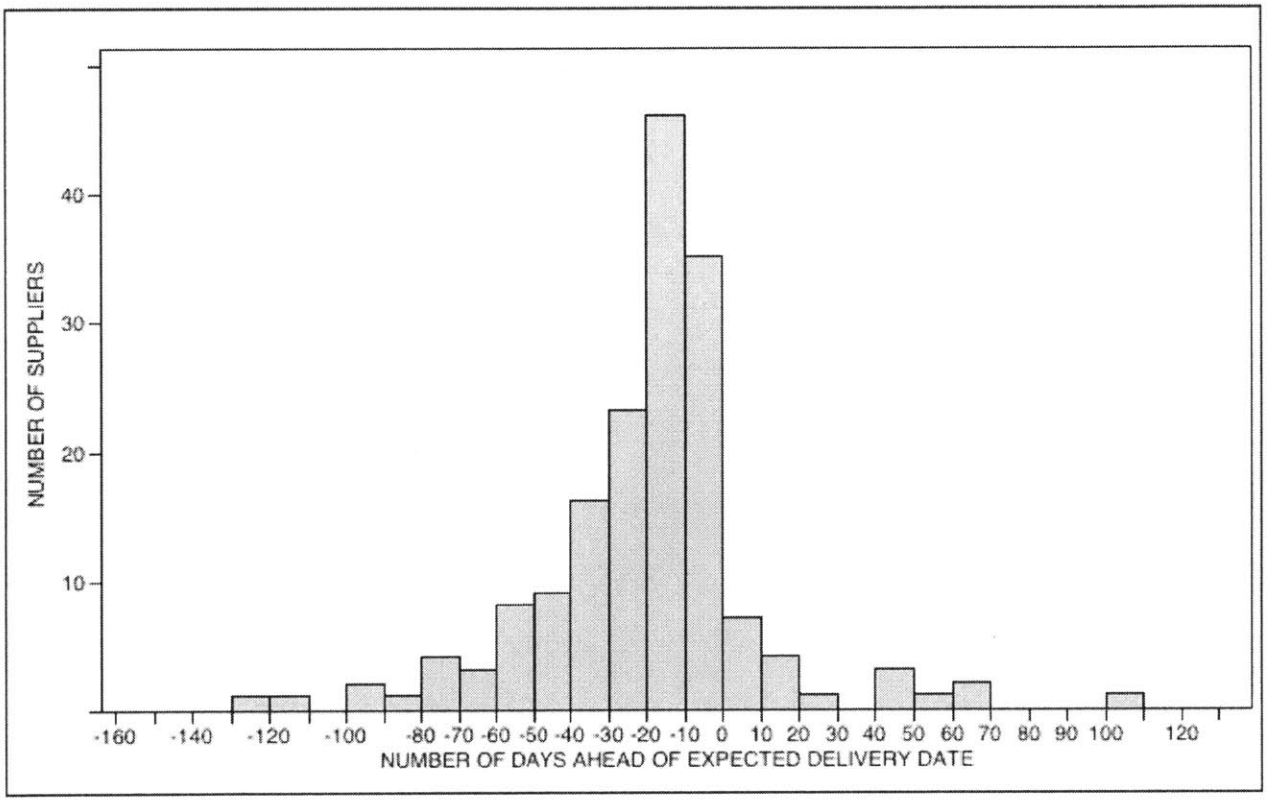

Figure 11: Distribution of supplier delivery performance

The findings suggest that, on average, consistent suppliers deliver materials nearly twenty days late. Also, there are 13 suppliers who are consistently early and deliver materials more than one week ahead of schedule. In total, these 13 suppliers cost Caterpillar Denison $62,000 in extra holding costs. Considering that in the reviewed period, Caterpillar Denison utilized 675 suppliers for over $50 million in expenditure, the financial impact of these 13 suppliers is small, and their actions constitute a minor source of excess material. Furthermore, during the study, the Purchasing Manager questioned the accuracy of the data used for the analysis. Overall, even if the data underlying the analysis are completely accurate, the results suggest that early supplier deliveries are only a minor contributor to the surplus inventory problem.

Another root cause of surplus material investigated by the LGO Fellow was low inventory record accuracy. This root cause was selected for investigation as a result of the survey conducted among the material value chain stakeholders. The survey identified inventory record accuracy as the most significant contributing factor to surplus material accumulation. Although there was no quantitative evidence to characterize the effects of inventory record inaccuracy on excess stock at Caterpillar Denison, literature sources do state that differences between inventory levels in information systems and physical inventory can deeply hinder a firm's performance (Sarac, Absi, & Dauzère-Pérès, 2010).

A specific example of one inventory record inaccuracy at Caterpillar Denison that supports the previous statement follows. During the inventory review process, an item type was discovered that was listed as "Gear & Pinion", with a quantity of 31 units, costing $14,500 per item. After investigation, it was discovered that the units were small fittings costing less than $1 each. While it was unclear when the item type first appeared on record, it is quite possible that the facility had mistakenly overstated its assets by $447,000 while declaring taxes for several years.

The Caterpillar Denison Materials Group tracked inventory record accuracy as one of its key performance metrics. However, this metric was not measured for several months in the middle of the year while materials were transferred from facility storage to an off-site storage warehouse. When the metric collection resumed, it was in the low 80% range, which several members of the materials team considered unrealistically high. Yet even an 80% inventory record accuracy can lead to significant problems in production and cause the purchasing group to order large amounts of excess inventory.

Inventory record inaccuracy is itself caused by several underlying factors. These factors were investigated at Caterpillar Denison and are presented below.

Causes of Inventory Record Inaccuracy
1. Material concepting issues that cause the system to place items in containers and bins which are too small for these items.
2. Undocumented material movement around the yard.
3. Parts mislabeled and misplaced outside the paint shop.
4. Parts lost during the machine ship-out process.
5. No clearly labeled material staging area.
6. Undocumented material retrieval by assemblers.
7. No standard procedure for material scrapping.
8. Material is not labeled and can get lost at the facility yard or the storage warehouse.

Figure 12: Causes of inventory record inaccuracy

Facility management recognized the identified problems and was planning to address each of the issues. Material concepting was mostly completed in the first nine months of 2012, and a material staging area was set up for one of the three production lines. Undocumented material movement and material retrieval were cultural issues that were addressed by facility management, although no specific metrics existed to document improvement in these areas. The issues of mislabeled and misplaced parts outside of the paint shop and prior to machine ship-out, as well as the issue of standardized material scrapping instructions, remained to be addressed at the end of the LGO project. Furthermore, to improve inventory record accuracy, the Supply Chain Manager ordered a physical check of the entire inventory at the facility at the end of 2012. While this is a time-consuming activity and requires significant human resources, it is the only way of rapidly improving inventory record accuracy.

Overall, the LGO Fellow investigated three root causes of excess inventory accumulation: a non-staggered material ordering scheme, early material delivery by suppliers, and inventory record inaccuracy. The non-staggered material ordering scheme analysis uncovered a significant cost savings opportunity of over $40,000 per Ultra machine built by the facility. The cost savings would come from reduced inventory holding costs incurred by the company. The analysis of the early material delivery by suppliers resulted in the identification of 13 suppliers that consistently deliver materials early. However, the total holding costs incurred by the facility due to this supplier action is only $62,000. The author believes that this is a relatively minor figure when compared with the holding costs of excess inventory generated by other factors. Finally, the effect of inventory record inaccuracy on excess inventory could not be quantified; however, literature-based analysis of this topic and facility stakeholder sentiments suggest that this is a significant cause of excess inventory. The inventory record accuracy at Caterpillar Denison was estimated at slightly over 80%; however, facility management did not fully trust this figure, and some believed that the actual accuracy was below 80%. The Supply Chain Manager believed that inventory accuracy was a significant problem, and initiated action to improve the measure. The improvement strategy had two thrusts: first, the elimination of causes of inventory record inaccuracies, and second, the correction of existing inaccuracies through a physical inventory check.

4.6 Implications of the Excess Inventory Study for the Hypothesis

The analysis of the underlying causes of excess inventory accumulation at Caterpillar Denison uncovered over twenty factors responsible for creation of excess inventory. Since the effect of each root cause could not be quantified and the dominant view of the research and practitioner communities disagrees with the hypothesis, the author believes that the fist hypothesis is not confirmed. Therefore, the statement that several key root causes are responsible for the accumulation of the majority of excess inventory and that their elimination therefore leads to a major reduction of the excess inventory problem cannot not be verified. The next section of the thesis examines inventory reduction techniques and predicts potential outcomes if the proposed techniques are utilized.

5 Excess Inventory Reduction

5.1 Summary

The following section will focus on the second hypothesis proposed in the thesis, which states that a basic inventory review process can be effectively used to identify and reduce excess inventory. First, the section will cover the formulation of the excess inventory review process. Next, the text will present an analysis of the inventory at Caterpillar Denison. Then, the thesis will discuss the application and results of the process created. Finally, the text will discuss the implications of the findings at Caterpillar Denison on the validity of the hypothesis.

5.2 Formulation of an Excess Inventory Review Process

Caterpillar, like any other manufacturing corporation, has to deal with the problem of excess inventory. Therefore, the company has created a formal excess inventory management process that is used in all of Caterpillar's facilities. However, because Caterpillar Denison was just joining the Caterpillar production network and only starting to implement Caterpillar standards and processes, the Supply Chain Manager decided that the facility was not yet ready to adopt the standard Caterpillar excess inventory management process at the time of the project. Specifically, he thought that the standard excess inventory process was too resource-intensive, and planned to implement it once the higher-priority facility transformations were complete. Yet the Supply Chain Manager still wanted to execute the recommendation of the Acquisition Synergy committee and reduce excess inventory. Therefore, he requested that the LGO Fellow formulate a material review process that could be used to identify and reduce excess inventory, and that could be executed by facility personnel with minimal outside involvement.

Since the facility did not have a set inventory policy, a periodic inventory review process, or a set excess stock definition, the first step in reducing excess stock was to actually define excess inventory. While there are numerous ways to define excess inventory, the definition for Caterpillar Denison had to be simple and based on the data available in the enterprise resource planning system. Therefore, in conjunction with the Aftermarket Manager, the LGO Fellow drafted a definition that satisfied the two stated conditions: "Excess inventory is material that has no production demand and no sales history in the enterprise resource planning system." The logic behind the requirement for no production demand is based on the notion that if production demand exists, then the items will be used at some point in the near future and should be kept, while the absence of production demand for the material type signifies that the items will continue to languish. The second portion of the definition – no sales history requirement – was added to the definition because of the option of selling parts through the aftermarket channel as an alternative to using the parts in production. No sales history indicates that the parts have never been sold through the aftermarket channel and hence will generate no interest from the Caterpillar dealers.

Next, the materials value chain stakeholders reviewed and approved the excess inventory definition. In their opinion, the definition provided a clear and unambiguous description of excess material that could be applied immediately.

Once the definition of surplus material was established, the Materials Team formulated a material review process that could be applied to excess inventory. Since the subject of excess inventory reduction concerned Engineering, Purchasing, Aftermarket, and Accounting, each group was given the right to review identified parts and provide a disposition. Therefore, the process centered on decision filters and material reviews conducted by the Engineering, Purchasing, Aftermarket, and Accounting departments. The decision to include the various groups in the material review process was based on two factors: one, the data in the enterprise resource planning system was suspect, hence the groups wanted to make sure that no necessary material was disposed of; two, the cultural tendency to hold on to material was very strong at Caterpillar Denison, and the only way to get the groups to agree to reduce excess inventory was to involve them in the material review process.

Based on the literature and internal discussions, the following options were available for material disposition: return to supplier, rework for use in another product, transfer to a different facility, use as spare parts, sell to third party, donate, or scrap (Bower, 2011). However, as noted by the Crandalls, expediency and human resource requirements often trump a value-maximizing approach (Crandall & Crandall, 2003). This was the case at Caterpillar Denison. With the annual tax deadline looming, the materials group wanted to deal with surplus material as quickly and efficiently as possible. Therefore, out of the plethora of options available for dealing with surplus material, the smallest number of those options that would satisfy all of the participating groups was selected. What follows is a brief explanation of the selected material resolution options.

Material Dispositions
1. Keep: Material will be stored in its existing condition with no further actions; material will remain on the facility's accounting ledger, because one of the groups believes that the material will be used in production, even though there is no current production requirement in the system.
2. Transfer to aftermarket: Material will be transferred to the aftermarket group for ownership, storage, and management. Even though there is no sales history of the material, the aftermarket group believes that they can sell the material in the future.
3. Transfer to suppliers: Material will be transferred back to the supplier. Purchasing will negotiate the terms of the transfer with the supplier.
4. Rework: Material will be reworked to an updated specification and then transferred back into production stock.
5. Scrap: Material is not wanted by any of the reviewing groups and will be scrapped.

Figure 13: Excess inventory: possible dispositions

As mentioned in the literature review, one of the effective ways that companies around the world identify excess inventory is through the use of the "red tag" process. This process was also applied at Caterpillar Denison to identify excess material, due to the process's simplicity and efficacy. Design engineers and quality representatives dedicated several hours to the "red tag" process, and identified material that was either no longer used in production or damaged beyond repair. These materials were placed in the quarantine area and became the second input to the excess inventory review process along with the material that matched the excess inventory definition.

Next, the reader can examine the formulated surplus inventory review process. The process flow diagrams are presented in Figure 15 through 20. The documented method has two material inputs: material that matches the excess inventory definition and material identified during the "red tag" events. Once the material enters the review process, it flows through a number of steps that determine whether the material is labeled and identified. Next, the material coming from the quarantine pool is physically examined for quality defects. After several steps of data management, the engineering group reviews the materials; it determines whether the material can be used in future production. If the material can be used in future production as is or through a cost-effective rework, then the material is kept. However, if the engineering group determines that the material will not be used in production, it divides the material between that which can be sent back to the supplier and that which must be scrapped. The material that Engineering deems is returnable to the supplier is reviewed by Purchasing; Purchasing decides whether the material truly can be sent back to the supplier, contacts the suppliers, and manages the material return process. If Purchasing determines that the material cannot be sent back to the suppliers, then the material joins the pool of scrappable material and is reviewed by the Aftermarket Group for sale opportunities. If the Aftermarket Group decides that it can sell the material, the material is transferred to the Aftermarket Group; however, if the group decides that it cannot sell the material, then the material is transferred to Accounting. The Accounting Group reviews the material against the reserve data and writes off the material before it is scrapped.

Another process parameter that had to be defined before the process could be used was the batch size for material review. While the idea of continuous reviews was considered, the Materials Team decided against it due to the time constraints of the reviewers. It was determined that a continuous review process would take more time per item reviewed due to the non-value-added processes associated with information transfer between the steps of the review process. Therefore, it was decided that batching would be used; however, no specific batch size was identified as optimal. The next section will discuss the analysis of excess inventory held by the facility.

5.3 Excess Inventory Analysis

Once excess material was defined and the excess inventory review process was formulated, the Materials Group applied the excess inventory definition to the enterprise resource planning data and analyzed the resulting data dump. The inventory analysis can be seen in the figures below. Materials that were to be consumed by production constituted 77% of inventory; material that was being used in production but had no current production requirements constituted 12%; material that fit the excess inventory definition composed the remaining 11%.

Next, the Materials Group analyzed materials that fit the excess inventory definition, and determined that this category consisted of 4,575 item types totaling $6.9 million. The 100 most expensive items composed 62% of inventory value, 389 items composed 80% of inventory value, 1297 item types cost less than $50. Surprisingly, the excess inventory data analysis yielded results that showed even higher value concentration than suggested by the Pareto rule that "eighty percent of stock is in twenty percent of lines" (Wild & Wild, 2002). Specifically, 8.5% of excess inventory parts constituted 80% of inventory value. This finding suggested that excess inventory could be effectively reduced by focusing on 10% of surplus materials. The next section describes the application of the excess inventory review process and the results of the process.

5.4 Application and Results of the Excess Inventory Review Process

The excess inventory review process ran for three months. The result of the review program was a 34% reduction of surplus inventory, which translates into $2.36 million. Using a conservative annual inventory holding cost estimate of 20%, the one-year savings of the reduction is $470,000. At the end of the LGO project, the review process was ongoing, and roughly 10% of excess inventory was under review. Ultimately, if the Materials Team reviews and resolves all excess inventory, under the conservative estimate of the annual inventory holding costs, the one-year cost savings could total $1.38 million.

Analysis of the surplus inventory review process yields interesting observations. The surplus inventory review process started in earnest approximately three months before the end of the year, when the corporation would have to declare its inventory for tax purposes. Prior to this point, surplus inventory review did not receive sufficient support from the stakeholders; however, as the end of the year appeared on the horizon, the topic of surplus inventory started gaining support. This dynamic was observed and discussed by the Crandalls. Furthermore, once the review process began, the goal of the review was to analyze as much inventory as possible rather than withdrawing the maximum dollar value out of each material type. However, it is possible that the focus on expediency is a results maximization technique learned by the stakeholders earlier in their careers. Since the time dedicated for material review is constrained, it is quite possible that the stakeholders actually maximized value by reviewing more material types rather than focusing on withdrawing the maximum value from each material type. Interestingly enough, researchers do not discuss time constraints of the material reviewers in publications on excess material review, and therefore recommend the "value maximization of each item" approach.

The process itself was run in a single batch, which was predicated by the reviewers' preference. In general, the time constraints of the reviewers dictated the pace of the review and the number of materials that were ultimately reviewed. Even though the excess material review was a high priority item due to the tax implications, the stakeholder participation was less than impressive. This could be explained in part by the lack of strong incentives for participation, since inventory parameters are only a key performance indicator (KPI) for materials organization.

5.5 Implications of Excess Inventory Reduction Results for the Hypothesis

The results of the excess inventory review process at Caterpillar Denison suggest that a basic process can be effectively used to identify and reduce excess inventory in a compressed timespan. As a result of the excess inventory review process2 Caterpillar Denison reduced its excess inventory by nearly 35%, or $2.36 million. Further, by applying an annual holding cost estimate of 20% to the inventory reduction, the annual cost savings top $470,000 thousand. The process can be considered basic because it did not rely on numerical algorithms and only used a set of yes/no filters. Furthermore, the results were achieved in three months with limited participation of the reviewing stakeholders.

6 Recommendations for Improvement

6.1 Summary

The following section will discuss the recommendations for the Caterpillar Denison facility proposed by the LGO Fellow that should reduce excess inventory even further and slow its creation rate. The first section will focus on excess inventory reduction, while the second section will review excess inventory root causes and ways to eliminate them. The third section will discuss additional areas of research stemming from this thesis.

6.2 Excess Inventory Reduction

As stated by the Crandalls in their analysis of excess inventory, any manufacturing organization that uses demand-forecasting processes is bound to have excess inventory (Crandall & Crandall, 2003). Since Caterpillar Denison is moving away from an engineered-to-order strategy toward a build-to-stock production and sales scheme, excess inventory will remain a fact of life. Therefore, Caterpillar Denison must learn to manage excess inventory effectively and efficiently.

To this end, Caterpillar provides a comprehensive excess inventory management process that is documented by a CPS manual. By setting up the process and following its quarterly review requirement, Caterpillar Denison can effectively and efficiently manage excess inventory. The challenge for materials organization is twofold: one, configure the enterprise resource planning system reporting functionality to identify Caterpillar-defined excess inventory; two, sustain the quarterly material review effort. While the first challenge is IT-related and requires the involvement of an SAP specialist, it can be overcome in a relatively straightforward manner. The second challenge requires the involvement of representatives of materials value chain functional groups and is cultural in nature; therefore, it is much more difficult to control. One possible solution to this cultural challenge is a realignment of incentives in such a manner that minimal excess inventory directly benefits all reviewing parties. Given that Caterpillar Denison facility management can master the two identified challenges, the excess inventory at the facility will be well managed.

6.3 Excess Inventory Root Cause Elimination

The analysis of the root causes of surplus material at Caterpillar Denison identified over 20 factors responsible for surplus material accumulation. As D. Juran and H. Deshin state, "Remedies must flow from causes, otherwise there will be no improvements" (Juran & Dershin, 2002). Therefore, the facility management at Caterpillar Denison must focus on eliminating the identified causes. The following list of recommendations addresses the factors identified that lead to accumulation of excess inventory.

Functional Group	Recommendations for Addressing Root Causes of Excess Inventory
Sales	Accept only limited machine modification requests, and implement the changes at dealer sites. This will stop the purchase of unnecessary parts by the facility, and will reduce the complexity of the operation.
Engineering	Update the BOMs as soon as design changes are known to engineering, so that the wrong material is not ordered.
	Eliminate duplicate part numbers from the system to avoid wrong parts specification.
	Assign engineering change effective dates so that the material on hand is used up prior to the new revision taking effect. This will reduce the creation of excess inventory.
	Increase part commonality in future and current machine designs, so that materials can be used interchangeably among machines. This will reduce the creation of

	excess inventory.
	Correct material routings inaccuracies, so that the MRP system can be used effectively and drive staggered material deliveries.
	Design and build a machine configurator, so that the customer can design his/her machine, and the design does not have to be translated into a BOM from a description paragraph. This will eliminate the possibility of human error during the translation of the machine design paragraph into an engineering specification.
	Consolidate piece parts into assemblies and outsource some of these assemblies to suppliers; this will reduce the number of line items in storage and therefore decrease excess inventory accumulation.
Purchasing	Introduce an electronic data interchange (EDI) system that will communicate with suppliers and will both forecast future demand and communicate the facility's material needs to suppliers. This kind of system could reduce material lead time and streamline communication between the facility and suppliers. This will result in less excess inventory held by the facility.
	Create supplier incentives and penalties to improve supplier performance accuracy and quality.
	Hire an Engineering Change Coordinator who will oversee the ECN process and make sure that the right part design specifications are sent to the suppliers. This will reduce instances of incorrect materials being purchased by the facility.
Quality	Increase the size of the quality-rejected area in the storage yard, so that all rejected material can be staged in one place and none of is lost among active material.

Materials	Improve material handling standards and practices by means of a training program, incentives, surveillance systems on forklifts, and the introduction of reusable packaging. The proposed recommendations will improve material handling and, in turn, reduce the excess inventory accumulation rate.
	Introduce material labeling to reduce the loss and misidentification of material. The solution can be implemented through a barcode or RFID labeling technology. In either scenario, the inventory record accuracy will improve, and excess inventory accumulation will decrease.
	Enforce the First-In-First-Out (FIFO) material handling policy; this will reduce the probability of parts being damaged by the elements or becoming obsolete through an engineering design change.
	Identify and fix the enterprise resource planning system glitches which lead to misplaced and lost items in the material storage warehouse.
	Introduce systems to provide part visibility within the facility, so that each part can be tracked from arrival at the facility to the point of use on a machine. This will reduce the number of parts lost and misplaced within the facility.
	Create material staging areas on the plant floor for all machine types; this will reduce cases of lost material in production.
Production	Introduce strict policies prohibiting part removal from finished machines stored in the yard.
	Investigate partial use of material kits in production and remove extraneous parts from the kits.

Figure 14: Recommendations for addressing excess inventory root causes

The challenge for facility management is to prioritize the improvement efforts. At the moment, neither the research publications nor the findings at Caterpillar Denison suggest strategies for this kind of prioritization. Therefore, the Supply Chain Manager needs to guide his decisions based on resource availability, interdepartmental collaboration strategies, and intuition.

6.4 Further Research Opportunities

The excess inventory analysis and reduction project at Caterpillar Denison identified one key challenge that should be investigated further. While the causes of excess inventory and methods of eliminating causes of excess inventory at Caterpillar Denison and similar manufacturing facilities are identified and discussed in research literature, the prioritization of excess inventory factors remains unclear and should be investigated further.

One approach to prioritizing such factors is to determine the quantitative effects of each factor on the creation of excess inventory. This would identify the dominant factors of excess inventory accumulation and help supply chain managers prioritize improvement projects. In order to quantify the effects of the factors, a top-down approach could be taken, creating a methodology to link each factor with existing excess inventory. Alternatively, a bottom-up approach could analyze the causes of a sample of excess inventory items and then rank the factors. The difficulty with both approaches is the chance that strong correlations of root causes would appear, which would complicate the prioritization efforts. In other words, it is likely that multiple root causes could be linked to each excess inventory item. However, in the current absences of any prioritization methodology, the research discussed should be considered.

7 Conclusions

7.1 Summary

The research project undertaken at the Caterpillar Denison drill manufacturing facility was used to test two hypotheses. The first hypothesis states that the majority of excess inventory at a heavy equipment manufacturing facility is caused by a small number of factors, and that if these factors are eliminated, the excess inventory accumulation rate will be significantly reduced. The findings at Caterpillar Denison do not support the first hypothesis. The second hypothesis states that a basic material review process can be used to effectively identify and reduce excess inventory at a heavy equipment manufacturing facility within a six-month timeframe. Findings at Caterpillar Denison confirm this hypothesis; the facility was able to reduce its excess inventory by 34% within three months.

7.2 Factors Leading to Excess Inventory Accumulation

Excess inventory accumulation is a persistent problem at heavy equipment manufacturing facilities, and therefore, supply chain managers all around the globe face the challenge of coming up with ways of reducing the accumulation rates. The hypothesis in the thesis proposed that just a few key root causes are in fact responsible for the majority of excess inventory accumulation. Based on this hypothesis, a project was undertaken at the Caterpillar Denison drill manufacturing facility to identify the key root causes of excess inventory, eliminate these causes, and observe a drastic reduction in the accumulation rate. However, the root cause search yielded over twenty root causes and unearthed no data to rank the effects of theses causes. Based on this information, the first hypothesis is not confirmed.

In the absence of a root cause ranking, a financial analysis was conducted for two of the causes as directed by the facility's Supply Chain Manager. The first analysis focused on the cost savings associated with a staggered material delivery policy as compared to a single delivery date policy. Under a single delivery date policy, all of the material required to build one machine was delivered four weeks prior to the start of the build process. Under the staggered material delivery policy, the material was to be delivered two weeks ahead of the actual need date. Furthermore, the analysis was applied to a class of machines that had an approximately three-month assembly time, with material costs ranging between two and three million dollars. The result of the analysis showed that the facility could save up over $40,000 in inventory holding costs on each machine, which translates into a significant profitability improvement on this product.

The second financial analysis examined the supplier performance data. Specifically, the analysis focused on systemic early deliveries of material, which increased the facility's excess inventory. The findings suggest that systemic early deliveries are not a significant problem at Caterpillar Denison. Out of the 675 suppliers that the facility relied on, only 19 suppliers exhibited systemic early delivery behaviors. Of these 19 suppliers, only 13 delivered material at least one week ahead of schedule. The increased inventory holding cost attributed to these 13 suppliers is $62,000; however, in the scope of the facility's revenues and costs, this figure is relatively minor. In fact, the data suggest that late supplier deliveries are actually a much more salient issue; 22% of suppliers delivered material after the contract date.

7.3 Excess Inventory Reduction

To reduce excess inventory at any manufacturing facility, the supply chain group must complete the following three steps: identify potentially excess material, review the items with the value chain stakeholders to determine if the material is indeed excess, and dispose of the material in a manner that maximizes revenue. In accordance with these steps, the Caterpillar Denison supply chain organization defined excess inventory. Next, the facility created a simplified inventory review process that involved the value chain stakeholders. Finally, it applied the process to the potential excess material. At the end of the three-month excess inventory review and reduction period, the facility had decreased potential excess inventory by 34% percent, which translates into an annual holding cost reduction of $470,000. These results affirm the second hypothesis.

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9 Appendix

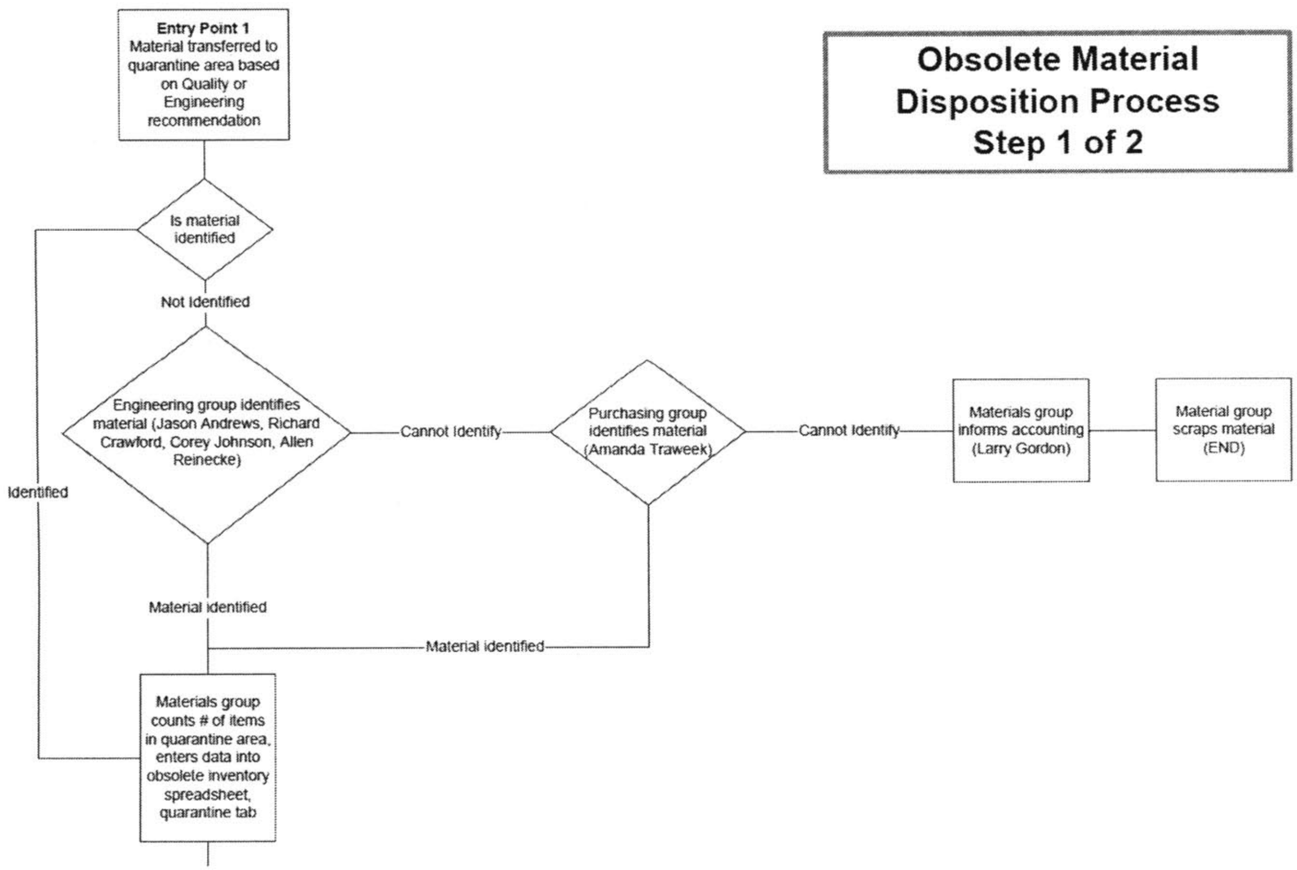

Figure 15: Obsolete material disposition process part one of four

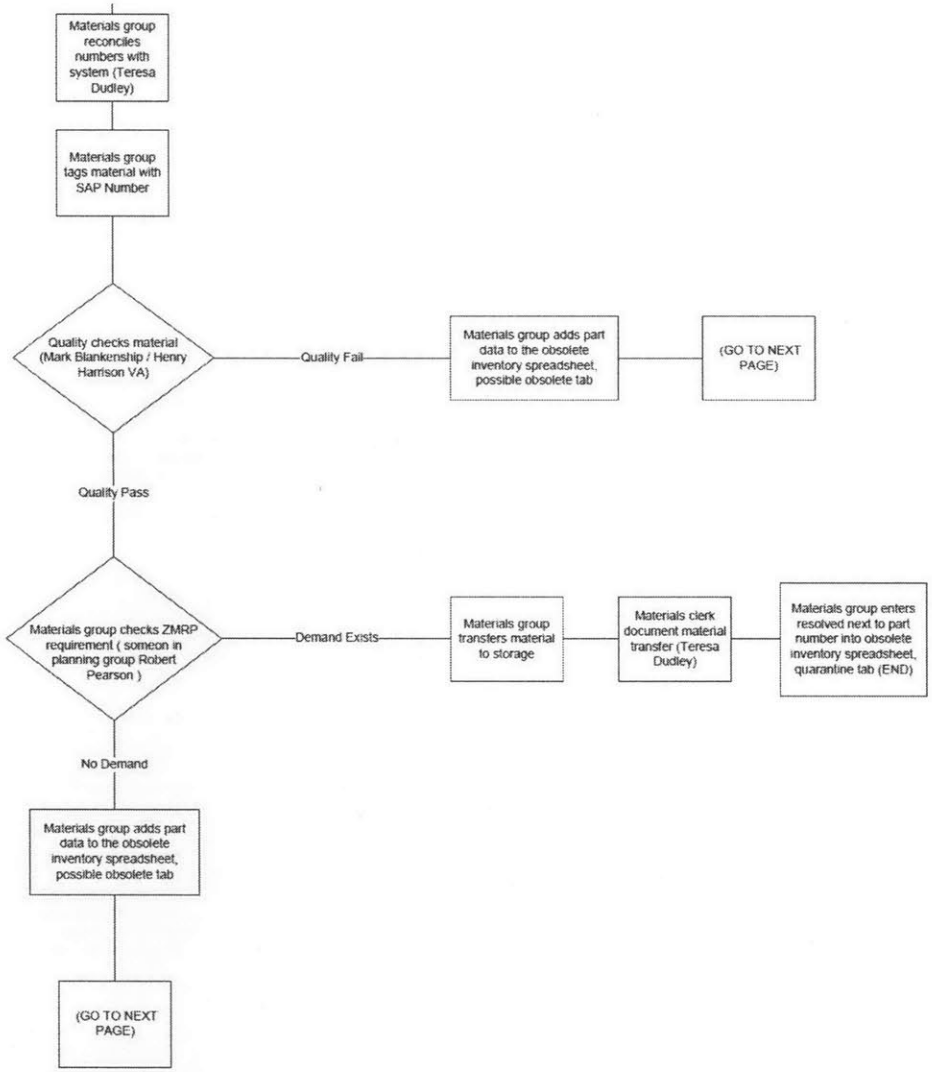

Figure 16: Obsolete material disposition process part two of four

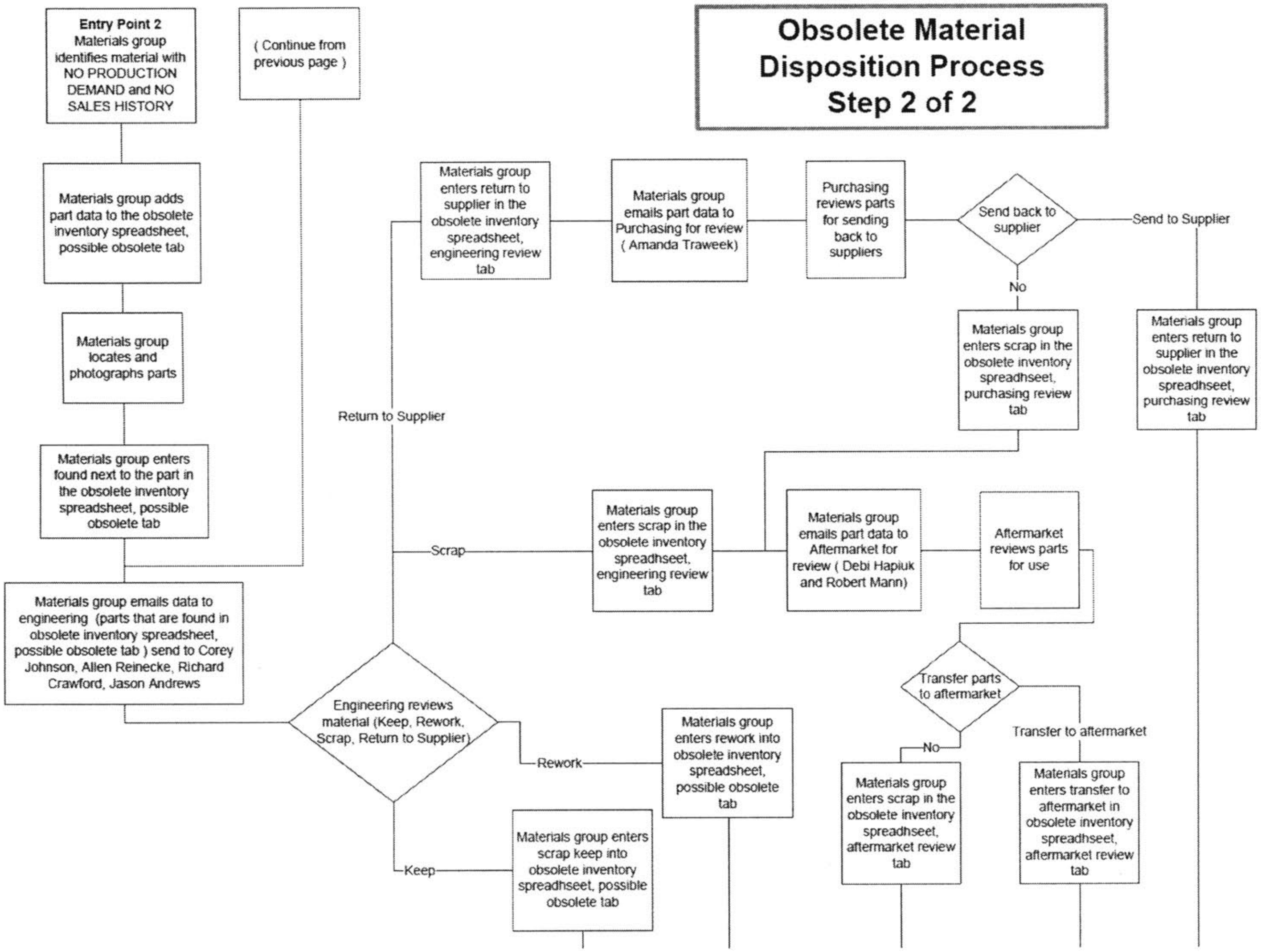

Figure 17: Obsolete material disposition process part three of four

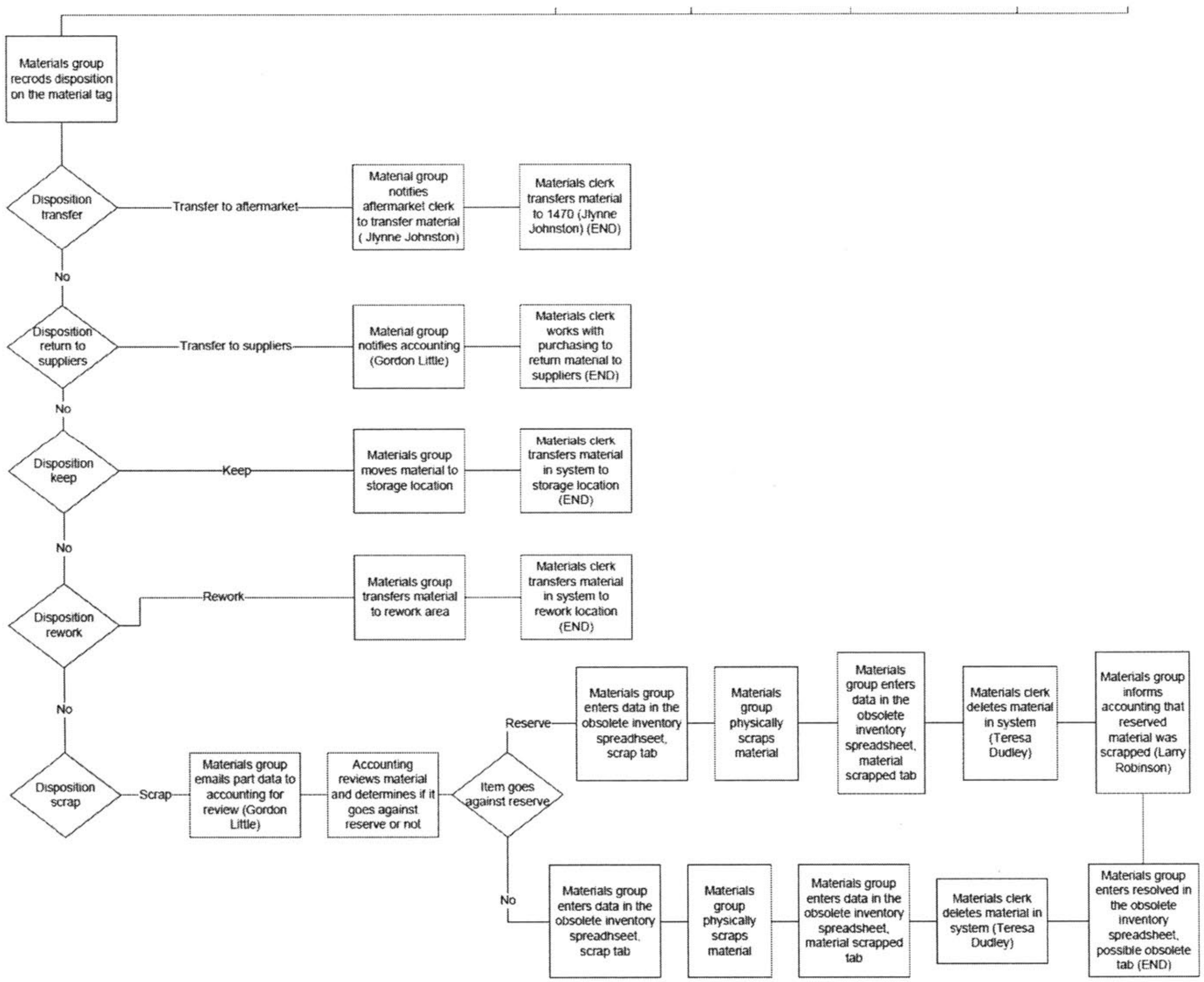

Figure 18: Obsolete material disposition process part four of four

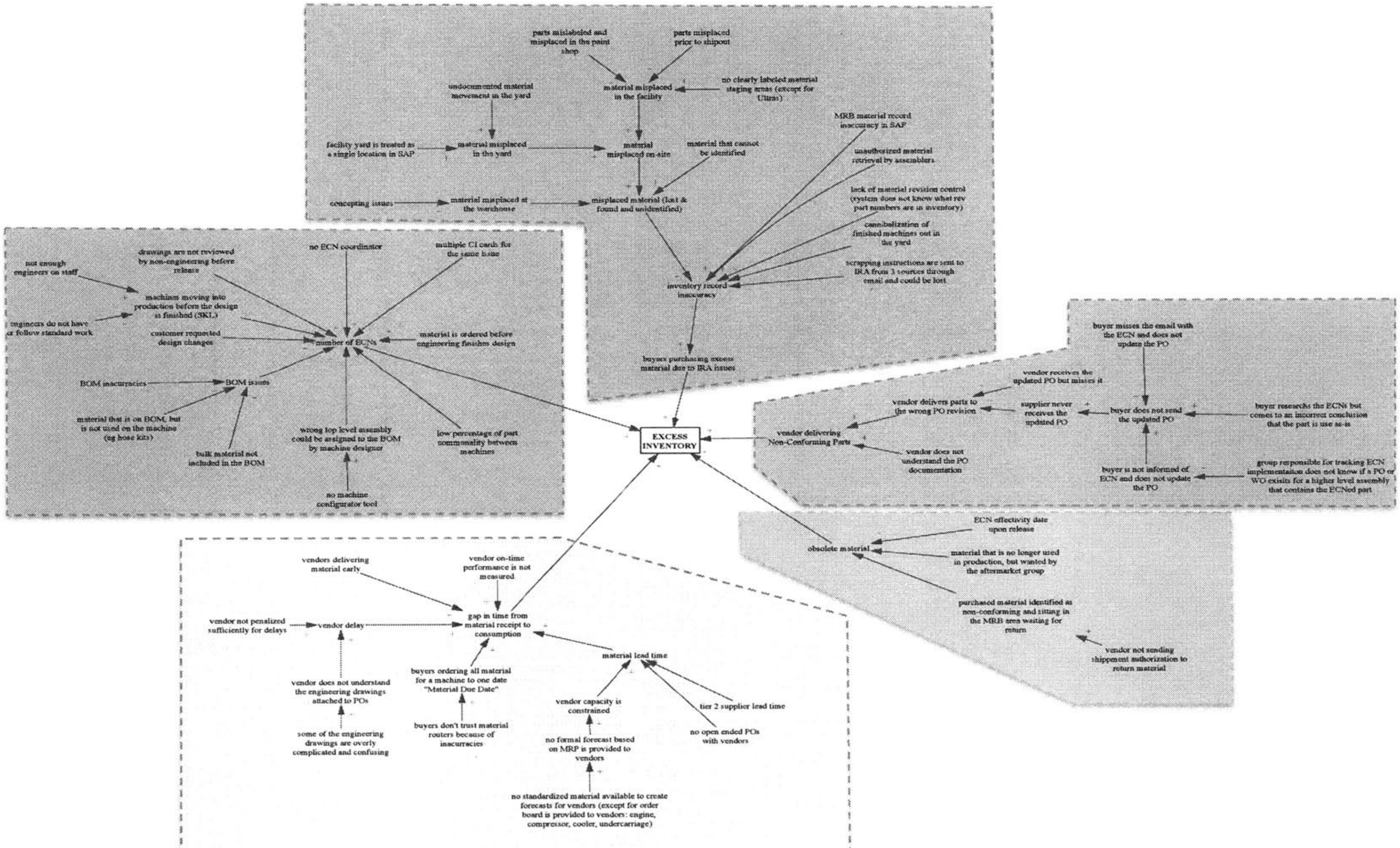

Figure 19: Cause and effect diagram for excess inventory

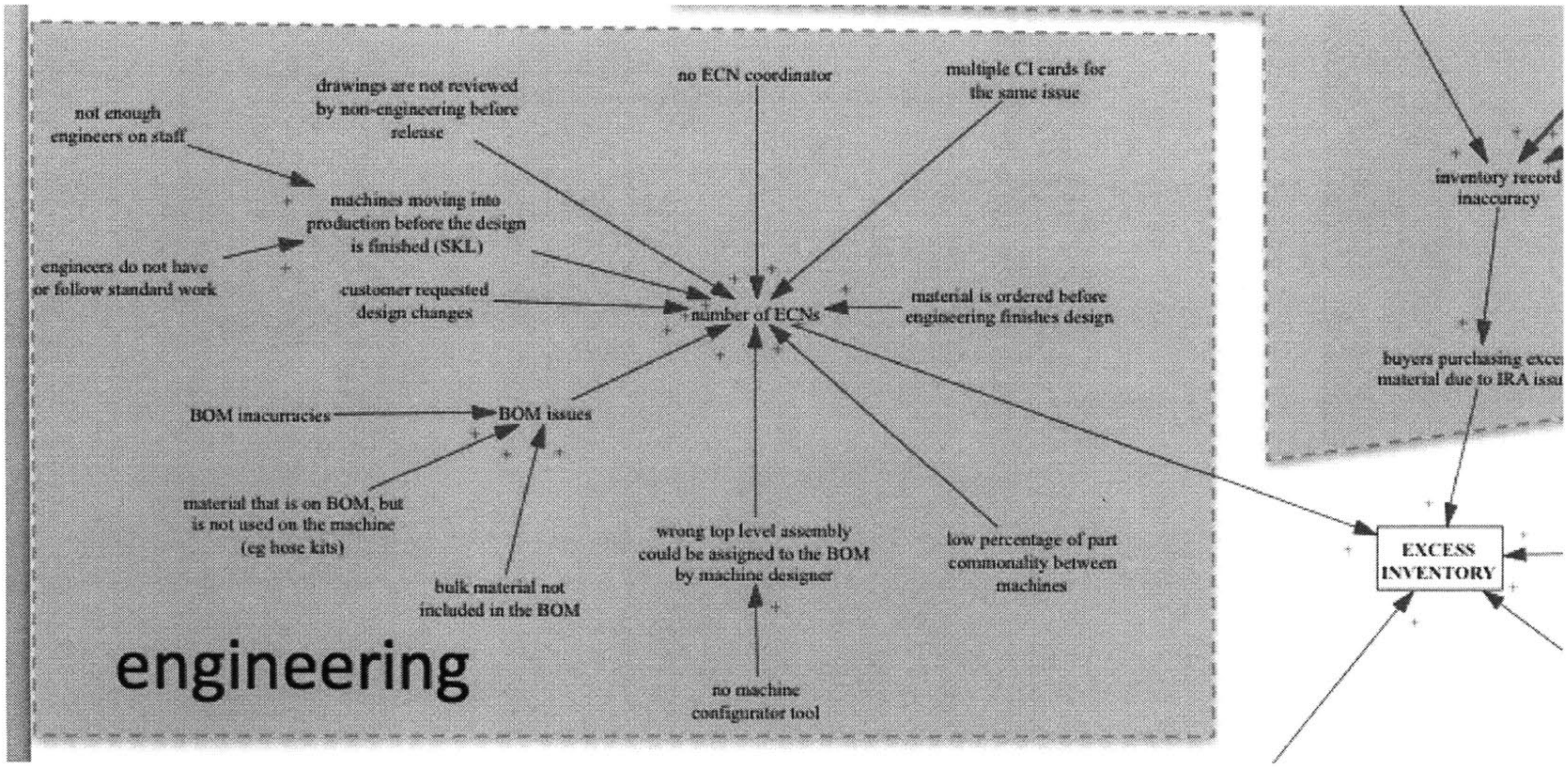

Figure 20: Cause and effect diagram for excess inventory: Engineering

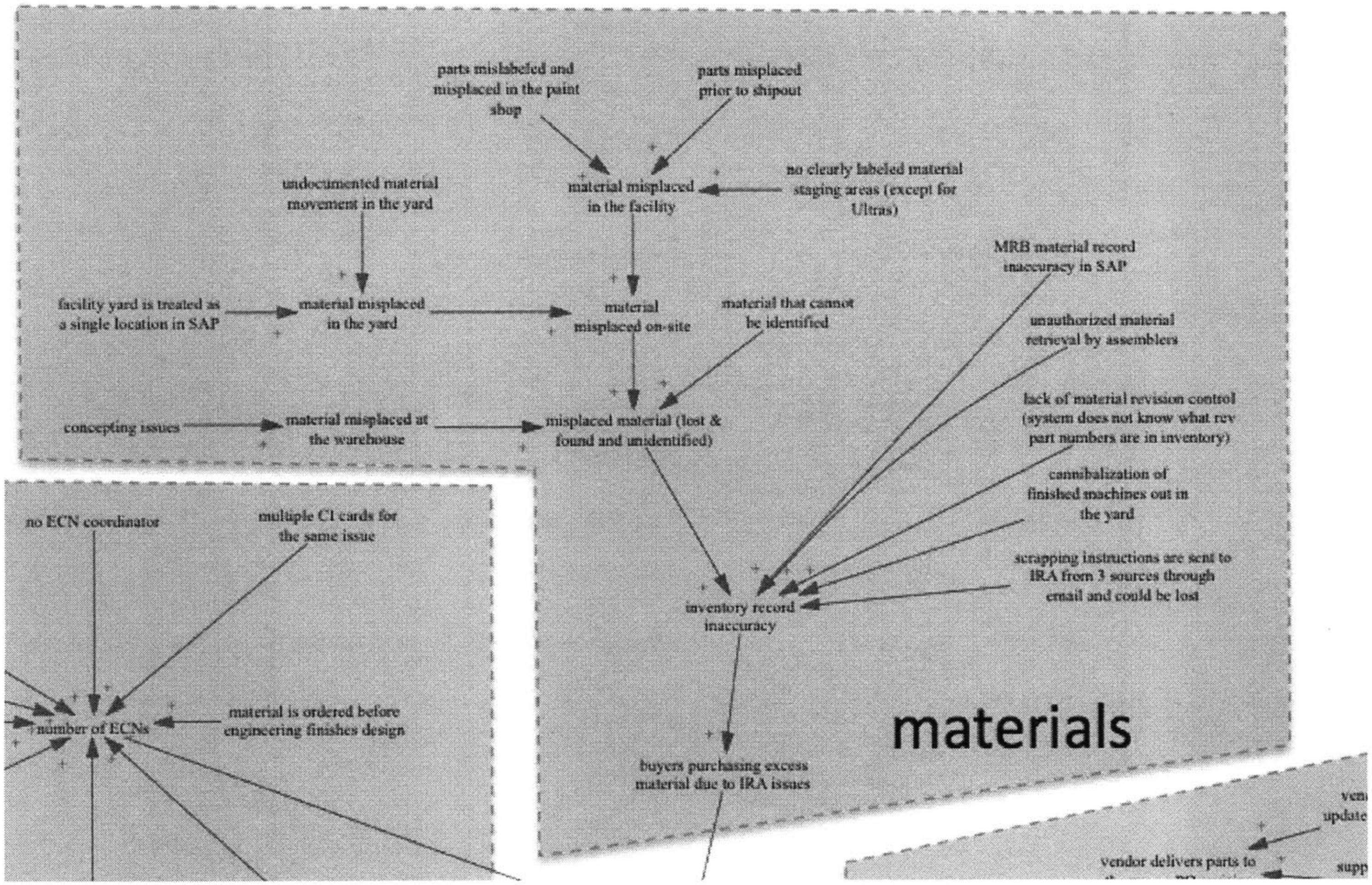

Figure 21: Cause and effect diagram for excess inventory: Materials

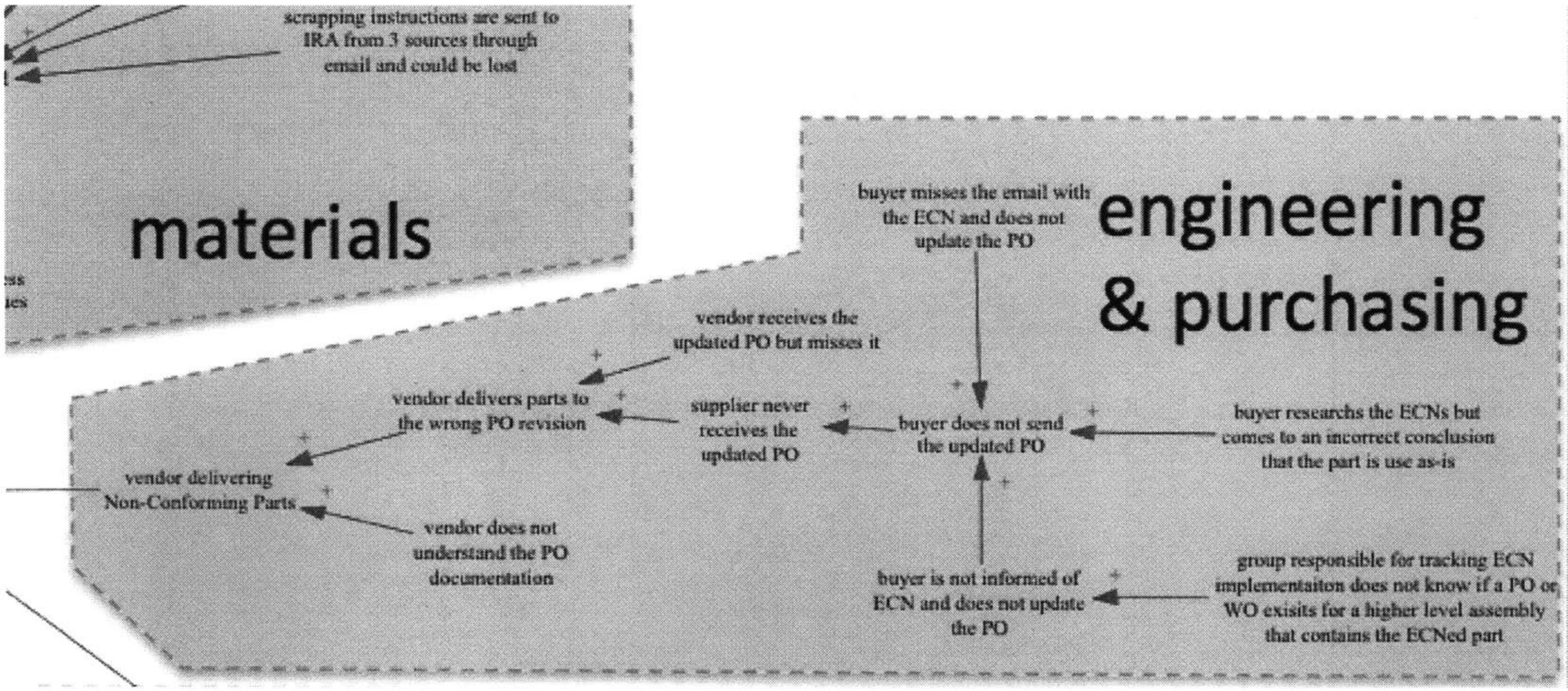

Figure 22: Cause and effect diagram for excess inventory: Engineering & Purchasing

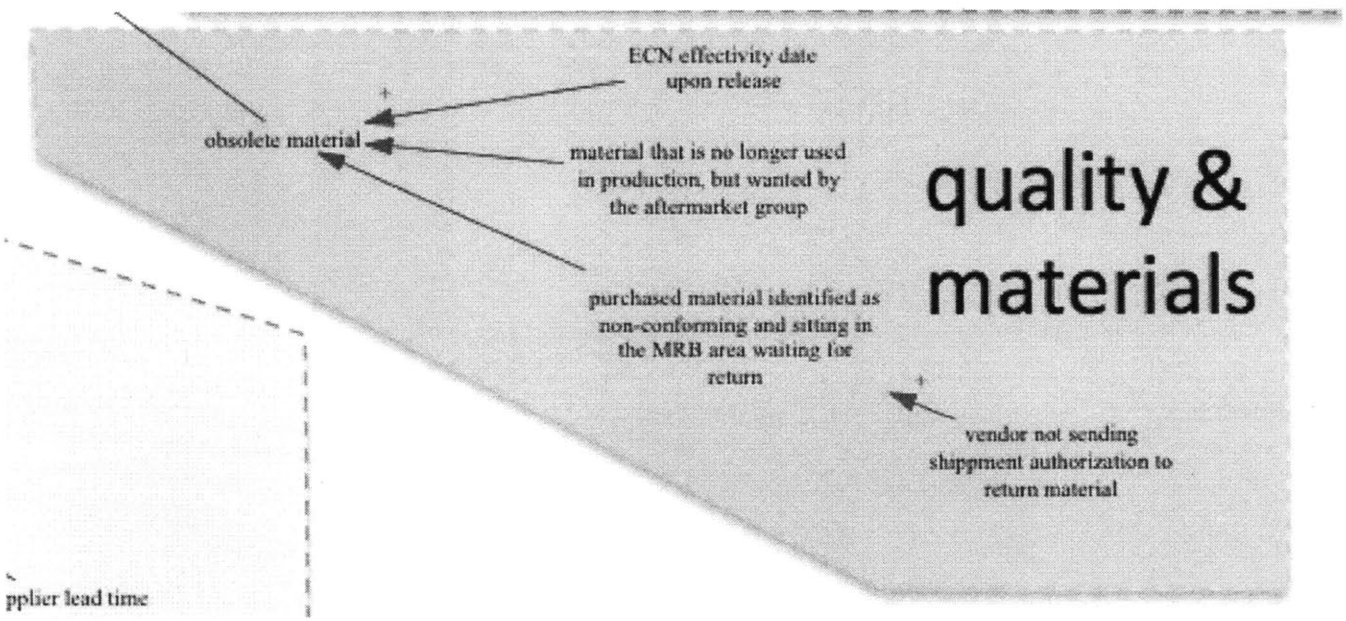

Figure 23: Cause and effect diagram for excess inventory: Quality & Materials

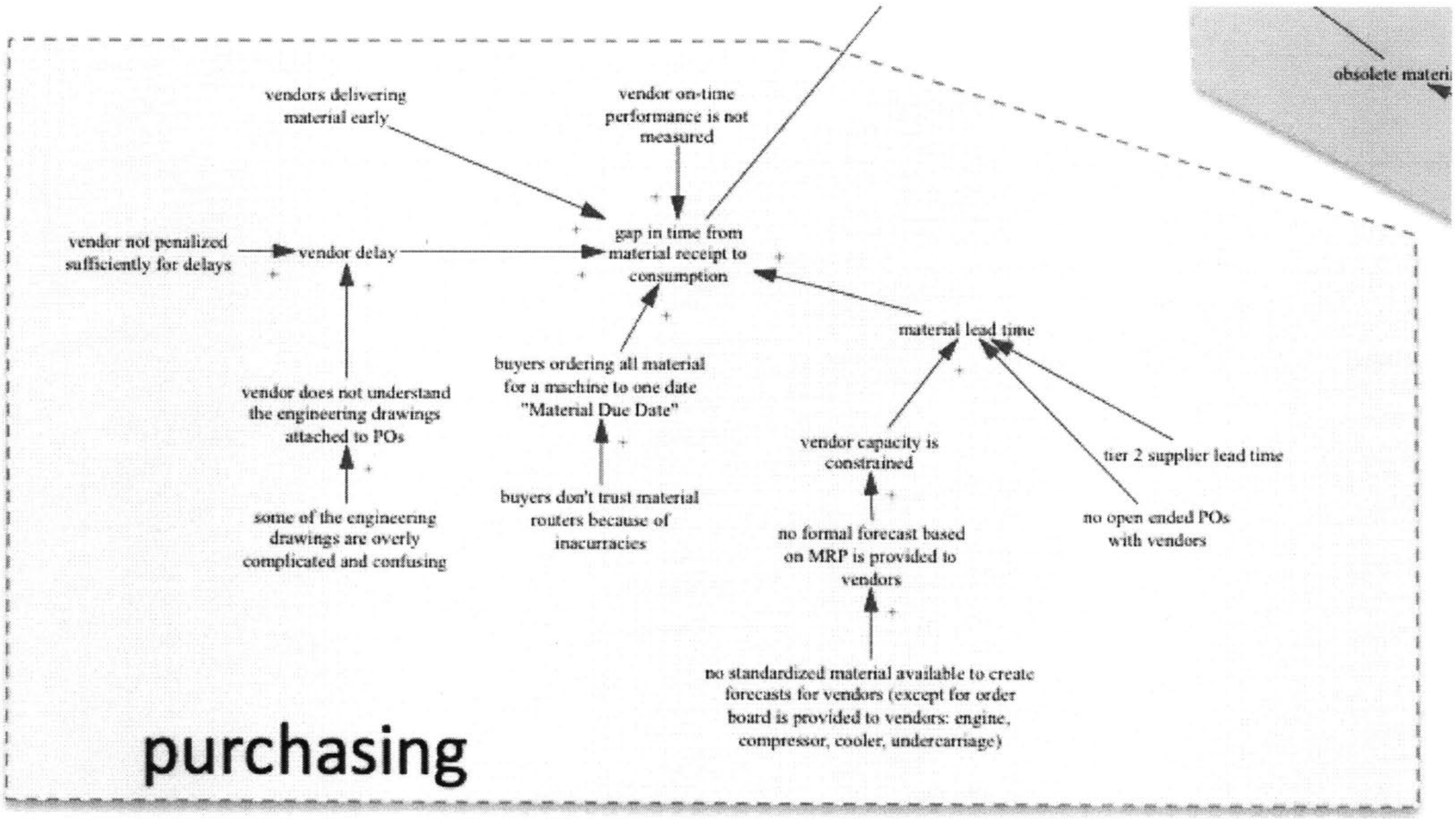

Figure 24: Cause and effect diagram for excess inventory: Purchasing

PROBLEM	FUNCTIONAL GROUPS	ROOT CAUSES A	B	C	D	E	F	
Excess Inventory	Sales	special customer requests accepted by the factory						1
	Engineering	BOMs are not always updated	duplicate part numbers for the same part	low part commonality among machines	accurate material routers are not established	machine design proliferation	no order configurator - machine design is translated from a written description	2
	Planning	early material delivery date established	MRP is not fully implemented					3
	Purchasing	no vendor penalties for poor performance	no formal forecasting to vendors	material purchased prior to completion of the machine design	some ECNs are never sent to vendors			4
	Suppliers	suppliers deliver non-conforming materials	suppliers are slow to send out material shipment authorization for rejected material					5
	Quality	inaccuracy in the rejected material information record	MRB misplaced outside of the MRB area	no quality module in the SAP system				6
	Materials	low inventory record accuracy	material damage due to mishandling or contamination	parts misplaced prior to ship out	FIFO not fully implemented	system faults that cause record inaccuracy in the warehouse	no rev level material control	7
	Production	material loss on the line	material substitution without changes to engineering drawings	only partial use of material kits followed by return to the warehouse and misidentification as full kit				8

Table 5: Root causes of excess inventory accumulation