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Performance measures of closed-loop supply chains

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PERFORMANCE MEASURES OF CLOSED-LOOP SUPPLY CHAINS

By

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Supply chain management has evolved over the course of history in order to provide faster and efficient service to those companies that follow its principles. As there have been advances in technology and changes in the way business is conducted across the globe, supply chains also have had to change in order to remain effective. With greater attention paid to resource depletion, environmental impact, and waste reduction; the concept of closed-loop supply chains has garnered the attention of managers who look to make their production processes more efficient. Finding ways to judge the performance of these supply chains is critical to managers. By identifying key performance measures, they are able to gauge how their closed-loop process is performing as well as identify areas for improvement.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Since it was first put into practice, supply chain management has always reflected the changing landscape that occurs in business and manufacturing. This is necessary because the aspects involved in getting products made and sent to their customers are frequently changing. Change can be due to technological advancements, shifts in public policy, or adherence to customer expectations. When these changes do occur, managers must be certain that their manufacturing and distribution processes take these changes into consideration. Regardless of what changes, adapting is an essential element to staying competitive.

Currently, there is a change occurring in business that shaping the way supply chains conduct their activities. A greater amount of attention is being paid on how industries are having an impact on the environment. Governments across the world have begun to establish legislation to curtail this impact. From a business perspective, this often means having to find ways to become compliant with government regulations. However, if a business can somehow increase their profits while conforming to these environmental laws, then their business can prosper from both a financial and public relations standpoint. Reducing waste and using less resources can be common goals between business manager and environmentalist. Both can help alleviate costs while also benefiting the environment.

In terms of logistics, steps have been taken in achieving these goals by way of implementing closed-loop supply chains. This concept involves the reuse or remanufacturing of items or products in a manufacturing process. Generally speaking, using materials again that are able to be redistributed helps in reducing wastes and makes companies less dependent on their sources of raw materials. This, in turn, reduces their costs and creates less of an environmental impact.

Closed-loop supply chain management is a relatively new concept, though it is derived from the basic idea of recycling. Taking something old and refurbishing it into something that can be useful again is not a novel concept. However, taking that concept and applying it to supply chains has led to this latest trend in the management science. This new area of supply chain management requires research and study so that managers know how to effectively use it. One area of study is the development of performance measures for these new types of supply chains. Performance measures in a supply chain help to determine whether or not certain levels of achievement are being met in the production process. It also helps to indicate areas in the process that can be improved upon. With the additional activities involved in closed-loop supply chains, it is important to understand what performance measures must now be considered and how do some of the performance measures of a traditional supply chain change with considering closed-loop activities.

First, a review of the literature is done to identify the historical development of supply chain management and how closed-loop chains play a part in that development.

This is followed by a comprehensive look at the mechanics involved in closed-loop supply chains and their relationship to forward supply chains. The research then focuses on performance measures and their role in managing closed-loop supply chains. Once this general understanding is established, an in-dept look at specific performance measures is investigated.

CHAPTER II

EVOLUTION OF CLOSED-LOOP SUPPLY CHAIN MANAGEMENT

History of Supply Chain Management

While the concept of closed-loop supply chains is a relatively novel one, the practice of logistics has existed in some form or manner for hundreds of years. Although projects earlier in history may have lacked the technology used today, they still required a certain level of coordination and planning in order to turn raw materials into finished goods. Issues regarding supply chain management date back to as far as the industrial revolution (Nahmias, 2005). The steps taken in the realm of manufacturing during and after this time would pave the way for advances in organizing labor and materials so that items could be produced in large amounts without taking significant time. These advances progressed into the middle of the 20th century, where the idea of traditional supply chain management was developed. As quality control theory and computer technology enhanced the way business was performed around the world, supply chains would also adapt to these changes as well. The ever-changing landscape of supply chain management continued into the 21st century, where concepts such as closed-loop supply chains would be implemented.

There are several examples of historical events in manufacturing that would lead to the future development of supply chains (Hopp and Spearman, 2008). American inventor Eli Whitney was contracted by the U.S. government to make muskets for the nation's war efforts at the beginning of the 19th century. His concept of using interchangeable parts to manufacture the weapons is an early example of using labor and material resources efficiently. In 1855, Henry Bessemer developed a manufacturing process of refining iron which allowed for the production of steel. This process reduced both the cost and labor necessary to make steel and sparked the production of railroads, buildings, turbines, and other industrial machinery during the latter half of the 1800's. Henry Ford's introduction of the moving assembly line in 1913 revolutionized American manufacturing. The concept of the assembly line spread to other industries and the mass production of complex mechanical products for lower prices became a hallmark of American business (Hopp and Spearman, 2008). However, supply chain management itself would begin to take shape during the middle of the 20th century.

It was at this time that systems engineering would begin to play a role in decision making for large organizations. Management science began being used primarily with operations research, which is a mathematical approach to solving large-scale problems involved in designing or operating a system that is constrained by limited resources. Operations research became popular during World War II, when engineers were called upon by the British military to solve logistical problems such as radar deployment and bombing operations (Winston, 2004). This mathematical science is still popular today, as operations research concepts are used to quantify and solve current supply chain issues. The study of systems engineering would transition to being used in industry, as described by systems engineering pioneer Jay Forrester. In 1958, Forrester (1958) saw the advantages of bringing together the various aspects of management when he stated, "management is on the verge of a major breakthrough in understanding how industrial company success depends on the interactions between the flows of information, materials, money, manpower, and capital equipment". Based on the conduct of businesses and the academic setting during this time, it is clear that the lessons learned with regards to manufacturing would be applied on a larger scale when developing the principles of supply chain management.

The 1960's and 1970's established a period where manufacturing theory was combined with computerized technological advances to create dynamic systems of production. This era also saw American production continue to rise. According to Chandler (1977), the top 200 American industrial firms accounted for 60.9 percent of the world's manufacturing assets by 1969. The United States was certainly a world leader in manufacturing at this time; however, countries around the world were recovering from World War II and using manufacturing as a tool for rebuilding their economies.

One of the key manufacturing theories developed during this time is know today as materials requirements planning (MRP). MRP is a set of procedures with which demand forecasts for a finished product are used to develop requirements schedules for subassemblies and raw materials that comprise that product (Nahmias, 2005). Another major theory developed was the Toyota production system (TPS). This theory is widely known for the use of its kanban card system. While MRP systems follow a schedule and products are "pushed" through the system accordingly, the kanban cards in the TPS instruct when and how many products need to be "pulled" to satisfy demand. These theories are still widely discussed today and apply to the broader spectrum of supply chains (Bonney et al., 1999).

Outside of theoretical advances, the future idea of supply chain management was aided at this time by advances in computer technology as well as reemerging economies in Asia (Hopp and Spearman, 2008). Access to computing power in the form of personal computers gave management more data and ability to make faster, better decision. At the same time, Japan had focused on perfecting their manufacturing from a quality perspective. All of these occurrences led to the creation and development of supply chain management during the following decades.

Supply chain management started to be scientifically defined in the 1980's. Not only were academics looking into the way supply chains functioned, but the quality movement of the 60's and 70's began to influence production systems. According to Evans (2008), "while the Japanese were developing remarkably higher standards for a whole host of products… many U.S. managers were smugly dozing at the switch." The combination of studying supply chains and realizing the emphasis for quality products encouraged managers to maximize profitability across their distribution systems as opposed to solely within their own department. Also, government efforts to recognize companies that had sound quality programs were created at this time, most notably the Malcolm Baldrige National Quality Award (Evans, 2008).

Supply chain technology developed in the 1990's adapted to the needs of managers who used the knowledge that comes with tracking a product's progress from manufacturer to consumer. Electronic data interchange coordinates operations by transmitting business documents from one company's computers to its associates within the chain. Data that could be exchanged includes point-of-sale demand, inventory, and order information (Cannon, 1993). Also, radio frequency identification began to take hold as means of tracking products within the chain, using microchips powered by batteries or radio signals. While bar codes have been the primary choice of tracking, these microchips are steadily gaining popularity as their cost decreases (Nahmias, 2008).

The science of supply chain management did not change as much in comparison to the environment with which supply chains operated in to start the 21st century. Instead of game-changing technological advances, learning how to interact with partners in a chain became more important during this time. As far as management was concerned, much of the management theory had already been developed with programs such as enterprise resource planning; the key to success now became managing knowledge across the chain to make decisions that would benefit all parties involved (Gunasekaran and Ngai, 2007). Furthermore, e-commerce became a critical aspect of selling products to a much wider customer base, as the Internet became more commercialized and computers made connectivity possible (Chu et al., 2007). Foreign competition also played a major role as countries in Asia, specifically China and India, became major players on the global stage, both in terms of politics and industry.

Because the effects of globalization have led to more producers and consumers, environmental sustainability has become an important factor in the recent history of supply chain management. Industries across the business landscape are examining how their strategic and operational management actions are impacting the environment (Croom et al., 2009). While protecting the environment is a sign of social responsibility on the part of managers, these actions tend to be sacrificed for options that are more profitable for the chain. One of the major themes of closed-loop supply chain management is to attempt to find both environmentally sustainable and monetarily profitable solutions for members of a chain. Part of any closed-loop supply chain is the resemblance it has to a traditional supply chain that relies upon the basic rules of manufacturers turning raw materials into a product sold by distributors to customers.

Defining Supply Chain Management

Regardless of the product or service that they attempt to provide to customers, supply chains across all industries have certain similarities and goals. One common goal of supply chain management is to facilitate collaboration between members within a chain. This collaboration can be in the form of sharing resources, exchanging information, or developing relationships. Research into the bullwhip effect illustrated the importance of collaboration. When Proctor and Gamble recognized that the customer demand for baby diapers remained relatively stable compared to the highly variable inventory levels within the chain, this brought about the need for collaboration between P&G and its partners (Lee et al., 1997). By exchanging information about demand forecasts and inventory levels, P&G was able reduce the bullwhip effect in their chain because of their collaborative efforts. In studying supply chains, it is important to understand the roles of each member of the chain and how they relate to one another. This understanding can help firms develop their individual business and logistical strategies and become aware of external factors and uncertainties that influence their chain. With all of these factors in mind, a broad definition of supply chain management can be developed. Supply chain management is the collaboration of various business entities that work together in order to provide a product or service. This collaboration includes sharing informational resources and developing business partnerships in order to benefit all members of the chain that share similar business strategies. Collaboration also helps those in the chain to rely on their partners in order to overcome uncertainties in the market.

Members of a supply chain include firms that: provide raw materials to make products, companies that manufacture subassemblies or make finished products, and retailers that sell finished products (Simchi-Levi et al., 2000). One other important member of the supply chain is the customer. While customers do not have a hand in making the product, they are the reason why the product is made in the first place; they create the market in which the firms compete. A basic example of a supply chain where items flow from suppliers to customers is shown in Figure 2.1.

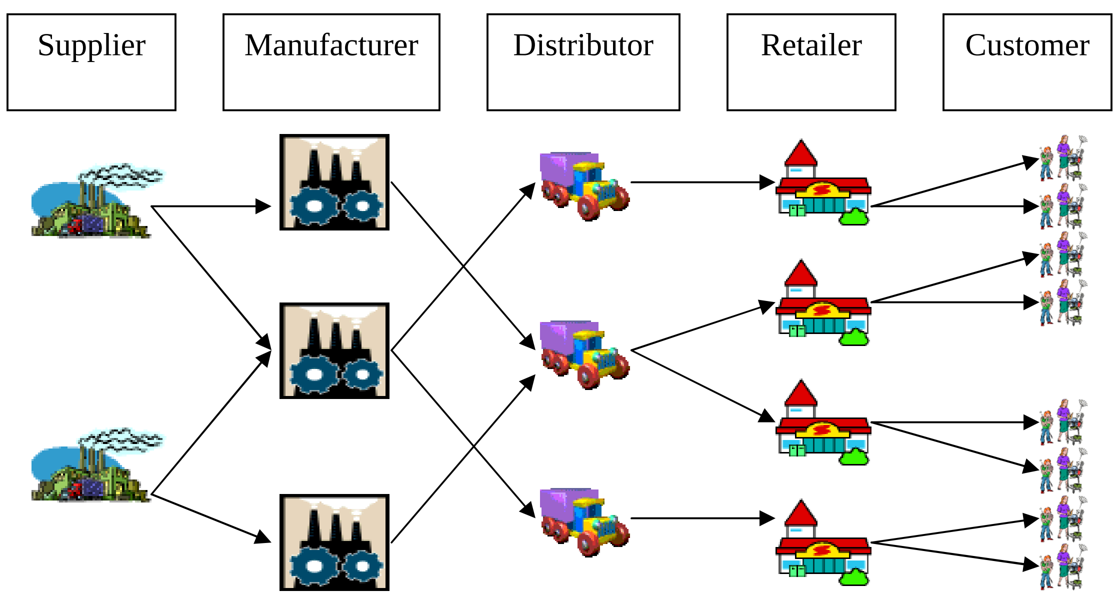


Figure 2.1 Basic Example of a Supply Chain

In this basic example, the supplier provides raw materials to the manufacturer who makes the product. The distributor then collects products from the manufacturer and keeps them in inventory until the retailer needs them to satisfy customer demand. An example of a similar supply chain setup is used for apparel sold at Walmart. Cloth or textiles are supplied to clothing companies so they can manufacture clothes. Then Walmart uses its distribution warehouses as cross-docking points to send deliveries of these items to their retail outlets that sell them to customers who visit Walmart stores. This is a very elementary example of a supply chain, but it illustrates the point of all the players that are involved in a supply chain. Furthermore, not all chains operate in this manner. For instance, there are several companies that are involved in the manufacturing level that Walmart must consider when selling apparel, not just two or three clothing lines. Also, some supply chains act without some of these traditional levels. Dell provides computers directly to customers from their manufacturing locations, traditionally bypassing the retailer stage of the supply chain (Dell and Fredman, 2006). They primarily use their website as their channel to connect with customers. Walmart's relationship with clothing lines and Dell's logistical setup are both fundamental factors that are key to making their supply chains a success.

Along with knowing the different participants in a supply chain, knowing how they perform together is important to understand. Chopra and Meindl (2007) identified six major supply chain drivers that play a vital role in the performance of a supply chain: facilities, inventory, transportation, information, sourcing, and pricing. How these drivers are managed depends upon the product or products being sold as well as the resources available to the chain. Facilities are the locations where products are stored or produced. Locating these facilities is obviously a decision that influences the chain. Facitlity locations are the basis from which the distribution network can get products to customers. Tradeoffs between being close to customers or suppliers must be made when choosing these locations. Also deciding on the tasks and capacity of each location is pivotal as well. Inventory considers raw materials, subassemblies and finished products that are needed to satisfy demand. Satisfying customer demand with inventory takes place throughout the entire chain; a retailer is a customer of a manufacturer and a manufacturer is a customer of a supplier. Transportation deals with moving inventory between stages in a chain. There are numerous modes of transportation that reach most areas around the world, making it possible for products to reach different markets. Decisions in transportation customer lead times and other variables that influence supply chain performance. Information is the lifeblood of the supply chain (Lee and Whang, 2000). While most of the flow in the supply chain goes from producers to customers, information is one aspect that derives from the customer end of the supply chain. Inventory levels, demand patterns, and price fluctuations are just a few of the many examples of essential data that managers throughout the chain to make decisions. How information is gathered, shared, and interpreted influences the other supply chain drivers.

Choosing who will perform certain supply chain tasks is called sourcing. For example, determining which level in the chain is responsible for storing and managing inventory of a particular product is a sourcing decision. Sourcing is needed so that every department or facility knows what they are supposed to be doing and how their contribution affects the final product as well as the rest of the supply chain. Finally, pricing is the driver that determines how much a customer should be charged for a product or service. This driver has rippling effects throughout the chain and has significant influence on all parties involved. By setting prices, this establishes how much value the supply chain makes from its products in order to make profits as well as have the capital to further production. Chopra and Meindl (2007) indicate that all of these supply chain drivers require supply chain management to be viewed as more than just an exercise in logistics; it requires a collaborative effort from all its members to ensure success.

The six drivers previously discussed have a hand in how supply chains formulate their strategies in order to be profitable. These strategies help determine the level of responsiveness and efficiency of a firm (Fisher, 1997). A responsive supply chain can be characterized by products that conform to customer needs, an inventory that is able to buffer against demand or supply uncertainty, and where lead times for order fulfillment are lower. All of this comes at a cost, which usually relates to a higher product cost for the customer. In the shoe industry, an example of this can be found at Zappos.com. The online shoe retailer has a wide variety of shoes that come in different colors and sizes in order to meet various demand patterns, but their prices are relatively high. On the other end of the spectrum, efficient chains can be described as those that provide goods or services where low costs are a priority. Products from these chains are inexpensive because the chain makes cutting costs a major part of their strategy; thus offering a product selection less likely to demand, inventory that is less able to buffer against uncertainty, and where lead times for order fulfillment are higher. Payless Shoesource is an example of an efficient company in the shoe industry. Their stores carry a limited inventory in terms of variety and sizes, thus susceptible to demand changes, but their prices are much cheaper. Notice that both these examples are not completely responsive or efficient. Responsive chains were described to have lower lead times, but Zappos customers have to wait longer to receive their order than a customer at Payless who receives their purchase immediately. Therefore, tradeoffs in how much service is provided must be made.

Striking a balance between responsiveness and efficiency is key to achieving what Chopra and Meindl (2007) call strategic fit. To achieve this fit, a supply chain must determine who their customers are, what they want from a product, and how much they are willing to pay for it. Once they have an understanding of their customers, strategies of product development, marketing, and logistics can then be determined. The key to strategic fit is that all of these strategies conform together in order to satisfy the customers that the supply chain is targeting with their products or services. When the competitive goals are out of sync with the business strategies, the chain tends to lack direction and could lose out on potential sales (Hult et al., 2007). Going back to the shoe store examples, Zappos uses friendly customer service as well as free return shipping to overcome the fact that customers cannot try on their shoes upon purchase. Meanwhile, Payless customers may expect for their local store to not have a specific style or color of shoe in stock, but they know they will not have to spend a lot of money to purchase a pair of shoes. Each company seeks out a certain kind of customer and then curtails their supply chain to meet the needs of that customer.

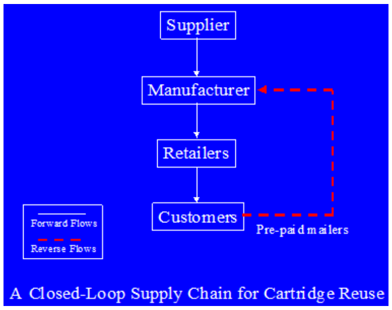
Chopra and Meindl (2007) continue their discussion of strategic fit with some common obstacles that firms must overcome. Increased product variety, shorter product life cycles, and increasing customer demands have made developing those strategies more difficult and more difficult to fit together because these they introduce more variation into the system. Also, sourcing the supply chain to multiple parties has made communication within the chain even more necessary. These parties may not necessarily be located in one place, making globalization a business reality that firms must deal with.

Being part of the global marketplace is just one of the many external factors that supply chain managers must account for when running their business. Uncertainties in the business world and beyond can change decisions on a frequent basis, and handling the risk involved with these uncertainties is very important (Cucchiella et al., 2008). Much effort has gone into finding ways to study and reduce the effects of uncertainties. Forecasting has become a significant part of business planning, from predicting the supply and demand of products to charting future patterns in employment (Nahmias, 2005). Also, building conceptual models that capture the qualitative, as well as quantitative aspects of business planning, have become popular with analysts as well (Pidd, 2003). Conceptual models are diagrammatic representations that show the interconnected activities of an organization, specifically illustrating how people from different departments interact with one another. Knowing of this interaction can be useful when designing or running a supply chain.

Much has been discussed of the flow of material within a chain in order to satisfy demand. However, supply chains are now shifting their focus onto a new component of the chain, reverse logistics. There is a need to study the practice of reverse logistics. These chains require additional resources and capital in order to run, and management would be well served to know how they work in tandem with their traditional supply chain. Even in a traditional chain, there are certain elements that flow up the supply chain, such as information. Reverse logistics takes this concept into practice and expands the possibilities of product movement in the supply chain.

Reverse Logistics

Reviewing the history of supply chain management showed that the concept of moving raw materials and products from producers to consumers has been around for many years. A number of studies on supply chain management indicate that improving production and delivery processes is essential to the continued growth of all firms within a supply chain; in essence, if a company is not looking to improve the way they do business, they will soon lose a portion of the market to their competitors (Lambert and Cooper, 2000). One major movement that looks to improve supply chain performance, from an efficiency and environmental standpoint, is the development of closed-loop supply chains. However, the benefits of a closed-loop chain cannot be appreciated until it is known how the loop is to be closed. The closing of the loop is provided by reverse logistics, which encompasses all of the activities in a supply chain that bring products or materials back into the production system so that they can be reused or redistributed in some form or manner. There are many intricate aspects of reverse logistics that managers must consider. Given the product or products that the chain deals with, there must be economical and logistical reasoning for undertaking activities that close the loop. Once this reasoning is established, managing product returns becomes an issue. Also, coordinating these activities to integrate with the traditional supply chain activities is also important in creating a seamless supply chain environment that reaps the full benefits a closed-loop chain can provide. In Figure 2.2, there are two basic examples of closed-loop supply chains, one for printer ink cartridges and the other for single-use cameras. For ink cartridges, the item is mailed to the manufacturer to be refilled while single use cameras get sent back to the retailer to be developed.



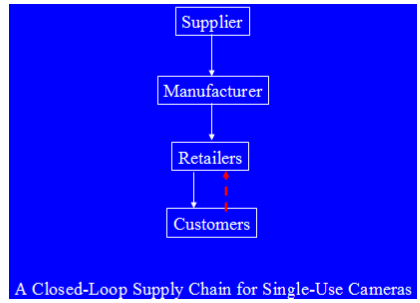


Figure 2.2 Closed-Loop Supply Chain Examples (adopted from Guide Jr., CIMSO Supply Chain Forum)

According to the European Working Group on Reverse Logistics, the concept of reverse logistics, “refers to all logistic activities to collect, disassemble and process used products, product parts, and/or materials in order to ensure a sustainable (environmentally friendly) recovery (REVLOG website). This generalized definition describes what reverse logistics means to a closed-loop chain, but it is important to identify the major players of this part of the chain as well as their role in it. Determining their roles as well as their personal objectives is instrumental in coordinating the efforts of all parties within the chain.

First, there are several common steps that reverse logistics chains have in common (de Brito and Dekker, 2004). Collection is usually the first step. Items need to be gathered in an organized way so they can be managed properly and be reused appropriately. Those in charge of collection may potentially be in charge of transporting the used items to the party that deals with processing. Once the collection is done, inspecting or sorting the goods takes place. Not everything collected will be of significant, reusable value and may have to be discarded completely. This step ensures that rework resources are being used on materials that can be salvaged. After sorting, the recovery steps are taken to actually recycle or refurbish the items that were received. Finally, the recycled materials or products are redistributed to firms within the chain or to external customers for additional use.

With regard to the actual people or companies that are involved in the reverse logistics process, this list includes those who are part of the traditional supply chain, those who specialize in reverse logistics actions, and can also include opportunistic players that may or may not be permanent fixtures of the chain (Fuller and Allen, 1995). Those involved in the traditional chain can act as receivers of products that are returned by end customers, or they themselves can act as a sender by returning items or raw materials back up the chain. Being a sender or receiver of used items is why traditional chain players may find themselves as a link in the reverse logistics chain. Those who specialize in reverse logistics actions are obviously keys to the process. Specialized recycling or transportation capabilities make their services essential to carrying out the tasks of reusing old products. Collecting and processing materials are the basic ideas of the reverse logistics definition stated above, and these specialists are equipped to perform those actions. For example, scrap metal recyclers are able to collect large amounts of left over products and extract certain materials that can be used by manufacturers (Kumar and Putnam, 2008). Opportunistic players are those that find themselves participating in a supply chain in an unofficial capacity. Charitable organizations that collect used items and redistribute them in some manner also take part in reverse logistics. The Vietnam Veterans of America give tax incentives for those who donate vehicles while also organizing pickup service of used clothing items (Vietnam Veterans of America website). On a smaller scale, these charitable organizations are absorbing a piece of the used product market. They, along with the other reverse logistics players, must be accounted for when managing the reverse logistics of a firm's supply chain.

The European Working Group on Reverse Logistics identifies three reasons as to why a company would either form or be a part of a reverse logistics process; economic benefits, legal obligations, and environmental protection (REVLOG website). The first reason is obvious because every company is in business to make money and practicing reverse logistics properly has the potential to reduce costs and increase profits. Production costs can be lowered by combining recycled materials with new materials, as opposed to just using new materials, to make new products. From a strategic standpoint, companies may engage in reverse logistics as a means to combat competition. By recovering materials, companies can prevent their competition from acquiring their technology (de Brito and Dekker, 2004). Dijkhuizen (1997) reported that IBM got involved in parts recovery so as to avoid their competition's attempts to acquire and analyze their computer parts. Legal obligations are effective methods for making companies adopt reverse logistics methods. Rules and regulations set up by government agencies make product recycling and recovery a mandatory part of supply chains that deal with products which fall under those rules. In the United States, agencies such as the Federal Trade Commission are established to enforce the laws of, "consumer protection and competition jurisdiction," (Federal Trade Commission website). Tying into the legal obligations is the environmental protection motivation for companies. Laws that protect the environment make reverse logistics a way to comply with regulations, but they also have the ability to show that a company is doing its part to make less of an impact on the environment. This can lead to a path of earning the customer's trust, acquiring goodwill with a sense of social responsibility (Sarkis et al., 2010).

Just as there are reasons for companies to belong to a reverse logistics arrangement, there are reasons for customers to want to return items back to their seller or manufacturer. de Brito and Dekker (2004) outlined some of the common types of returns that are often seen in reverse logistics; manufacturing returns, distribution returns, and customer returns. Subassemblies or materials that are recovered during production at any point in the chain are considered manufacturing returns. These returns include raw materials that were not used in processing goods, leftover items, or products that did not meet a certain level of quality. All of these returns occur within the traditional supply chain before the final product reaches the end customer. Distribution returns are logistical moves on the part of supply chain members to redirect goods upon distribution. Product recalls, for instance, must be sent back to where they came from to either be reworked or scrapped. Unsold products, damaged goods, insufficient shelf life are all reasons why distribution returns take place. Also, redirecting inventory to alternate locations to satisfy demand is an example of distribution returns. de Brito and Dekker (2004) also consider a special case of functional returns, where distribution items such as pallets need to be returned so that future stocking and shipments can take place. Customer returns are the third type of return transaction initiated by a sender. Return policies set up by many retailers allow for products to be returned in exchange for a refund or store credit. Other items that are intended to last longer may initially have been sold with a warranty, and these would be returned in order to repaired or replaced. Customers can also return certain items that are either at the end of their use or at the end of their lives. Cell phones are good example of this; many people turn in their old cell phones either because they started using a newer model or the old one has ceased to function properly. There are many reasons to return items in a reverse logistics setting; these returns and where they come from must be considered by supply chain managers.

Performing reverse logistics activities can be a worthwhile endeavor for firms that can manage them efficiently. Knowing who is in charge of what activities, deciding what products can be remanufactured, and determining how products will be moved and processed is essential but does not represent the entire challenge. The challenge is finding the right methods to connect all of these issues properly in order to develop a winning strategy. It was discussed earlier that companies must attain strategic fit by matching their competitive strategy of making money with their supply chain strategy of executing processes. With reverse logistics introduced, this new component of the business model must now also fit in with the business' existing strategies.

Closed-Loop Supply Chains

Guide Jr. and Van Wassenhove (2009) defined closed-loop supply chains as the, "design, control, and operation of a system to maximize value creation over the entire life cycle of a product with dynamic recovery of value from different types and volumes of returns over time." Traditional supply chains have always operated to maximize value across the chain while the reverse logistics operation focused on dynamic recovery; the combination of these two theories leads to the concept of closed-loop supply chains. The same management issues found in a traditional chain are also found in a closed-loop system but with the dynamics introduced by the reverse flow of products. Forecasting the return of items into the system, organizing recovery locations with the network, and managing the inventory of both new and used items are just some of the operations that closed-loop supply chains must perform (de Brito and Dekker, 2004). Depending on the products that are recovered and the supply chain strategies they implement, managers must adopt a closed-loop concept that is right for them. There are four general frameworks that most closed-loop chains fall under: production, distribution, use-related, and end-of-life (Flapper et al. 2005). These concepts share the idea of items returned from customers to their previous or original location in the supply chain, followed by some action involving remanufacturing or recycling the product.

Production closed-loop supply chains involve the returning of items during the production process. These items are unable to be used in the production of the finished good and need to be sent back. If a part is defective or does not meet a certain level of quality, the manufacturer may be able to send the part back to its supplier to be reworked so that it can be used. Parts in this case also maybe reworked and quality is still lost, but the product is still used while being sold at a lower price (Flapper et al., 2002). Also, parts can feed into a closed-loop chain if they become obsolete. Materials and defects that are beyond the help of remanufacturing still have properties that are needed in future productions; reacquiring these properties can help prevent the unnecessary purchase of new raw materials. Production chains also occur when items are used in the distribution of the product. Pallets are needed to carry large amounts of supply and are distributed to different locations in the chain; returning these items is important for future shipments (Linton et al., 2007).

There are examples of production closed-loop chains that span over a variety of industries. Bayer Schering Pharma is a European pharmaceutical company that is involved in fertility, therapeutic, and diagnostic product. As part of their climate change initiative, the company aggressively pursues recycling bi-products and impure solvents (Teunter et al., 2005). Chemicals that are still useful can be found in the bi-products; they are extracted and returned to the production system to be used in making new items. Not only do these recycling programs protect the environment, but also help the firm to reduce production and materials costs (Bayer Schering Pharma website). Another example is provided by NEC Computers, a subsidiary of the NEC Corporation group. The company manufactures computer servers as well as desktop and notebook computers. In the computer manufacturing industry, technology changes at a rapid pace. This means that a particular part or model could become obsolete in a matter of months. NEC was also losing ground due to products on the production line that were defective; if a computer could not be repaired in 24 hours, it would be scrapped. To resolve these issues, NEC created the Notebook Server Recovery department (Geyer et al., 2005). This department is in charge of repairs that take longer than 24 hours. They also analyze the failures that occurred in production with potentially obsolete parts and relay their findings back to the production departments along the chain. With this information, forecasts for computer parts can be refined and more accurate. The Heineken Group also implemented a production closed-loop chain that helped managers, in their case, to find the correct amount of packaging material needed. Much of their beer is delivered in crates that are reusable. Their Chip in Crate program would chart the circulation time of a crate of beer from one location in the chain to another with the by inserting a computer chip into the crate. This information helped Heineken to find the optimal amount of packaging to have in their system. Along with information on storage duration, knowledge from the Chip and Crate program helped managers make long-term decisions on packaging investments (van Dalen, 2005).

Distribution closed-loop supply chains differ from production chains due to the end customer's role in the process. Here, the customer actually receives a finished product and sends it back to the seller or manufacturer. Commercial returns of products are a good example of this (Shulman, 2009). Many retailers have established return policies with customers so that they can receive a refund if the product does not meet their needs or satisfaction. While the company may lose out on a sale that was already made, return policies build goodwill with customers. This is particularly effective with online retailers. Since customers are unable to touch or feel the product, making returns easier increases the consumer's confidence in the seller (Chopra, 2007). Besides commercial returns, errors in delivery are also examples of distribution chains (Flapper et al. 2005). If a product is not on time, either too early or too late, it may need to be returned if it cannot be stocked or if it has a short shelf life.

Hewlett Packard (HP) uses a distribution closed-loop supply chain to manage its product returns. HP is a leader in the manufacturing of inkjet printers and scanners, but like most computer companies, they needed to learn how to handle products that have short life cycles. Davey et al. (2005) describe three main reasons why HP products were being returned: unfulfilled customer expectations (quality of printing), improper knowledge of the product (improper installation), and customer behavior (buyers remorse or finding a better deal). Furthermore, defective products made up only a small portion of returns. HP countered this by first reducing total business costs and then maximizing revenues from remanufactured products (Davey et al., 2005). Costs were reduced by recognizing the link between costs and return volume; by reducing the causes of returns through sales initiatives and enlightening supply chain partners on the negative effects or returns, HP was able manage their return process better. To maximize revenue on remanufactured products, HP looked for ways to generate demand for these kinds of items while also making sure remanufactured products did not affect the demand for new products.

Use-related closed-loop supply chains involve products that are returned to their owners after being reworked. The reworking process provides the customer with the opportunity to reacquire the original product standards at a lower cost than a new product (Jayaraman et al., 1999). Product warranties and recalls are a form of use-related closed-loop chains (Flapper et al., 2005). If a part breaks or malfunctions, manufacturers must be ready to honor any warranties that are made along with the sale of the product and fix what needs repairing. Recalls work in a similar manner; when the manufacturer realizes that the product fails to meet a certain quality standard or does not do what it is supposed to do, a recall should be available for customers so that they can be aware of the product's shortcomings and have the opportunity to get them fixed. Not all recalls can be considered a use-related closed-loop chain. Product recalls involving foods or edible commodities, such as tomatoes potentially infected with harmful bacteria, are not likely to be returned to customers because the threat to cause harm cannot be removed.

Use-related closed-loop chains are a ubiquitous in the automotive repair industry. For instance, Mercedes-Benz had implemented an engine replacement program for their customers back in the late 1990's (Driesch, 2005). The cars, trucks, and vans made by Mercedes are automobiles known for their quality and longevity, so having the ability to replace the engine after the original purchase is an attractive incentive for customers. The replaced engine is a remanufactured one that is of the same type and quality as the original, but for a price that is 30% less than a new engine, depending on market conditions (C. Worthington, personal communication, April 7, 2010). Driesch (2005) mentions that Mercedes has to be able to provide service parts for over 20 years. Instead of keeping production facilities open to make old parts for old cars or keeping high levels of inventory to satisfy demand for many years, remanufacturing used engines has been found to be the cheaper alternative. With respect to product recalls, unintentionally hazardous items can occur in a wide variety of industries, leading to a closed-loop process to rectify the situation. In 2009, certain Acer laptops had to be recalled from the Singapore market because of a faulty cable wire that potentially could overheat. Though officials stated that the defect "was not major," Acer established a voluntary recall where owners could have the laptop collected or dropped off at a service center, replace the faulty part free of charge, and return the laptop to the customer (Luo, 2009).

End-of-life closed-loop supply chains are associated with products which are no longer of use to the owner and are returned to the manufacturer or distributor. These products have reached the end of their useful life because they do not meet a certain level of desired functionality or they do not work as well as when the product was new (Flapper et al., 2005). A subgroup of the end-of-life chain is the end-of-use chain (Agrawal & Toktay, 2009). Cars that reach the end of their lease or that are traded in when purchasing a new car are examples of these chains. For instance, an old car can either be made inoperable by stripping it for parts that are still in good condition and reusing them in new vehicles (end-of-life), or the car can be resold by the dealer at a discounted rate (end-of-use). Cars that are resold by a dealer seem similar to a use-related chain; but because the car is no longer useful to its original buyer and is changing ownership, it has in fact reached the end of its usefulness, to the original owner, while not reaching the end of its life.

A good example of a product that falls under the categories of either end-of-life or end-of-use is a cellular phone. Cell phones have become commonplace technology around the world, with capabilities that keep increasing with technology. Like the personal computer, cell phones are facing shorter life spans because having the latest model phone allows users to perform more functions. Customers are finding that one way of disposing of their old phones is to recycle them, which is what companies like ReCellular do. ReCellular is a leader in the cell phone recycling industry, allowing customers to buy refurbished phones, setup partnerships to sell old phones, or even make donations of old phones (ReCellular website). These three kinds of partnerships act as supply sources, which become very important when trying to sell old items in an industry known for new items arriving frequently. From a business standpoint, ReCellular is able to generate business by establishing relationships with those who buy old cell phones using end-of-use practices. On a large scale, this occurs when ReCellular acquires phone models that are dropped by a cellular company in one geographic location and sells them in an area of the world where the phone is still supported by other phone companies. From a public standpoint, ReCellular is an environmentally friendly company due to their end-of-life practices. If a phone is no longer usable or unable to be resold, ReCellular sells the phones to recyclers and scrap dealers in order to prevent harmful materials in phones from reaching the environment upon disposal (Guide Jr. et al., 2005). Figure 2.3 below describes how cell phones are part of a closed-loop supply chain.

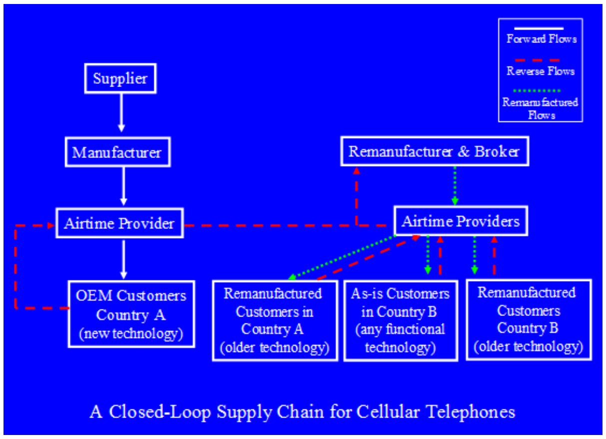


Figure 2.3 Flow Diagram of Closed-Loop Supply Chain for Cell Phones (adopted from Guide Jr., CIMSO Supply Chain Forum)

Based on the current practices, it is apparent that closed-loop supply chains come in various forms and span an array of industries. The concept of product returns has shown to be beneficial for those who incorporate closed-loop ideas into their supply chain models. However, managers of these models need to gauge the performance of these activities in order for them to be beneficial as well as to adapt to changes in the business environment. Performance measures of the supply chains help to do this and are just as important at evaluating the reverse flow of products into a chain. This section is concluded with a table that summarizes the different closed-loop supply chains that were discussed.

Table 2.1 Description and Examples of Closed-Loop Supply Chains

Closed-Loop Chain	Description	Examples
Production	Items returned during the production process	Bayer Schering Pharma byproduct recycling, NEC Notebook Server Recovery, Heineken Chip in Crate
Distribution	Finished product is returned to seller or manufacturer	Commercial returns of products, HP inkjet printers and scanners
Use-Related	Product returned to owner after being reworked	Mercedes-Benz parts replacement, Acer laptop recall
End-of-Life and End-of-Use	Product no longer of use to current owner and returned to seller or manufacturer	Cars that are traded in or reach the end of their lease, ReCellular cell phone recycling

Managing Closed-Loop Supply Chains

Closed-loop supply chains require a great deal of attention in order for them to be effective. From acquiring used products, to transferring them to the remanufacturing site via reverse logistics, to refurbishing or recycling the product, it is clear that management must be dedicated to performing these tasks and believe they are worthwhile undertakings. Guide Jr. et al. (2003) stated that in the United States, firms are likely to adopt a closed-loop system because of their economic benefits while companies based in the European Union are motivated by legislation that moves firms to reduce their impact on the environment. This type of legislation can be useful to encourage companies to create sustainable business solutions, but it should be more of a catalyst for improvement and less of a legal obligation. This improvement can come in the form of lower costs, faster service, and improved quality; however, making dramatic changes to the supply chain does not come easy. There are several issues and challenges that management faces in a closed-loop system. If and when a closed-loop system is set up, the challenges continue. Finding effective means to observe performance is key to managing the supply chain.

Guide Jr. et al. (2003) indicated that there are a great number of challenges facing managers of closed-loop supply chains. For instance, supply chains deal with a variety of products, from those involved in commercial returns to end-of-life goods. The reverse chain should be able to handle this variety; it cannot be good for just a single product. Another common challenge faced by management is the "silo approach" to supply chains. Steps in the closed-loop chain are often treated as independent activities, which often leads to suboptimization. Acknowledging that an activity such as product returns influences other activities like inventory control can be beneficial to overcoming this challenge. In terms of business, finding sales channels for remanufactured items can prove to be difficult. This is especially true when consumers are looking for the latest items on the market to satisfy their demand. To compound this, manufacturers often sell refurbished items at a discounted rate which means less of a profit for them. However, reselling items leads to another challenge managers face known as cannibalization (Guide and Van Wassenhove, 2009). When old products are reintroduced into the market, they take away the potential sale of new products to those customers who are willing to settle for a used or remanufactured item. With these challenges as well as others, it is understandable why senior leaders of companies may be hesitant at first to adopt closed-loop supply chain practices. Guide Jr. et al. (2003) suggests that managers can counter these challenges by emphasizing the benefits of closed-loop chains and how they can release potential and value that is currently unrecognized.

One way that managers can demonstrate effective changes they have made to the system is by pointing out specific performance measures of the chain that have improved. Generally speaking, performance measures of a supply chain provide decision makers with system feedback that allows them to gauge performance, reveal problems, indicate progress, or "enhance transparency among several tiers of the supply chain," (Nukala and Gupta, 2007). A great deal of attention must be paid to determining those specific parameters that signify improvements or setbacks. Obviously, profits and other monetary indicators are important values to any company; but there are other numerical and intrinsic values that reflect performance. Neely et al. (2000) stated that there are two types of performance measures in any organization, those associated with results, like financial performance, or those associated with factors that determine results, like quality. Beyond this, it is difficult to create a general approach to supply chain performance measures because different systems require specific measures to judge performance. However, there are some general themes that performance measures can follow regardless of the system specifics.

Maskell (1989) developed several design measures that are pertinent to performance measures. First, the measures should be directly related to the firm's manufacturing strategy. This is similar to the notion of strategic fit discussed earlier, where the actions of the production system coincide with the goals and strategies of making a profit. Non-financial measures should also be adopted. This makes sense because while the goal of a company is to make money, how that money is made lies in the process of creating a product or providing a service; profits are a byproduct of successful processes. Performance measures should be able to vary between locations-one measure may not be suitable for all departments or sites. This is a reflection on the need of companies to reduce the effects of suboptimization, specifically where one department performs better at the expense of another. As the circumstances change, performance measures should change with them. Systems are often in a dynamic business environment rather than a static one, so measures should also be adaptable and able to change. Measures should also be simple to understand and easy to use. For purpose of convenience, simple and easy measures allow for quick analysis that is comprehendible by most employees. If the measures are simple then they should also be able to provide fast feedback in order to make quick, informed decisions. Finally, measures should be designed so that they encourage continuous improvement as opposed to simply monitoring the situation. Doing this allows the measure to act as a sort of benchmark; a desired level of productivity that the department or company sets out to achieve.

Beamon (1999) also gives some defining characteristics of good performance measures. Measures should have some level of inclusiveness that reflects all pertinent aspects of a system. Instead of having multiple measures that relate to multiple aspects of the system, having a few measures that encompass all of the aspects would be efficient when it comes to gauging the performance of the system. Measures should also be universal for allowing comparisons between different operating conditions. When changes are made along the production line or shipment route, the same variables that judge performance should be the same. Performance measures should be derived from attainable data so that they accurately reflect what is going on with the system. Data collection is always an important step when conducting systems analysis.

Performance measures have a key role in the management of supply chains because they let company leaders know how whether or not their business is meeting expectations. Research has been done on performance measure system design for forward supply chains, but there seems to be less attention paid to these measuring systems when it comes to closed-loop supply chains. The same performance measures exist in forward supply chains as they do in closed-loop supply chains. For example, profits are an important measure regardless of supply chain setup. However, there are differences in how profits are made when considering a forward chain or a closed-loop chain. The following chapter focuses on specific performance measures and how they are viewed upon in both kinds of chains, noting the similarities among and differences between the two with regard to those measures.

CHAPTER III

ANALYSIS OF CLOSED-LOOP PERFORMANCE MEASURES

Reputation and Environmental Impact

When it comes to closed-loop supply chains, the central theme behind making the necessary changes to become closed-looped is certainly motivated by costs. However, there is more to gain from adopting closed-loop strategies than just having a better bottom line. Taking steps to reduce the impact a company's processes has on the environment can go far in shaping that company's reputation as a responsible corporate citizen. Reducing environmental impact ties into so many other goals that companies have; such as meeting environmental protection standards, complying with local and federal laws, and, in some instances, reducing production costs. As mentioned before, closed-loop chains are the next step in the evolution of supply chain management. This is in large part due to the attention that has been placed on protecting the environment; with more countries becoming industrialized, pollution around the globe is also likely to increase. Closed-loop chains look to cut down the pollution. Achieving the environmental goals of closed-loop chains can be helped by implementing green technologies within supply chains.

There are several benefits for considering reputation and environmental impact as a performance measure for supply chains. Morse and Babcock (2007) outlined these benefits, the first of which is considered to be corporate goodwill. By enacting methods to being more environmentally friendly, companies project a positive image of themselves to their customers as well as business partners. Besides businesses, groups such as the International Organization for Standards develop standards and guidelines that companies must meet in order to achieve levels of certification. These certifications ensure the company's practices are in accordance with environmental standards as well as further measures to protect against pollution and unnecessary waste. For example, Wallenius Wilhelmsen Logistics (WWL) based in Oslo, Norway became the first shipping company to achieve conformity with ISO standards to quantify and report the emissions and removal of greenhouse gases from their inventory processes (Lambert, 2010). By achieving this status, WWL can market their certification to prospective customers, illustrating their commitment to preserving the environment. Conforming to ISO standards means time, money, and energy that WWL had to spend on making changes to their system; however, WWL managers state it was all worth because of future federal legislation regarding carbon output would require them to make changes anyway. By being ISO compliant, they are ahead of their competitors who may delay making these changes.

Part of the process of making environmental reputation a performance measure in a closed-loop chain is to use alternative sources of energy as well as reusable materials when providing goods or services. Wind and solar power, as well as the advent of biofuels, are examples of alternative fuels that are being streamlined into production processes so that they cut down on the use of energy resources that are non-renewable. Beyond energy sources, inventing equipment that is capable of using these alternative fuels must also be addressed. For instance, many auto manufacturers have recognized the demand for cars that run on less fuel or alternative fuels. The same demand applies in the closed-loop supply chain; companies need trucks and other vehicles in their transportation fleet to be energy efficient and environmentally friendly so that they can improve on their performance of reducing the effect they have on the environment.

Walmart has numerous examples of changes it has made to its supply chain in order to capitalize upon the environmental reputation performance measure (Walmartstores website). In there logistics department, Walmart set out to increase their truck fleet efficiency with regard to fuel consumption. In three years, they managed to increase their efficiency by 38%, which exceeded their initial goal of 25%. The bar for Walmart is now to double their current efficiency by 2015. Actions to reach this goal included working with truck manufacturers to design fleet vehicles that will economize on fuel while still getting the job done. Walmart has engaged in bold, unique thinking with their ideas, one of which includes a pilot experiment in Phoenix, Arizona where fifteen trucks are being fitted to run on reclaimed brown waste cooking grease. The grease is collected from Walmart stores, effective creating a closed loop with a former waste product.

For forward supply chains, the reputation performance measure is looked upon in the sense of how much service is the chain providing to its customers. Reputation can also be extended to mean the perception that competitors have for a certain company within the industry. With regards to service, reputation can be judged by statistics such as percentage of on-time deliveries, the rate of returning customers, or other metrics that gauge the level of customer satisfaction. These metrics are chosen to show how reputable the company is in providing a product or service. Furthermore, these metrics are quantifiable, which means raw data can be collected and analyzed to show how a company is performing or how far off they are from providing a desired level of reputable performance. Being able to quantify these measures is a particular advantage for forward supply chains; however, the reputation performance measure takes on a different image in the closed-loop setting.

One very important link between the reputation measure and closed-loop chains is the role of reducing the effects on the environment. Certainly there are measures that can help a company understand the impact they are having on the environment. Environmental expenses incurred, the amount of waste disposed, or the number of public relations events conducted to promote environmentally conscious production are all examples of quantifiable measures that help in achieving environmental friendliness (Nukala and Gupta, 2007). Meanwhile, reputation is the perception that customers and competitors have of the company, and managers must find ways of taking the results of environmental friendliness and turning it into positive public perception. Promoting the image and the degree with which the company goes "green" can have significant impact on the reputation performance measure of a closed-loop supply chain.

Companies are searching for any avenue that leads from environmentally friendly procedures to a positive corporate image by way of enhancing their reputation. One way to do this is to partner with reputable firms that promote clean, environmental practices which set standards for the industry. The appliance department at Sears and the electronics leader Best Buy are examples of this. As of May 2010, they are the only two retail appliance stores certified to be part of the Responsible Appliance Disposal (RAD)

Program in partnership with the U.S. Environmental Protection Agency (Aberman and Nessler, 2010). RAD is a voluntary program started to help protect the ozone layer from the wrongful disposal of chemicals found in refrigerators, freezers, window air conditioners, and dehumidifiers that have been discarded. Refrigerant materials are recovered, foam material is properly disposed, and metals and plastic are properly recycled. Recovery, disposal, and recycling are three common activities found in closed-loop chains. Furthermore, the EPA provides Sears and Best Buy with reports on reduced emissions data and cost savings analysis. From a performance measure perspective, the two companies capitalize on being the only appliance retailers certified by RAD by advertising their partnership with an environmentally friendly organization such as the EPA. RAD is not limited to just retail appliances; in fact, most companies that are certified by RAD include utility companies such as Georgia Power and Pacific Gas & Electric (Aberman and Nessler, 2010). Besides retailers, manufacturers have also attempted to enhance their image of environmental consciousness. For example, Proctor & Gamble launched a sustainability initiative in October 2009 called "Future Friendly." The goal of the program is to accumulate $50 billion dollars in sales of sustainable products by 2012. The public relations campaign for this targets traditional "green" consumers as well as the average shopper. According to the P&G, a sustainable product is one that conserves 10% of water or energy in making or using the product or a 10% reduction in packaging (Mohan, 2009).

Concern for the environment clearly has an impact on how reputation is judged as a performance measure. This is especially true because environmental reasons are a major theme of many closed-loop chains. Besides the environment, supply chain responsiveness is another major issue for supply chains. When discussing closed-loop supply chains, it is important to examine how responsiveness changes when having to consider the additional activities involved in closed-loop supply chains.

Responsiveness

Companies' decisions about the level of service to provide to the customers define their level of responsiveness to the needs of its customers. If the company provides some sort of good or tangible product, then product variety, product quality, or product delivery time are factors that need to be considered. If the company provides some sort of service, then services such as customer assistance, individual attention, or rapid troubleshooting are factors that need to be considered. These targets of responsiveness, and the degree with which the company desires to satisfy customers, changes between supply chains depending on product or service is being sold as well as what resources are available to the supply chain itself.

Successful supply chains should be able to figure out all of these factors to determine how responsive they are to the needs of their customers. They should also have a plan on how to execute their responsiveness; who is in charge of contacting customers, which department processes orders or returns, etc. This plan of responsiveness should align with the goals of the company in terms of strategic fit (Chopra and Meindl, 2007). The same ideas of responsiveness remain in closed-loop supply chains, except now responsiveness needs to be considered with all of the activities that go into a closed-loop setup. Take product collection, one of the three major steps in closed-loop chains, as an example. A closed-loop supply chain may need to determine whether or not their distribution network of vehicles and warehouses can handle both the delivery of new products and the collection of old products simultaneously. How the chain handles both of these tasks with respect to customer service would determine the level of responsiveness achieved. Mathematical optimization models can help with task by deciding on location of collection facilities and the routes that need to be created in the transportation network to handle the movement of both new and old products. Other factors that have a role in responsiveness include conformity to customer specifications, flexibility of the closed-loop chain, and after-sales services. Again, product specifics and supply chain resources define how responsive a chain can be in these three areas.

One of the key elements of responsiveness is offering a line of products that fit the diverse needs of the customers (Simchi-Levi et al. 2000). Offering a variety of products is a distinct difference between responsive and efficient supply chains. By offering variety, the chain is responding to a wider array of customer needs, but this variety comes at a higher price that is passed onto the customer. Depending on the product being offered in some cases, consumers are demanding products that trend towards the notion of customization and service tailored individually for them. The same applies in the closed-loop supply chain, where customer specifications must still be met. This can be somewhat of a difficult balance. On the one hand, customers tend to want the latest technology or product that is on the market. On the other hand, the concept of most remanufacturing setups is to take an old product and refurbish it back to its original state. The latter concept does not necessarily produce a new product, but is a lower cost alternative to a brand new product. Enough of a market exists for refurbished products, thus making closed-loop chains a continued practice in production lines; however, it is necessary for these lines to develop chains that can handle product variety both in the forward supply chain and in the reverse logistical supply chain.

Companies like Dell who offer a great deal of product variety must be able to handle this variety in their closed-loop organization. Part of Dell's business model is that customers get to choose particular hardware components for the personal computers (Dell, 2006). This practically ensures that any closed-loop setup that Dell provides will have to account for all the variability among their computers. Different sized monitors, motherboard components, and peripherals such as audio and video equipment that are sold with the computers will all have to be sorted and processed efficiently so that they can either be resold on the refurbished market or recycled in an efficient manner. Also, Dell has developed into a top Fortune 500 company by diversifying their product variety to expand beyond individual personal computers (Fortune Magazine website). Other computing equipment such as commercial printers, copiers, and servers are also part of their product mix. Dealing with the return of these larger items, in conjunction with their personal computer enterprise, makes their closed-loop system able to deal with both old and new products.

In order to conduct their recycling initiative, Dell partners with FedEx and Goodwill in order to process returns. First, Dell offers to recycle their customers' products free of charge (provided the product was purchased from Dell) by having them go to their website and either find a Goodwill drop off location for their products or have them print a free shipping label through FedEx. This relieves Dell of having to do the actual collection of used products as well as sorting between the varieties of products that are sent for recycling. Once the products are in the hands of Goodwill recyclers, they strip the products or recyclable materials. At this point, product variety is less of an issue as all computer products are searched for recycled materials. In the end, recycled materials are resold to manufacturers (SF Goodwill, 2008).

Responsiveness is also driven by how agile a supply chain can be. Ismail and Sharifi (2006) define agility as, "the ability of the supply chain as a whole and its members to rapidly align the network and its operations to the dynamic and turbulent requirements of the demand network." Changes in the marketplace occur for various reasons. New technology can change a product itself or how a product is made. External forces also impact a supply chain's responsiveness, including current economic conditions and even inclement weather events such as hurricanes or blizzards. Changes do not have to be dramatic in order to make an impact. Demand patterns with respect to what the customer wants can represent change that tests a supply chain's agility. Being agile is a reflection of how well a supply chain can adapt to uncertainties and variation in the marketplace. The used car sector of automotive companies is an example of this. Car sales have multiple factors that determine whether or not a significant amount of demand is there for cars to be sold. These conditions impact the closed-loop chain of used cars, primarily when it comes to inventory of used cars. For example, in bad economic times, used cars sales are up because fewer people cannot afford to purchase new vehicles (Woodyard, 2009). By offering used cars, automobile companies increase their responsiveness to a greater number of customers, specifically those that are looking into getting a car, but one that is less expensive than a new one. Car manufacturers need to make sure their supply chains are adequately equipped and responsive enough to handle this change in demand. In terms of acquiring used car inventory, auto deals contact current owners to see if they would like to trade in their car for credit towards a new vehicle. Furthermore, they will also need to be able to plan for the future when the economy recovers and consumers are ready to purchase new vehicles. Another example of being responsive comes from Amazon.com and the sale of used textbooks. With so many textbooks and authors in the market, schools have a variety of textbooks to choose from for their classes. Often times, a popular textbook or author will be widely in use and Amazon.com makes sure it partners with textbook suppliers to have enough inventories to satisfy demand. However, change happens when textbooks switch to the latest edition. Now resources need to be spent on acquiring copies of new editions while also collecting old editions and paying out to students who sell back their old textbooks; similar to refurbished products, there is still a small part of the market that uses and needs the old edition textbook. Once again, being agile to changes in the market (especially those expected ones as in the Amazon.com example) goes a long way to being a responsive supply chain. Amazon.com reaches a greater level of responsiveness because it offers a larger variety of products (multiple textbook editions) as well as a larger variety of prices (cheaper books for older editions).

After sales service is another telling sign of responsiveness (Kim et al., 2007). This mainly deals with the level of service that a use-related closed-loop the supply chain provides to its customers after the sale has been made. It can come in the form of scheduled maintenance, honoring a warranty agreement, or assistance with any problems that may arise with the product. A large scale example of after sales service occurs when a product recall is ordered to protect the safety of the user. The efficiency with which after sales service is processed is the key to enhancing responsiveness in this area. A balance must be struck between the supply chain standing behind the quality of their product and the lengths they are willing to go to provide after sale service. Logically, if product quality is good, then there is less dependence on the need to be highly responsive after the sale. However, if product quality is poor, there will be more of a need to have a good after sale service. This is likely the reason quality is such an important aspect of product manufacturing; if the company can handle problems with a product during manufacturing before it reaches the consumer, the less they will have to pay in terms of after sale service or even the potential loss of goodwill because of a poor product. The recall of several Toyota models in January 2010 is an example of a responsive closed-loop chain designed to respond to a defective product. In several of its cars, sticking accelerator pedals caused several issues with vehicle safety (Brennan, 2010). What made matters worse for Toyota was they were just recovering from another safety recall in which floor mats on the driver's side of the vehicle were entrapping the accelerator pedal. Toyota, which had long had a reputation for quality craftsmanship, suffered a terrific blow to their reputation. To begin to rectify the relationship between them and their customers, Toyota offered to make the necessary repairs to their vehicles for anyone who brought their car to a Toyota dealership. Despite the bleak outlook early on, the recall and other marketing efforts to reassure customers of Toyota quality have lead to forecasts of profits for the automaker to rise by as much as 48% during the same fiscal year as when the accelerator pedal recall occurred (Kitamura & Hagiwara, 2010).

Responsiveness plays an important role in overall supply chain performance and needs to be considered as a measure in closed-loop models. Part of being responsive is the design of the supply chain network itself with respect to facilities. Facilities are the locations in the supply chain that perform specific tasks to satisfy customer demand. How these facilities are organized and where they are located are measures of supply chain success. Through facilities, a supply chain can reflect how responsive they are trying to be. On one hand, they can locate many facilities close to their customers and be highly responsive. At the same time, having too many facilities can get expensive as well as more difficult to manage. Tradeoffs have to be made in terms of how many facilities are in the supply chain, where they are located, and how high a level of service should each facility attempt to achieve.

Facility Potential

Part of providing a product or service to customers is having the ability to reach them in a place that is convenient for them while also staying competitive with customers. Major retail chains cannot open stores on every street corner, nor have a single shop at a distant length from customers. This is a reason why shopping centers and malls are effective; the retailer can lease space in the mall along side their competitors so that customers can have the convenient option of choosing who to shop with at the same location. On a larger scale, supply chains must also determine where to locate their facilities in order to be successful. Besides location, facility potential also deals with what is happening at each of these supply chain locations and if they are effectively contributing to the supply chain. In the closed-loop sense, this refers to the role that quality has in refurbishing products. It also refers to the level of automation involved in the closed-loop process at each facility as well as ways to quantify the facility potential as a performance measure.

Facility location certainly has an impact on supply chain performance and factors into the equation of facility potential as a performance measure (Nukala and Gupta, 2007). As mentioned earlier, it is one of the six major drivers of supply chain management. Choosing where to locate members of the supply chain can be difficult because so many factors are involved. First of all, an individual company may choose one location that is cheapest and most convenient. At the same time, this location may not be convenient for the company's supply chain partners, perhaps because of long distance or outside of the current transportation network. Also, companies tend to do business with multiple suppliers and multiple customers. Similar to the mall example earlier, it is good for a company to be close to customers, but there is a tradeoff here if this creates greater distance from suppliers. Choosing a location or locations must also be factored in with the type of transportation the company has at their disposal. Depending on the product, certain modes of transportation may or may not be available, so the location of the facility should coincide with the kind of shipping and receiving network the company has as a resource. From a closed-loop perspective, location selection becomes important when interfacing with customers who need to return items (Lu and Bostel, 2007). Product collection needs to be accessible to customers. In some instances, drop off locations can be setup at retail outlets or where the product was purchased by the customer. In other cases, the product could be mailed in to the manufacturer to be refurbished. For example, legislation was established in Germany to recycle passenger vehicles that carried a maximum of eight passengers. When it comes to collecting these vehicles, the legislation stated that the drop off locations for the vehicles had to be within a specific distance from each other so that it would be easier for people to leave their vehicle at a location that is near to them. By making this stipulation, recycling the vehicle provides more convenience to the owners and makes the recycling option a more attractive one (Schleiffer et al., 2004).

The issue of interfacing with customer is an interesting one due to the prevalent use of the internet as a means of acquiring products (Chopra and Meindl, 2007). Shipping products to customers is an economic reality for those who do business on the internet, but it may be less likely that a customer is willing to pay for the shipping to return an item to the manufacturer, thus potentially breaking the first link in the reverse logistics chain. If the customer does not want to pay to send the product, then having a reverse logistics process may not be necessary, as far as refurbishing old products are concerned. Offering to cover the return shipping costs is one way to overcome this. Examples of companies that offer to cover return shipping costs include Zappos and Netflix. Zappos sells shoes online and offers free return shipping in the absence of being able to try on shoes. Netflix covers return shipping costs in order to provide convenience as a way of competing with movie rental companies that have brick-and-mortar retail outlets. Having drop off locations that are on the same shipping routs as the forward supply chain may be the most beneficial if possible. It would eliminate the cost to ship the item for remanufacturing and would theoretically be on the transportation network's route. Previous studies have been done on how best to optimize systems that consolidate their forward and reverse shipping processes. Min et al. (2004) developed transportation network solutions using heuristics such as the genetic algorithm to find ways of determining the number and location of return facilities that collect, sort, and consolidate returned items. Their study supported the idea that collection and remanufacturing facilities remain separate from those within the forward supply chain and that the transportation network of the entire closed-loop chain be managed so that it can accommodate all facilities. Of course, it should be noted that developing this type of transport system is product dependent and may not work in all scenarios, but it demonstrates the importance of finding effective transportation network solutions when discussing closed-loop supply chains.

An important aspect that must be addressed when talking about closed-loop chains is the quality of the product once it has been refurbished. It may not be expected that a refurbished product has the same high quality as a new product, but a certain level of quality should be predetermined and achieved. Dedicated facilities are one way of going about to try and maintain a certain level of quality (Nukala and Gupta, 2007). These facilities are designed to perform one function or task in the closed-loop process, whether that task is part of the refurbishment process or part of returning the product to the customer. Being dedicated has its advantages because it allows the facility and its employees to focus on either one specific closed-loop task or work on a specific product. Not having to deal with multiple products or tasks will allow for a more streamlined process. However, dedicating a facility to do one task or take care of one product, a sure sign of responsiveness, is not very efficient use of resources. Taking an entire facility to do one job is difficult when supply chains have to deal with numerous products. Therefore, performance regarding facility potential must take into account the balance between dedicating a facility and being efficient with facility resources when it comes to ensuring sufficient quality among its refurbished products. For example, Barrett Distribution Centers is a 3rd party logistics company that offers warehousing and shipping services to its customers such as electronics retailer Best Buy. Barrett offers dedicated facilities to Best Buy, but more specifically, it offers a Best Buy a solution in terms of closed-loop processes by disposing of used items that get returned through proper auction protocols. Besides this closed-loop activity, Barrett also provides ISO 9001 compliance with respect to quality standards, ensuring that their facilities provide quality closed-loop supply chain solutions.

Automation is another factor that has to be considered when discussing facility potentiality (Yang et al., 2009). How automated a production system is can influence the amount of service that it can provide. When the products under question do not need to offer much in terms of service, an automated system can be beneficial. Systems where many of the processes are automated can produce throughput at a consistent level while also keeping errors at a minimum. Automation is welcomed in production systems where the products have much of the same characteristics and can be produced in the same way. However, when the products are different or need separate, customized attention, automation tends to be less useful. Applying this to the closed-loop supply chain, automation may have its limitations. When a product needs to be refurbished, the reasons for remanufacturing can vary; there are any number of possible conditions with which the product arrives, and not all products are returned for the same defect or reason. This works against automation and its inability to be flexible and change when needed. Being able to handle different scenarios that may arise in the remanufacturing step of a closed-loop supply chain is important (Salema et al., 2009). It is likely that it could take human workers to be able to adapt to any random, unexpected events that occurs in the process. An example of automation working well in a closed-loop chain would be in a production closed-loop supply chain. As discussed earlier, production closed-loop chains involve activities where items used in the manufacturing process are returned to their original location. In the case of crates, pallets, or packing material, these items could benefit from automation in terms of having automatic means to bring them back to their original location. The items are not being worked on themselves, but must still be processed so that future production can continue. Of course, for automation to work here, the closed-loop would have to occur in the same relative area or in the same production facility. An example of automation not working well in a closed-loop chain would be in the case of ReCellular discussed earlier. Cell phones come in very different makes and models, and to sort all of this variety may be difficult in an automated process. Phones have to be sorted according to how much damage they have, whether or not parts can be reused, or if the phone is in good enough working condition to be resold as is. This takes human observation to judge the usability of a phone sent to ReCellular. Again, it can be seen that automation is less able to deal with the high level of variation in processing items that are remanufactured.

In order to use facility potential as a performance measure, there are several ways that attempt to quantify it (Nukala and Gupta, 2007). One simple way is to take facility potential with respect to location and label it as the distance between the facility and the customer or market. Facility potential can also be judged by how much or how little money is spent on disassembly or sorting systems at the location. Also, the volume of products being remanufactured or the value recovered at each facility can also determine performance. In terms of processing remanufactured items, Nukala and Gupta (2007) suggest disassembly time multiplied by throughput so as to gauge how much time it takes to process a given number of parts. Also, the increment of quality, or how much the product quality has improved after being processed, can also be used to quantify facility potential, provided that quality itself is quantifiable under the given system.

Facility potential as a performance measure gives managers insight into what each location along the chain can do in order to satisfy demand. It is based upon various factors such as quality, dedicated tasks, and automation. Quantifying these factors has become the challenge for most firms in order to use this measure in an effective way. One performance measure that is easily quantifiable is cost, and it is often used as a barometer of success in any kind of business.

Financial Measures

Reducing costs to in order to increase profits is a bedrock principle of all businesses. Money is to be made when profits are controlled by revenues and costs. Increases in sales and revenue along with reduction in costs will generally lead to higher profits. Unfortunately for managers, it is not that simple. In order to make revenues and profits, companies usually invest their capital into the firm before any revenue is generated. The belief is that after the initial cost to start a business venture has been made, the business will start to see returns. Closed-loop supply chains work a lot in this manner; they involve a company making an initial investment in their supply chains with the hope that it will add value to the supply chain. This value has been previously discussed in the form of attaining better corporate reputation, reaching a higher level of customer responsiveness, and allowing supply chain facilities to reach a higher potential. All of these factors measure performance, but the most important set of factors that measures success are financial measures. Profits, revenues, and costs are literally and figuratively the bottom line of all businesses and therefore must be considered when discussing closed-loop supply chains.

Previously, there have been steps taken in studying closed-loop chains to optimize the system from revenue or cost perspectives. Chung et al. (2008) developed a model where the overall profits of both the forward and reverse supply chain in a closed-loop setting were able to increase based on creating an optimal policy of inventory management. Kannan et al. (2010) developed a model using the genetic algorithm heuristic to develop a multi-product, multi-echelon model that investigated product returns as well as decisions of in procurement, remanufacturing, and recycling in the area of battery recycling. Also, optimization models are widely used in determining facility locations of a closed-loop supply chain as in the case of finding the optimal locations of collection facilities and remanufacturing centers using tabu search heuristics (Easwaran and Uster, 2009). These optimization models and many others are created to design cost-efficient closed-loop supply chains that lower costs and raise profits.

It has been addressed that closed-loop chains are a combination of the forward supply chain activities and reverse logistics activities. Intuitively, the forward supply chain activities are the essential steps for a company to provide their product or service. The reverse logistics activities are not necessary for the forward chain to be productive; the latter in all likelihood can survive without the former. Yet, closed-loop chains are existent and are the next step in the evolution of supply chain management because they add value to supply chains in one form or another. This added value comes at a cost to the company. Added costs are generally frowned upon, which would make reverse logistical activities viewed as unnecessary. However, the value that they add to the supply chain is also considered, and if this value is worthwhile then the closed-loop chain is implemented (Srivastava, 2007).

Closed-loop supply chains can be considered a bold concept because of the creativity, as well as the capital, required to make them a reality in today's business climate. At the same time, they are becoming more of a necessity due to the increasingly stringent regulations imposed on manufacturers. It is reasonable to assume that large companies that are well established in both their industry as well as the national and global economies are best candidates to implement closed-loop supply chains. They have the most capital to spend on remanufacturing initiatives and also have the most incentive to convert to a closed-loop system. The incentive to push the manufacturing frontier forwards stems from being leaders of industry and being on the cutting edge of doing what is new. When industry leaders achieve closed-loop success, it can have a trickle-down effect to other companies and competitors who may also decide to implement closed-loop chains in order to remain competitive and improve performance. In the United States, the performance of large companies has long been considered a means to gauge the overall performance of the national economy. For instance, the stock prices of the top thirty American companies comprise the Dow Jones Industrial Average, which has long been considered an economic indicator of how well the national economy is doing (Sullivan & Sheffrin, 2003). Another way to identify the most successful large companies on an annual basis, in the United States, is by researching the Fortune 500 list published by Fortune Magazine. The Fortune 500 is an annual list that ranks the top 500 U.S. public corporations as ranked by their gross revenue after adjustments made by

Fortune to exclude the impact of excise taxes companies collect (Fortune Magazine website). The magazine also publishes an annual list of the best companies based across the world. Using the Fortune 500 lists, it can be researched whether or not the top businesses in the world are implementing closed-loop supply chains.

There are many ways that Fortune determines success in their rankings. For the purposes of this study, the latest data provided on the most profitable companies was used to determine the top ten companies in the United States. The latest data on the top companies based on overall ranking was used to determine the top ten European companies. Although there is a difference in the criteria of these lists, they were selected because they provided the most economic diversity as well as the best opportunity to find closed-loop supply chains being implemented. On the following page is a table that presents these two lists (Fortune Magazine website).

Table 3.1 Top Ten Companies in the United States and Europe

Top Ten U.S. Companies	Sector	Top Ten European Companies	Sector
Exxon Mobil	Energy	Royal Dutch Shell	Energy
Microsoft	Technology	British Petroleum	Energy
Walmart	Retail	Total	Energy
Proctor & Gamble	Manufacturing	ING Group	Finance
IBM	Technology	Volkswagen	Automotive
Goldman Sachs	Finance	Dexia Group	Finance
Merck	Pharmaceutical	ENI	Energy
AT&T	Telecommunication	Allianz	Insurance
Wells Fargo	Finance	HSBC Holdings	Finance
Johnson & Johnson	Manufacturing	Daimler	Automotive

When studying these lists as well as others provided by Fortune 500, the first observation made was the prevalence of the energy sector companies at the top of these lists. This is reasonable to understand because a vast majority of the populations in these developed parts of the world depend on energy providers to run their homes and their businesses. Also, the financial sector is well represented in these lists. Financial companies inherently make large sums of profits and are frequently at the top of these lists on an annual basis. Based on these two lists, the energy and finance sectors represent ten of the twenty companies listed.

Research was performed on these twenty companies to investigate whether or not they implement some sort of closed-loop supply chain process in any of their business functions. The belief is that if the top companies in their respective regions implement closed-loop supply chains, then there is a reasonable chance that closed-loop chains can be implemented in other firms in these regions too. Starting with the list of American companies, here are the companies in the top ten that implement some version of a closed-loop supply chain. This is followed by a table of European companies within its respective top ten list that implement a closed-loop supply chain.

Table 3.2 Closed-Loop Programs Found at the Top U.S. Companies

Top U.S. Companies That Implement Closed-Loop Supply Chains	Description of the Program That Implement Closed-Loop Supply Chains
Microsoft	Microsoft Refurbish PC Program
Walmart	Use of alternative fuels for trucks
Proctor & Gamble	Global Asset Recovery Purchases
IBM	Asset Recovery Solutions
AT&T	Cell phone recycling programs

Table 3.3 Closed-Loop Programs Found at the Top European Companies

Top European Companies That Implement Closed-Loop Supply Chains	Description of the Program That Implement Closed-Loop Supply Chains
Royal Dutch Shell	Closed-loop cooling water recycling project
British Petroleum	Sustainable polymers recycling project
Total	Carbon capture and storage facility
Volkswagen	Certified pre-owned vehicle resale
ENI	Integrated thermo-fermenting process
Allianz	Risk analysis associated with sustainable tech.
Daimler	Mercedes-Benz Used Parts Center

To offer elaboration on these programs, the closed-loop chains of the American companies are relatively straightforward. Microsoft's refurbishing program, IBM's asset recovery solutions, and AT&T's recycling program are classic closed-loop examples of salvaging materials from old products into making new products. The global asset recovery purchases program at Proctor & Gamble is designed to recover excess raw materials and develop them for use in other products. Walmart's closed-loop chain is the development of using cooking grease from their food production facilities and turning it into a viable source of fuel that is to be used in their shipping trucks.

The European closed-loop supply chain programs, meanwhile, tend to broaden the use of closed-loops to wider array of activities outside of remanufacturing. Royal Dutch Shell's cooling water recycling project looks to use and reuse natural sources of running water in order to provide for cooling systems at industrial plants. The water is recycled into cooling towers for reuse as opposed to exiting the system as waste water. At British Petroleum, the sustainable polymers recycling project seeks to find new ways of making plastics from the remaining raw materials used in other petroleum products. The carbon capture storage facilities being developed by Total is able to collect carbon emissions and pipe it to a storage site that converts it into natural gas, illustrating an example of a production closed-loop chain where byproducts are recycled. At ENI, their integrated thermo-fermenting process attempts to convert urban waste into biofuel that is used to power marine vehicles or generate electric power. Allianz is an insurance provider in Europe that has a unique role in terms of sustainable supply chain activities. They offer risk analysis to engineering firms that desire to develop closed-loop activities. Finally, Volkswagen and Daimler are two automotive companies that look to resell used vehicles and reuse old auto parts, respectively.

Based on these results, certain conclusions can be drawn about the prevalence of closed-loop supply chains among the leading companies in the world. For instance, energy and oil producing companies have a large amount of power and influence on national and global economies. If they can find ways to take the lead in developing closed-loop chains, the better the likelihood that other companies both in and out of the energy sector will follow suit. Also, one interesting observation is that the top three European companies are in the energy sector and all three have some form of closed-loop supply chain. Meanwhile, Exxon Mobil is the highest rank American company and yet does not have any closed-loop processes to be found. In their defense, energy companies may be best suited for implementing closed-loop supply chains. Their main objectives are to harness natural resources and refine them into useful energy. They may not have the opportunity to take old products and remanufacture them for reuse. It should be stated that some of their activities do capture the same goals as closed-loop chains. With regard to the environment, Exxon invests a great deal of research into alternative fuels in order to capitalize upon sustainability and corporate goodwill. However, in terms of a tactical closed-loop chain, there does not appear to be one that is implemented.

Another observation is the prevalence of financial institutions and companies that provide more services than products. Allianz is one company that fits this mold while also being a part of a closed-loop chain. Though none of their processes can be considered closed-loop, they aid other industrial companies in their risk assessment before undertaking closed-looped and other sustainable activities. They are part of the process and should be considered as a non-industrial company that is involved in closed-loop supply chains. Overall, financial companies that make these lists do not produce a product that benefits from remanufacturing.

Differences can be seen between the two lists in terms of geographic location. Seven out of ten European companies implemented closed-loop processes; the other three were financial firms that do no remanufacture products. On the other hand, five out of ten American companies had closed-loop processes and only two out of those ten were financial firms. This reaffirms the notion discussed early on regarding how closed-loop supply chains are viewed in Europe as opposed to the United States. In Europe, there is a concentrated effort from both government and industry to reap the benefits of closed-loop chains, the primary benefit being a healthier environment. Their circumstance of being a continent relatively small in size pushes them to develop ideas and technologies that will make businesses more sustainable and efficient. The United States has the circumstance of being a nation rich in land and resources, which allows less for relying on sustainable technology. As more information about depleted resources and global climate change occurs, America will continue to move in the direction of closed-loop supply chains, but at a slower pace than their European counterparts.

CHAPTER IV

CONCLUSIONS

The four performance measures discussed in the research give insight into some of the aspects that are involved in creating performance measures in a closed-loop supply chain. Using reputation, responsiveness, facility potential, or financial measures to judge the performance of a supply chain is not a new concept by any means. However, what has to change with supply chain management is the way these established performance measures are viewed upon. Specifically, how data is collected and analyzed to investigate these measures changes because now the processes that reflect performance have also changed. In a forward supply chain, reputation may simply mean how well the supply chain satisfies demand for new products. This changes in a closed-loop supply chain, where now reputation is also based on how the reverse logistics activities impact satisfying demand for new and used products. The same connection can be made with the other measures; primarily observing how the combination of forward supply chain and reverse logistics activities impact the way performance measures are analyzed.

There are plenty of avenues to expand upon the study of performance measures of closed-loop supply chains. From both a business and engineering point-of-view, much was discussed about how these four basic performance measures change when discussing closed-loop processes. This can be expanded upon by introducing ways to quantify these measures. Quantifying performance measures helps managers make comparisons between different situations based on numerical fact. This was addressed earlier in some cases; financial measures are often quantifiable because they deal with money, and facility potential can be quantifiable because output can be based on numerical data. However, reputation and responsiveness tend to be a little more difficult to quantify. Managers have to ask themselves how they put a numerical value on a measure such as reputation, where it is more of a public perception than a mathematical value. Certainly, excelling at these performance measures can be numerically judged by the way they impact profits, which are of course quantitative. However, a performance measure should be looked at deeper than how it affects the bottom line; it needs to be a reflection of how well the manufacturing and production processes are working.

Another avenue of future research relates to quantification of performance measures. It has been addressed that there are various attempts in research that use optimization models which consider these measures as variables. Modeling can be extended to economic and forecasting analysis that also takes these variables into consideration. Economic models could be a very powerful tool for closed-loop managers. The benefits of closed-loop supply chains mostly deal with environmental concerns, which are important, but not paramount when it comes to managers and their profit reports. Having an economic model that shows the benefits of a closed-loop supply chain for a reduced cost or increased profit perspective will only enhance the environmental benefits. The combination of reduced environmental impact and increased profits will only make closed-loop supply chains a more attractive alternative for supply chain managers.

REFERENCES CITED

Aberman, C. & Nessler, J. (2010). Best Buy joins the EPA responsible appliance disposal program: partnership demonstrates Best Buy's commitment to help consumers save energy, reduce waste and protect the environment. Accessed through http://www.epa.gov /ozone/partnerships/rad/downloads/Best-Buy-RAD-Press-Release.pdf on 05/28/10.

Agrawal, V. & Toktay, L.B. (2009). Interdisciplinary in closed-loop supply chain management research. Working paper, Georgia Institute of Technology, Atlanta, GA.

Bayer Schering Pharma, Protecting the environment. Accessed through http://www.bayerscheringpharma.de/scripts/pages/en/corporate_responsibility/protecting_the_environment/climate_change/index.php on 4/5/10.

Beamon, B.M. (1999). Measuring supply chain performance. *International Journal of Operations & Production Management*, 19, 275-292.

Bonney, M.C., Zhang, Z., Head, M.A., Tien, C.C. & Barson, R.J. (1999). Are push and pull systems really so different? *International Journal of Production Economics*, 59, 53-64.

Brennan, R. (2010, January 21). Toyota announces January 2010 recall for 2.3 million vehicles to fix sticky accelerator pedal: Remedy isn't apparent yet; lexus and scion not affected. *AOL Autos*. Accessed through http://autos.aol.com/article/Toyota-sticky-pedal-recall/.

Cannon, E. (1993). *EDI Guide: A step by step approach*. New York, NY: Van Nostrand Reinhold.

Chandler, A.D. (1977). *The visible hand: The managerial revolution in American business*. Cambridge, MA: Belknap Press.

Chopra, S. & Meindl, P. (2007). *Supply chain management: Strategy, planning, and operation*. Upper Saddle River, NJ: Pearson Education Inc.

Chu, S., Leung, L.C., Hui, Y.V., & Cheung, W. (2007). Evolution of e-commerce web sites: A conceptual framework and a longitudinal study. *Information & Management*, 44, 154-164.

Chung, S., Wee, H., & Yang, P. (2008). Optimal policy for a closed-loop supply chain inventory system with remanufacturing. *Mathematical and Computer Modelling*, 48, 867-881.

Croom, S., Barani, S., Belanger, D., Lyons, T., & Murakami, J. (2009). Proceedings from European Operation Management Association Conference '09: *Sustainable supply chain management- an exploration of current practice*. Goteborg, Sweden.

Cucchiella, F., Gastaldi, M., & Subramaniam, A. (2008). Translating the supply chain uncertainty into a firm new value. *International Journal of Agile Systems and Management*, 3, 192-215.

Davey, S., Guide Jr., V.D.R., Neeraj, K., & Van Wassenhove, L.N. (2005). Commercial returns of printers: The HP case. In Flapper, S.D.P., van Nunen, J.A.E.E, & Van Wassenhove, L.N. (Eds.), *Managing closed-loop supply chains* (87-96). Berlin, Germany: Springer-Berlin.

de Brito, M.P. & Dekker, R. (2004). A framework for reverse logistics. In Dekker, R., Fleischmann, M., Inderfurth, K., & Van Wassenhove, L.N. (Eds.), *Reverse logistics: quantitative models for closed-loop supply chains* (10-20). Berlin, Germany: Springer-Verlag.

Dell, M. & Fredman, C. (2006). *Direct from Dell: Strategies that revolutionized an industry*. New York, NY: HarperCollins.

Dijkhuizen, H.P. (1997). Reverse logistics bij IBM. In Van Goor, A.R., Flapper, S.D.P., & Clement, C. (Eds.), *Reverse logistics* (chapter E1310). Deventer, The Netherlands: Kluwer.

Driesch, H., van Oyen, H.E., Flapper, S.D.P. (2005). Recovery of car engines: The Mercedes-Benz case. In Flapper, S.D.P., van Nunen, J.A.E.E, & Van Wassenhove, L.N. (Eds.), *Managing closed-loop supply chains* (157-168). Berlin, Germany: Springer-Berlin.

Easwaran, G., & Uster, H. (2009). Tabu search and benders decomposition approaches for a capacitated closed-loop supply chain network design problem. *Transportation Science*, 43, 301-320.

Federal Trade Commission, About the federal trade commission. Accessed through http://www.ftc.gov/ftc/about.shtm on 3/27/10.
Fisher, M.L. (1997). What is the right supply chain for your product? *Harvard Business Review*, March-April 1997, 83-93.

Flapper, S.D.P., Fransoo, J.C., Broekmeulen, R., & Inderfurth, K. (2002). Logistic planning and control of rework in the process industries: A review. *Production Planning & Control*, 13, 26-34.

Flapper, S.D.P., van Nunen, J.A.E.E., & Van Wassenhove, L.N. (2005). Introduction to closed-loop supply chains. In Flapper, S.D.P., van Nunen, J.A.E.E, & Van Wassenhove, L.N. (Eds.), *Managing closed-loop supply chains* (3-18). Berlin, Germany: Springer-Berlin.

Forrester, J.W. (1958). Industrial dynamics: A major breakthrough for decision makers. *Harvard Business Review*, 38, 37-66.

Fortune Magazine. (2010). Fortune 500: Our annual ranking of America's largest corporations. Accessed through http://money.cnn.com/magazines/fortune/ fortune500/2010/index.html on 06/01/10.

Fuller, D.A. & Allen, J. (1995). A typology of reverse channel systems for post-consumer recyclables. In Polonsky, J. & Mintu-Winsatt, A.T. (Eds.), *Environmental marketing: Strategies, practice, theory, and research* (241-266). Binghamton, NY: Haword Press.

Geyer, R., Neeraj, K., & Van Wassenhove, L.N. (2005). Reverse logistics in an electronics company: The NEC-CI case. In Flapper, S.D.P., van Nunen, J.A.E.E, & Van Wassenhove, L.N. (Eds.), *Managing closed-loop supply chains* (33-43). Berlin, Germany: Springer-Berlin.

Guide, Jr., V.D.R. (Ed.). (2005). Proceedings from CIMSO Supply Chain Forum '05: The development of closed-loop supply chains. Pittsburg, PA: Duquesne.

Guide Jr., V.D.R., Harrison, T.P., & Van Wassenhove, L.N. (2003). The Challenge of closed-loop supply chains. *Interfaces*, 33, 3-6.

Guide Jr., V.D.R., Neeraj, K., Newman, C., & Van Wassenhove, L.N. (2005). Cellular telephone reuse: The ReCellular Inc. case. In Flapper, S.D.P., van Nunen, J.A.E.E, & Van Wassenhove, L.N. (Eds.), *Managing closed-loop supply chains* (151-156). Berlin, Germany: Springer-Berlin.

Guide Jr., V.D.R. & Van Wassenhove, L.N. (2009). *The evolution of closed-loop supply chain research*. Operations Research, 57, 10-18.

Gunasekaran, A. & Ngai, E.W.T. (2007). Knowledge management in 21st century manufacturing. *International Journal of Production Research*, 45, 2391-2418.
Hopp, W.J. & Spearman, M.L. (2008). *Factory physics*. New York, NY: McGraw-Hill.

Hult, T.M., Ketchen, D.J., & Arrfelt, M. (2007). Strategic supply chain management: Improving performance through a culture of competitiveness and knowledge development. *Strategic Management Journal*, 28, 1035-1052.

Ismail, H.S. & Sharifi, H. (2006). A balanced approach to building agile supply chains. *International Journal of Physical Distribution & Logistics Management*, 36, 431 – 444.

Jayaraman, V., Guide Jr., V.D.R., & Srivastava, R. (1999). A closed-loop logistics model for remanufacturing. *Journal of the Operations Research Society*, 50, 497-508.

Kannan, G., Sasikumar, P., Devika, K. (2010). A genetic algorithm approach for solving a closed loop supply chain model: A case of battery recycling. *Applied Mathematical Modelling*, 34, 655-670.

Kim, S., Cohen, M.A., & Netessine, S. (2007). Performance contracting in after-sales service supply chains. *Management Science*, 53, 1843-1858.

Kitamura, M. & Hagiwara, Y. (2010, June 28). Toyota, Nissan lead Japan carmakers' output rebound. *Bloomberg Businessweek*. Accessed through http://www.businessweek.com/news/2010-06-28/toyota-nissan-lead-japan-carmakers-output-rebound.html.

Kumar, S. & Putnam, V. (2008). Cradle to cradle: Reverse logistics strategies and opportunities across three industry sectors. *International Journal of Production Economics*, 115, 305-315.

Lambert, D.M. & Cooper, M.C. (2000). Issues in supply chain management. *Industrial Marketing Management*, 29, 65-83.

Lambert, G. (2010). Norwegian shipping company claims a sector "first" for ISO 14064 GHG reporting. Accessed through http://www.iso.org/iso/iso-focusplus_online-bonus-articles/isofocusplus_bonus_wwl-shipping.htm on 05/18/10.

Lee, H.L., Padmanabhan, V., & Whang, S. (1997). Information distortion in a supply chain: The bullwhip effect. *Management Science*, 43, 546-558.

Lee, H.L. & Whang, S. (2000). Information sharing in a supply chain. *International Journal of Manufacturing Technology and Management*, 1, 79-93.

Linton, J., Klassen, R., & Jayaraman, V. (2007). Sustainable supply chains: An introduction. *Journal of Operations Management*, 25, 1075-1082.

Lu, Z. & Bostel, N. (2007). A facility location model for logistics systems including reverse flows: The case of remanufacturing activities. *Computers & Operations Research*, 34, 299-323.

Luo, S. (October 13, 2009). Acer laptops here hit by recall. *The Straits Times*. Accessed through http://www.straitstimes.com/Breaking%2BNews/Singapore/Story/STIStory_441682.html on 04/31/10

Maskell, B. (1989). Performance measures for world class manufacturing. *Management Accounting*, May, 32-33.

Min, H., Hyun, J.K., & Ko, C.S. (2004). A genetic algorithm approach to developing the multi-echelon reverse logistics network for product returns. *The International Journal of Management Science*, 34, 56-69.

Mohan, A. M. (2009). P&G 'future friendly' campaign to educate consumers on green products. *Greener Package*. Accessed through http://www.greenerpackage.com/corporate_strategy/pg_future_friendly_campaign_educate_consumers_green_products on 05/28/10.

Morse, L.C. & Babcock, D.L. (2007). *Managing engineering and technology*. Upper Saddle River, NJ: Pearson Education Inc.

Nahmias, S. (2005). *Production and operations analysis*. New York, NY: McGraw-Hill Irwin.

Neely, A., Mills. J., Platts, K., Richards, H., Gregory, M., Bourne, M., & Kennerley, M. (2000). Performance measurement system design: Developing and testing a process-based approach. *International Journal of Operations & Production Management*, 20, 1119-1145.

Nukala, S. & Gupta, S.M. (Eds.). (2007). Proceedings from Northeast Decision Sciences Institute Conference '07: *Performance Measurement in closed-loop supply chain network*. Baltimore, Maryland.

Pidd, M. (2003). *Tools for thinking: Modelling in management science*. Chichester, England: John Wiley & Sons, Ltd.

ReCellular, ReCellular: The source and solution for used electronics. Accessed through http://www.recellular.com on 4/17/10.

REVLOG co-operation, What is reverse logistics? Accessed through http://www.fbk.eur.nl/OZ/REVLOG/Introduction.htm on 3/27/10.

Salema, M.I.G., Povoa, A.P.B., Novais, A.Q. (2009). A strategic and tactical model for closed-loop supply chains. *OR Spectrum*, 31, 573-599.

Sarkis, J., Helms, M.M., & Hervani, A.A. (2010). Reverse logistics and social sustainability. *Corporate Social Responsibility and Environmental Management*, 17, 122-135.

Schleiffer, R., Wollenweber, J., Sebastian, H., & Golm, F. (Eds.). (2004). Proceedings of the International Conference on System Science '04: Application of genetic algorithms for the design of large-scale reverse logistics networks in Europe's automotive industry. Honolulu, Hawaii.

SF Goodwill. (2008, March 19). Goodwill electronics recycling. Accessed through http://www.youtube.com/watch?v=DwWLscLVR2Q&feature=player_embedded.

Shulman, J. D., A. T. Coughlan, R. C. Savaskan. (2009). Optimal reverse channel structure for consumer product returns. Working paper, Northwestern University, Evanston, IL.

Simchi-Levi, D., Kaminsky, P., & Simchi-Levi, E. (2000). *Designing and managing supply chains: Concepts, strategies, and case studies*. Lexington, MA: McGraw-Hill.

Srivastava, S.K. (2007). Green supply chain management: A state-of-the-art literature review. *International Journal of Management Reviews*, 9, 53-80.

Sullivan, A., & Sheffrin, S.M. (2003). *Economics: Principles in action.* Upper Saddle River, NJ: Pearson Prentice Hall.

Teunter, R.H., Inderfurth, K., Minner, S., & Kleber, R. (2005). Reverse logistics in a pharmaceutical company: The Schering case. In Flapper, S.D.P., van Nunen, J.A.E.E, & Van Wassenhove, L.N. (Eds.), *Managing closed-loop supply chains* (21-32). Berlin, Germany: Springer-Berlin.

van Dalen, J., van Nunen, J., & Wilens, C.M. (2005). The chip in crate: The Heineken case. In Flapper, S.D.P., van Nunen, J.A.E.E, & Van Wassenhove, L.N. (Eds.), *Managing closed-loop supply chains* (43-56). Berlin, Germany: Springer-Berlin.

Vietnam Veterans of America car donation, Donate your car or truck: Car donation proceeds benefit the Vietnam Veterans of America. Accessed through https://www.helpourveterans.org/ on 3/28/10.

Walmartstores Corporate, Logistics. Accessed through http://walmartstores.com/ Sustainability/9071.aspx on 05/25/10.

Winston, W.L. (2004). *Operations research: Applications and algorithms*. Toronto, Canada: Brooks/Cole- Thompson Learning.

Woodyard, C. (2009, March 16). Economic slump drives used car sales, prices up. USA Today. Accessed through http://abcnews.go.com/Business/story?id=7098330&page=1.

Yang, G., Wang, Z., & Li, X. (2009). The optimization of the closed-loop supply chain network. *Transportation Research Part E: Logistics and Transportation Review*, 45, 16-28.