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Designing a reverse logistics operation for short cycle time repair services

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Abstract

An important means for companies to differentiate themselves, as well as increase profitability, in highly competitive environments is through the use of service management, i.e., those activities and interactions which follow a product's sale. One of the most important service management activities is repair services. And the existence, effectiveness, and efficiency of service management activities, such as repair services, depend heavily on effective reverse logistics operations.

Because reverse logistics operations and the supply chains they support are significantly more complex than traditional manufacturing supply chains, an organization that succeeds in meeting the challenges presents a formidable advantage that is not easily duplicated by its competitors. This paper discusses the competitive value of service management activities, particularly repair services, as well as the importance of the supporting role of effective reverse logistics operations for the successful and profitable execution of repair service activities. In addition, the manuscript presents a case study of a major international medical diagnostics manufacturer to illustrate how a reverse logistics operation for a repair service supply chain was designed for both effectiveness and profitability by achieving a rapid cycle time goal for repair service while minimizing total capital and operational costs.

Keywords: Service management; Repair services; Reverse logistics

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1. Introduction

How do companies differentiate themselves when operating in industries where most, if not all firms offer high quality products and customer service at the time of sale? As James Stock put it,

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"After a while, those features just become your admission to the game" (Meyer, 1999, p. 28). A potential solution to this dilemma is offered by Dennis and Kambil (2003), using what they term "service management," which provides both competitive differentiation and an opportunity to increase profits. Service management is "the sum of all customer interactions that follow a product's sale, delivery, and installation … include (ing) customer support; training; warranties, maintenance, and repair; upgrades; product disposal; and sale of complementary goods" (Dennis and Kambil, 2003). The benefits of service management can also be related to the service profit chain framework, which integrates investments in service operations with customer loyalty and firm profitability (Heskett et al., 1994).

One of the most important service management activities is repair services. According to Blumberg (1999), the demand for repair services is robust and increasing, both in the US and worldwide. Furthermore, the existence, effectiveness, and efficiency of service management activities, such as repair services, depend heavily on effective reverse logistics operations.

Because reverse logistics operations and the supply chains they support are significantly more complex than traditional manufacturing supply chains (Dennis and Kambil, 2003), an organization that succeeds in meeting the challenges presents a formidable advantage that is not easily duplicated by its competitors. Effective reverse logistics operations benefit both the organization and its customers. Service management activities, such as repair services, positively impact customers' total cost of ownership (Tibben-Lembke, 1998), thereby increasing customer loyalty. Consequently, the organization benefits because it has the opportunity to realize additional profit streams from after sale services as well as repeat purchases from loyal customers.

In the next section, we discuss the issues surrounding the value of after sales service, i.e., service management, particularly repair services. We also discuss the importance of the supporting role of effective reverse logistics operations to the successful and profitable execution of repair service activities.

In the last section, we show how a reverse logistics operation for a repair service supply chain (RSSC) can be designed for both effectiveness and profitability by achieving a rapid cycle time goal for repair service while minimizing total capital and operational costs. To illustrate this method, we utilize a case study of a major international medical diagnostics manufacturer with a repair cycle time goal of just 6 hours. The RSSC design process includes analysis of the following questions:

- Where to stock parts inventory.
- How much parts inventory to carry.
- Where to locate service crew domiciles.

In the final section, we offer conclusions for the case study presented, as well as managerial implications of designing service-to-profit supply chains for effective, short cycle time repair services supported by competent reverse logistics operations.

2. Background

2.1. After sale services

For many products, a customer's relationship with the product's manufacturer does not end with product purchase. In fact, this relationship can be significantly influenced by the activities that occur after purchase, during the entire period of product ownership. After sales services can encompass multiple activities, including: customer support through training; product warranties; maintenance and repair; product upgrades; sales of complementary products; and product disposal. Management of these service activities can form an important part of corporate strategy. For instance, when customers perceive that an organization supports its products, the products may be able to command premium prices (Cohen and Lee, 1990). In addition, after sale services represent important opportunities to create and strengthen customer loyalty. After sale support services can also be the source of significant revenue potential, accounting for as much as 25% of revenues and 40%–50% of profits for manufacturers (Dennis and Kambil, 2003).

Examples of companies offering significant after sale services include Caterpillar, which has a global network that supports guaranteed parts delivery; and Dell Computer, which supports its commanding market share in the PC market by providing customers with rapid repair services (Cohen and Whang, 1997). Similarly, Saturn enjoys such a superior reputation for after sales service that its customers tend to return to their Saturn dealerships for service and repairs more frequently than do customers of other car manufacturers. This sort of customer behavior increases revenue generating opportunities for Saturn dealerships, as well as creating the potential for repeat auto sales revenues (Cohen et al., 2000).

An important driver of enhanced customer loyalty engendered by after sale services is the concept of total cost of ownership (TCO). TCO encompasses "all costs associated with the acquisition, use, and maintenance (Ellram and Siferd, 1993, p. 164) of a product. This simply means that when contemplating a product purchase, a customer considers costs that occur prior to a product's acquisition, during the actual transaction associated with product purchase, and during product use. Ellram terms these cost categories: pre-transaction components, transaction components, and post-transaction components, respectively. The category of most interest to this discussion is, of course, the post-transaction category. Post-transaction costs include: line fallout, defective products rejected before sale, field failures, repair/replacement in field, reputation of purchasing firm, costs of repair parts, and costs of maintenance and repairs. For a manufacturing customer, the drivers of these post-transaction costs include such elements as labor downtime and finished goods inventory backup or shortages (Ellram, 1993). Naturally, any assurance that can be provided regarding costs and cycle time for after sale service, such as repairs, will reduce a customer's perception of TCO for a potential purchase. And, a solid record of after sale service can enhance customer loyalty and increase the probability of repeat purchases.

As the discussion above on TCO illustrates, maintenance and repair services are one component of after sale service activities. Evidence of the significance of after sale repair activities is provided by Blumberg (1999), who, based on surveys and interviews of logistics and purchasing executives in more than 400 medium and large manufacturing companies, estimates the compounded annual growth rate for repair services in the United States to be 14.9%, and the compounded annual growth rate for repair services worldwide to be 15.8%. Of particular interest to this discussion is the fact that Blumberg's analysis of the worldwide repair services market by product type indicated that the segment with the highest annual growth rate in demand for repair services was medical electronics/diagnostics, at 23.2%.

One of the most important issues discussed in Blumberg's article is that many firms turn a potential opportunity to enhance their competitive positioning into a problem by failing to offer their customers efficient and effective repair service solutions. However, in order to effectively accomplish after sales services activities, such as repair services, firms must be aware of the significant role that the design of a competent reverse logistics operation plays.

2.2. *Reverse logistics operations*

One of the more interesting and significant trends in supply chain management is the recognition of the strategic importance of reverse logistics operations (Handfield and Nichols, 1999). These reverse logistics operations support a variety of activities ranging from what is termed "green logistics," i.e., "efforts to reduce the environmental impact of the supply chain (Rogers and Tibben-Lembke, 2001, p. 130)," to activities that encompass product returns, repairs, and refurbishment. Estimates of the costs of reverse logistics operations range from \$37–\$921 billion annually. Despite this, four in 10 logistics managers consider reverse logistics operations to be a very low priority for their companies. Obviously, the type and extent of reverse logistics activities vary according to industry, but the extent of these activities are already significant in many industries and they continue to grow (Rogers and Tibben-Lembke, 2001).

Although recognition of the strategic importance of reverse logistics operations is not by any means universal, but there is some evidence that this is changing. According to Meyer (1999), the

> … new frontier of management is *reverse logistics* … after companies have downsized, reengineered, TQMed, racheted up customer service, and wrung out every conceivable cost efficiency, it may well be one of the last business frontiers business can conquer (p. 27)

Reverse logistics operations can be quite complex to manage, since the activities involved tend to be so varied. In addition, demand can be difficult to predict, making product and information flows quite challenging to manage. Complicating the problem of managing reverse logistics operations is the fact that very few, if any, standardized software solutions designed for reverse logistics operations exist (Rogers and Tibben-Lembke, 2001; Meyer, 1999).

Although reverse logistics operations in general can be quite difficult to manage, there are some particular challenges to managing reverse logistics operations for repair services. According to Blumberg (1999) and Dennis and Kambil (2003), these challenges include the following:

1. uncertain and inconsistent demand (for repair parts), which can result in low inventory turns;
2. extensive repair parts inventories, requiring what seems to be an explosive number of SKUs;
3. customer specific repair processing requirements (depending on the nature of a customer's operations);
4. short cycle times (necessity for rapid processing of repairs);
5. the need for coordination (e.g., among multiple parties involved in repair services);
6. flexible capacity requirements for storage, processing and transportation activities.

Logistics activities needed to support repair service activities can include, but are not limited to: storage and warehousing; collection and sorting; substitution; transportation and distribution; disposal; repair and remanufacturing; and recertification.

However, although effectively managing these multiple and complex reverse logistics operations to support what Dennis and Kambil (2003, p. 42) term "service to profit supply chains," requires considerable skill and integration, both Blumberg and Dennis and Kambil stress the potential advantageous competitive positioning and market opportunities for firms that handle these important after sale services effectively. Dennis and Kambil point out the value of using reverse logistics activities to develop "service-centric" supply chains to adequately support delivery of after sale services. Such supply chains are vital tools as companies seek to differentiate themselves from their competitors, increase customer loyalty, and boost profit margins. Blumberg's research demonstrates that customers demanding effective repair services currently see significant inefficiencies in reverse logistics repair operations. Given the significant and growing demand for these services, firms that can effectively implement and manage the necessary reverse logistics operations to meet these needs will significantly enhance their competitive position.

With this background discussion of the strategic role of after sales services, particularly repair services; and the role of reverse logistics operations in supporting service to profit supply chain operations, we present a case study of a reverse logistics and repair design for a medical diagnostic equipment manufacturer.

3. A case study of reverse logistics and repair service design

The case studied here involves a major international manufacturer of medical diagnostic systems. This manufacturer will be referred to in our discussion as the medical diagnostic manufacturer (MDM). The manufacturer's customers include medical diagnostic laboratories of all types, such as those in hospitals, research centers, and medical clinics. Thousands of laboratories around the world utilize these diagnostic systems.

The MDM was preparing to market a recently developed innovative medical diagnostic apparatus that consolidates the operation of many different pieces of diagnostic laboratory equipment. This reduces the cycle time of medical diagnostic tests and increases the efficiency of the laboratory. This product, which we will refer to as the "Alpha", is an integrated system of hardware, software, and reagents, which offers economic viability through task consolidation. In other words, it does the work of many pieces of laboratory equipment, reduces the cycle time of diagnostic laboratory tests, and reduces the labor required from laboratory personnel. The majority of laboratory workload can be streamlined on this single multi-tasking system. Diagnostic results are available more quickly while simultaneously reducing laboratory staffing.

As a result of its multitasking capabilities, the operation of the Alpha becomes critical to the operation of the laboratory for customers who adopt this innovation in place of traditional equipment. This is a significant change. Traditionally, medical diagnostic laboratories have utilized many different pieces of equipment, so that any one piece of equipment being out of service was generally not an emergency; traditionally, there have been other pieces of equipment that could be used in case of equipment failures. The Alpha changed this by replacing multiple pieces of equipment. Therefore, when the Alpha is out of service, in essence, the laboratory is out of service. This creates an emergency situation, because, when laboratory results are delayed, medical treatment can be delayed. Surgeries and other vital treatments may have to be postponed, impairing the quality of care to patients.

The Alpha was designed to minimize unscheduled downtime as much as possible. Regular preventative maintenance is used to minimize the amount of unscheduled down time, and remote diagnostics capabilities allow many service requests to be handled without an on-site visit. In the event of a product failure, for customers within the continental US (except those in remote areas) the goal is to respond within 6 hours or less. This 6-hour response time, referred to in our discussion as the repair service cycle time or the repair cycle time is defined as the time from when the field service crew is dispatched until the needed part(s) and the service crew arrives at the customer location. Thus, supporting Alphas in need of repair services involves two separate problems: (1) repair parts must arrive within 6 hours, and (2) service crews must be able to travel to customer locations and arrive within 6 hours.

Each Alpha product failure requires design, analysis, and operation of reverse logistics and supply chain operations to ensure that the repair service cycle time of 6 hours is achieved with minimum total integrated costs. Based on the two problems identified in the paragraph above, the two required supply chain operations will be referred to as *repair part supply chain (RPSC)* and *service crews supply chain (SCSC)*. The integrative design, operational coordination, and optimization of these two supply chains are required to achieve the most effective and efficient repair services to Alpha's customers.

The demanding repair cycle time goal of 6 hours creates unique challenges for design of the RPSC and SCSC. If 24 hours were available, a single location for repair parts would suffice by utilizing express overnight airfreight. Similarly a single location would suffice for service personnel who could fly to the customer location. The much shorter 6-hour goal necessitates supply chain networks with multiple geographically dispersed locations for service parts and crews.

The two supply chains, RPSC and SCSC, must be managed in an integrative fashion to meet the target repair service cycle time. However, the design factors for the RPSC (managing the flow of repair parts) and SCSC (managing the service crews), must be considered independent of each other.

1. The RPSC must be designed to minimize the total cost of inventory and logistics while achieving the cycle time goal. The RPSC design process should allow a determination of: (a) how many service parts inventory locations are required; (b) where these should be geographically located; and (c) what amount of inventory should be stocked at each location.
2. The SCSC design should provide repair service coverage within the targeted 6-hour cycle time with minimum total capital and operational costs. The SCSC design should address the

following issues: (a) how many repair crew domiciles are required; (b) where these domiciles should be geographically located; (c) which customers should be assigned to each crew domicile location.

The RPSC and SCSC design processes are presented in the next two sections, respectively. Further design details may be found in Retzlaff-Roberts and Amini (1998) and Amini and Retzlaff-Roberts (1999).

3.1. RPSC design process

The current MDM supply chain is shown in Fig. 1. The solid arrows in Fig. 1 indicate parts moving from one inventory location to another inventory location. Dashed arrows indicate parts moving out of inventory and being installed in a non-operational Alpha for an urgent repair. The main distribution center (MDC) is in Europe and the primary US distribution center, which will be referred to as the USDC, is centrally located within the continental US. The next level of inventory location consists of what are termed "platforms". The intended purpose of the inventory platforms is to have as few locations as possible and utilize "next flight out" (NFO) shipping to get parts to customers as quickly as possible. This refers to literally putting a package on the next flight out to the intended destination, making it essential that platforms be located near busy airports with good flight availability.

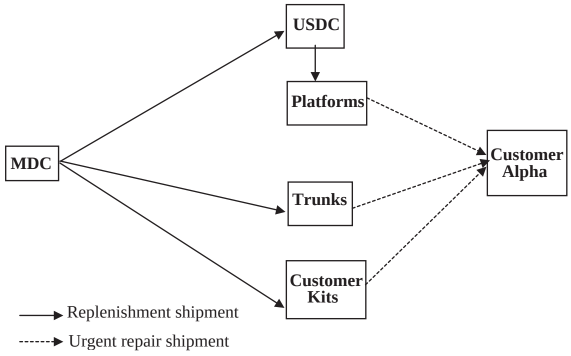

Fig. 1. Supply chain for repair parts.

The USDC itself also acts as an inventory platform and serves the central portion of the US. In fact, by utilizing NFO shipping, it was determined that this central location is capable of covering most of the continental US. Therefore, only two additional platforms were needed, with one being in the Northeast and the other on the West Coast. This means there are a total of three platforms with one being the USDC.

Since the Alpha is repaired only by company trained and employed technicians who travel by car to the customer site, a third level of inventory location is the technicians' car trunk. The final inventory location is actually at the customer location. This inventory location is referred to as the "customer kit." The inventory policy for all locations is that a designated stock-up-to level will be determined for each part, and a replacement will be ordered as soon as possible after the part is used. Reorders are placed at regular intervals, such as every 2 days or once a week. All inventory locations other than the two platforms (Northeast and West Coast) are replenished directly from the MDC as shown in Fig. 1.

While the first RSSC decision focused on the *number* of inventory locations throughout the chain, discussed above, the next decision is to determine which parts should be inventoried at each location and in what quantity. There are hundreds of different parts involved, with some parts costing less than $1 per unit and others costing more than $15,000 per unit. As a result of this wide range in unit value, a "one size fits all" inventory strategy is not appropriate. A plan that utilizes a mixture of all three alternatives (platforms, trunk inventory, and customer kit) is needed. And the inventory decision needs to be mass customized for each part based on the part's cost, reliability, and other factors.

For example, if there are 100 technicians, then at least 100 of a given part are required if they are kept in the technicians' trunk inventories. However, if these parts were kept instead at the inventory platforms (USDC, Northeast, West Coast), a total inventory level of 10 among the three platforms may suffice, based on the part's reliability. Clearly high-cost, high-reliability parts belong at the platforms because the savings in inventory cost will more than offset the NFO shipping cost. Inexpensive parts belong in the customer kit inventory or trunk inventory. The question is: where are the break points for moving from one inventory location to the next?

To make the best decision, development of a model for doing "what-if" cost calculations is necessary. This means being able to quantify the total inventory and logistics costs for any given part for each inventory location, thus allowing a decision maker to answer questions such as: What if we kept part *xyz* at the platforms? How much inventory would we need? What are the costs involved?

In considering the total inventory and logistics costs of the RPSC there are actually two types of cost involved: (1) the *annual* logistics cost, and (2) a *one-time* inventory setup expense. These two costs cannot be combined because one is an ongoing annual expense and the other is a one-time expense.

The total annual logistics cost includes five cost categories (Lambert and Stock, 1993):

1. transportation costs,
2. warehousing costs,
3. order processing costs,
4. lot quantity costs, and
5. inventory carrying costs.

Inventory setup cost is the one-time cost of initially placing the appropriate amount of inventory. "The appropriate amount" refers to having a sufficient amount to achieve the desired service level. Again, this cost is important to measure because of the potentially large differences among inventory alternatives.

3.2. Decision support model

A decision support model was developed to allow "what-if" total cost calculations for parts for the inventory locations. Fig. 2 shows a flowchart which illustrates the relations among data values, decision, and dependent variables to show how they interact to product the total logistics and inventory costs. Data requirements are shown as rectangles in Fig. 2, while decisions are shown as diamonds and dependent variables are shown as ovals. The data, or input parameters include:

1. a part's reliability (average time until failure),
2. the number of Alphas being supported out of the inventory location,
3. the lead time distribution for replenishing inventory,

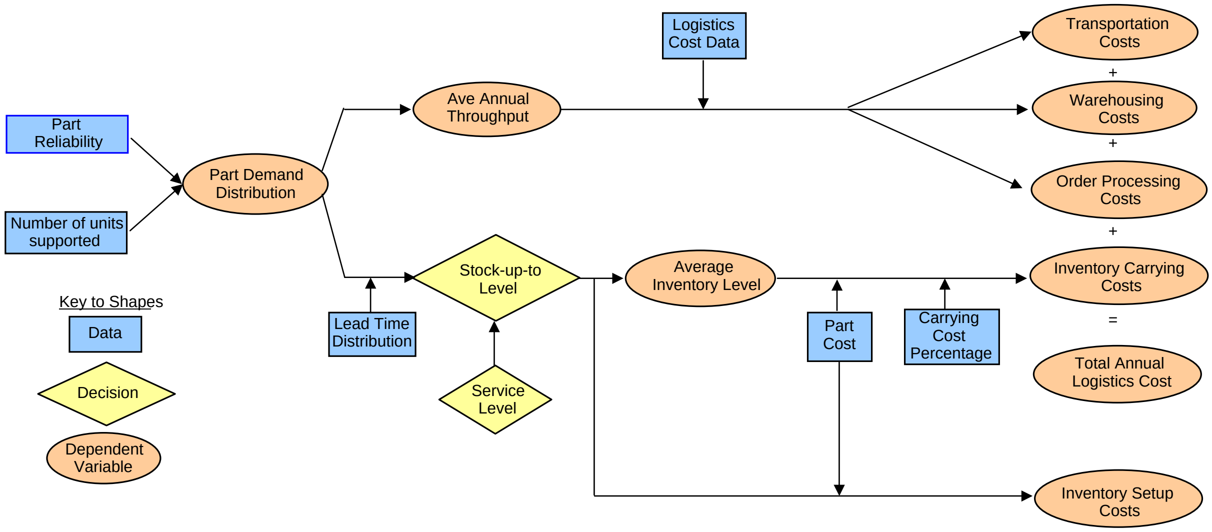

Fig. 2. Inventory and logistics cost calculation flow chart (for a given part and inventory location).

4. the logistics cost data for both distributing and replenishing the part,
5. a part's cost, and
6. the inventory carrying cost data.

When considering a particular part for a particular inventory location we begin at the left end of Fig. 2 with the part's expected reliability along with the number of units supported out of the particular inventory location. These two combine to produce the part demand distribution, which in turn yields the average annual throughput. For example, if a part fails on average every 6 months and there are 100 Alphas supported from that inventory location, then the average annual throughput is 200 per year. However, parts fail randomly. In one instance the part may last 1 week and in another the same part may last 2 years. When a part fails, a part demand "arrives" at the inventory location. It is assumed that the random time between consecutive part demands can be modeled with the exponential distribution.

The probability of a stock-out occurring depends on the part demand distribution, the lead time distribution, and the chosen stock-up-to level. The lead time here is defined as the time from when a part is used until it has been replenished, so the period between orders as well as the shipping time must be considered. For example, if reorders are placed once a week and take 2–3 days to arrive, the lead time would range from as little as 2 days to as long as 10 days depending on when in the order cycle the part was used. In Fig. 2 the lead time distribution is shown as data because the replenishment policy decisions had been previously made by management in this study. However, in applying Fig. 2 in a more generic sense, the lead time distribution could be shown as a decision, since management can choose their replenishment policy. This includes the inventory policy for how and when a reorder is triggered and the speed with which the replenishment arrives.

Before the appropriate stock-up-to level can be chosen, management must first choose the desired service level. The higher the service level the lower the probability of a stock-out. Certainly no organization wants to experience stock-outs, but similarly no organization wants to maintain an excessive level of inventory. For some organizations a stock-out probability of 5% or larger may be acceptable. For others, 1% or even smaller may be the desired goal if there are severe consequences for a stock-out. In this study the goal was to achieve a very high level of service so a very low stock-out probability was used. Here the service level goal is chosen prior to calculating the cost. When the service level goal is chosen prior to calculating the cost, in effect, management is choosing a service level goal *regardless of cost*. An alternative approach would be to skip the step of choosing the service level a priori, and instead incorporate stock-out costs in the total cost calculation. In this approach the service level would become a dependent variable.

An organization is at risk of a stock-out from the time the last unit has been used until the replenishment has arrived. Since the arrival of part demands is random and the lead time is random, determining the appropriate stock-up-to level is not simply a calculation where parameters are entered into a formula. Instead, the probability distributions are used to conduct a what-if analysis for a given stock-up-to level and the resulting probability of experiencing a stock-out is determined. A computer simulation can be used to show random fluctuation of the inventory level over time as part demands and replenishments arrive randomly. If the probability of a stock-out is unacceptably high, then the stock-up-to level is increased and the analysis is repeated until the probability is sufficiently small to achieve the goal.

After the stock-up-to level is chosen the average inventory level can be determined. This along with the part cost and inventory carrying cost percentage determine the inventory carry cost. The stock-up-to level also determines the initial inventory setup cost.

By conducting this type of what-if analysis, the total cost for each potential inventory location (platforms, trunk inventory, and customer kits) is calculated. In this way managers can identify whether the minimum cost alternative is customer kits, trunk inventory, or platform inventory and how much inventory to stock at the chosen location.

Table 1
Costs of example scenarios

		Part cost					
		$500			$1000		
Part reliability	6 months		Platforms	Trunks		Platforms	Trunks
		Setup cost	$4,045	$32,363	Setup cost	$8,089	$64,726
		Annual cost	$32,964	$13,473	Annual cost	$33,773	$19,945
	12 months		Platforms	Trunks		Platforms	Trunks
		Setup cost	$3,272	$33,682	Setup cost	$6,545	$67,363
		Annual cost	$16,732	$10,236	Annual cost	$17,386	$16,973

3.3. Example scenario

Table 1 illustrates the use of this tool in the decision making process. For the four scenarios shown in Table 1, values for parameters 2 through 4 and 6 are identical. Only part cost and reliability vary. For each of the four scenarios shown, which represent four different parts, the inventory setup cost (referred to as setup cost) and the expected annual logistics cost (referred as the annual cost) have been determined for the platforms and the trunks. Notice that the term "expected" is applied only to the annual logistics cost. This is because the inventory setup cost is fairly deterministic after the stock-up-to level is chosen. Whereas the annual logistics cost will vary from year to year based on the random failure of parts.

The lower right portion of Table 1 indicates the costs for a $1000 part with an average reliability of 12 months. The setup cost for the platforms is $60,818 lower than for trunk inventory because considerably less inventory is necessary. The expected annual costs are very similar with the platforms' annual cost being only $413 higher. This makes a clear case for choosing the platforms because there is a substantial savings in the setup cost which easily offsets the slightly higher annual cost. The break-even point, without considering the time value of money, would be 147.3 years

The contrast to this is in the upper left portion of Table 1 for a $500 part with a 6-month average reliability. The platforms' setup cost is $28,318 lower and the average annual cost is $19,491 higher. The break-even point is only 1.45 years. Here it seems worthwhile to place this part in the trunk inventory and incur the extra $28,318 in setup cost, in order to have annual costs that are on average $19,491 lower.

Being able to quickly and easily perform these what-if calculations will help managers determine which inventory locations are best as well as provide a prediction of costs for budgetary purposes. In this way, the supply chain can be optimized to minimize cost while achieving the 6-hour repair service goal.

3.4. SCSC design process

Achieving a 6-hour service cycle time goal in addition to design of an effective part supply chain simultaneously required design of a SCSC such that availability of both appropriate parts and crews at the right location and in a timely fashion are ensured. The service crew supply chain can be viewed as a network of geographically dispersed crew domiciles where each is capable of providing repair services for a subset of Alpha customers within a 6-hour repair service cycle time. The network should allow coverage of all existing Alpha locations. The design decisions are to determine (a) how many maintenance crew domiciles are needed within the SCSC; (b) where to locate these domiciles geographically to allow the targeted repair service cycle time; and (c) which customers should be covered by each service crew domicile.

Theory and methods for design of an effective SCSC are presented within the area of *facility location*. Facility location theory is concerned with design of network of facilities/sites such that a certain set of qualitative and/or quantitative criteria are met. Business applications encompass location of warehouses, plants, emergency centers, retail outlets, service facilities and/or personnel, hospitals, fire stations, and police stations. A basic review of service management along with methods applied in service facility location can be found in Fitzsimmons and Fitzsimmons (1998). Contributions of operations research/management science fields to location analysis are reported in Chajed et al. (1993). The most current survey of facility location application and methods is presented in Drezner (1995).

The multiple factors that affect the decisions related to a SCSC design are: geographic location, number of locations, and optimization criteria. To represent the geographic location, we used interstate highway networks throughout the US to determine domicile location options and travel distance. We considered potential locations to be the current SCSC for maintenance of the current lines of products, as well as all metropolitan statistical areas (MSAs) and consolidated metropolitan statistical areas (CMSAs) with populations of more than 600,000 (Famighetti, 1997). The optimization criterion applied in this study seeks to minimize the total number of domiciles in the SCSC such that coverage of the current and projected future Alpha installations throughout the US continent within the 6-hour repair service cycle time goal is attained.

The high degree of complexity presented in the design process of an effective SCSC is due to the fact that the aforementioned host of factors must be considered simultaneously. Finding the best alternative design from a significant number of potential alternatives calls for a systematic approach that would allow formulation of various mathematical models, each representing a certain strategic SCSC design scenario meanwhile depicting the performance criteria and various involved factors and constraints in a simultaneous fashion.

3.5. The SCSC mathematical modeling process

An effective SCSC should provide coverage for all Alpha installations. The repair service cycle time goal of 6 hours determines the maximum distance a domicile can be located from a customer. In addition, the maximum distance depends upon the crews' mode of transportation. Using air transportation, it might be possible to have a single domicile centrally located in the US, having service crews and private jets on standby at all times. However, this is not considered an economically viable approach. The existing practice at the MDM calls for service crews to travel by car. This requires a decentralized approach, with service crews spread throughout the US. Technicians have already been placed in various geographic locations within the US to service other MDM products. However, these locations had been chosen in the past for a variety of reasons that may have little or nothing to do with the Alpha's repair service cycle time goal of 6 hours.

The main objectives of the modeling exercise are to determine whether: (a) the current SCSC with crews at their existing geographic locations are able to provide 6-hour repair service coverage for current and future Alpha installations; (b) additional domiciles and crews are required to provide adequate maintenance coverage for current and future Alpha installations; and (c) geographic relocation of domiciles and crews, and redesign of the current SCSC, are required to achieve the predetermined customer repair service cycle time goal of 6 hours.

A variety of modeling efforts have been reported in the literature focusing on facility location in public and private sectors. For example, in the public sector location, decisions include regional health services planning (Abernathy and Hershey, 1972) emergency ambulance deployment (Fitzsimmons, 1973), urban population service facilities (Brown et al., 1974), airport facilities (Min, 1995) blood banks (Price and Turcotte, 1986), and emissions testing stations (Swersey and Thakur, 1995). Examples in the private sector include location decisions related to retail stores (Craig et al., 1984), warehouse locations (Beasley, 1988), company sales regions (Gelb and Khumawala, 1984), hotel sites (Kimes and Fitzsimmons, 1990), and global manufacturing location strategies (Verter and Dincer, 1992).

The present modeling effort began with preparation of two geographic maps. The first depicted the current SCSC in terms of crew domiciles and Alpha installations. The second map showed the current SCSC with existing service crew locations, as well as the current and 5-year projected forecast of potential Alpha installations. In addition, to allow consideration of further SCSC design alternatives, the set of all MSAs and CMSAs with populations over 600,000 were identified as potential crew domiciles. Hence, four alternative optimization models each depicting a SCSC design space were considered. These models can be verbally stated as follows:

Current model: Determine a SCSC design with a minimum number of service domiciles such that 6-hour repair service coverage can be provided for all current Alpha installations.

Model 1.1.: Consider only the current crew domiciles.

Model 1.2.: Consider only MSAs and CMSAs.

Future model: Determine a SCSC design with a minimum number of service domiciles such that 6-hour repair service coverage can be provided for all current and projected future Alpha installations.

Model 2.1.: Consider only the current crew domiciles.

Model 2.2.: Consider only MSAs and CMSAs.

Each of these four scenarios involved developing and solving an optimization model. The objective function of each model was to minimize the total number of required crew domiciles to deliver the 6-hour repair service cycle time. The constraints ensured that each of the current and/or projected future Alpha installations would receive 6-hour repair service coverage from at least one crew domicile within the SCSC.

3.6. The SCSC model recommendations

The final models were developed using *binary integer programming,* where each binary decision variable indicates whether a given service crew domicile is capable of providing repair service coverage to a given Alpha installation within the 6-hour time window. Each model is solved by *LINDO* mathematical programming software (Schrage, 1991). While the first two models provided design characteristics for a new SCSC to serve the current customers, the last two models capture a long-term view of the SCSC by including the current and potential future installations. To highlight the effectiveness of modeling exercises in the design of an effective SCSC, we present major conclusions and recommendations offered by models 1.1 and 2.2 (see Appendix A).

Model 1.1.: This model considers the current SCSC with the existing service crew domiciles and the current Alpha installations. The main purpose of this model is to determine the minimum number of current domiciles that can provide the desired 6-hour repair service cycle time to all current installations. With regard to the current crew domiciles and Alpha installations, the first model reveals the following: (a) the current SCSC is not capable of providing 6-hour repair service coverage to 17% of the current installations; (b) the geographic locations of 62% of current crews would not allow 6-hour service coverage; (c) 23% of current Alpha installations could have alternative service coverage from more than one crew domicile.

The first model has identified the ineffectiveness of the current SCSC in providing the desired repair service cycle time to the current customers. The results suggest that redesign of the current SCSC by relocation of the current domiciles is necessary to provide the desired repair service cycle time for all current installations. The relocation decision should be made in concert with a homogeneous coverage load for the current domiciles. Also, such a decision must consider alternative service coverage to minimize the chance of a longer service time window when multiple installations covered by a single domicile require maintenance simultaneously.

Model 2.2.: This model ignores the current crew domiciles and considers 68 metropolitan areas (MSAs and CMSAs) with populations of 600,000 or more within the US continent as potential crew domiciles. Also, it focuses on the current and 5-year projected Alpha installations. To allow complete development of Model 2.2, the projected future installations were estimated on a regional basis. The main objective of this model was to select a minimum number of metropolitan areas to provide the desired 6-hour repair service cycle time for current and projected Alpha installations.

Model 2.2. provides the following conclusions:

(a) 68% of the current crew are not capable of providing the desired 6-hour repair service cycle time,
(b) in the current SCSC, alternative service coverage from more than one domicile is available to 17% of the Alpha installations,

Based on these conclusions, Model 2.2 makes the following recommendations:

(a) for current and projected future installations of Alphas, only 20 out of 68 metropolitan areas should be included in a newly designed SCSC. The selected 20 service crew domiciles have a heterogeneous coverage load. That is, some cover only one customer while others provide coverage to many installations,
(b) the newly designed SCSC would be capable of covering 98% of current and projected future Alpha installations. The remaining 2% of installations are located in remote areas with greater than 6-hour distances from metropolitan areas.

These recommendations provide a newly designed SCSC that improves customer service quality by 9% (reducing service coverage inefficiencies form 17% to 8%). It is obvious that without implementation of the new SCSC, the inefficiencies of the existing SCSC will be extended into the future and additional Alpha installations take place.

However, realizing that implementation of the new SCSC would certainly interrupt current maintenance operations and would also be quite costly, it is recommended that a relocation plan be considered. In such a plan, relocation of 68% of the presently under-utilized service crew domiciles must be addressed. Also if necessary, additional non-metropolitan domiciles could be considered for providing service coverage as the number of Alpha customers continues to grow.

An additional recommendation involves strategies to enable the MDM to manage customer expectations for repair services. The first such strategy involves managing service promises, both within the MDM organization and also between the MDM and its customers. It is essential that the marketing and maintenance operations of MDM clearly communicate issues and concerns related to repair service cycle time goals and coordinate their efforts. Promising what the organization cannot realistically deliver damages customer perceptions of the organization. Furthermore, when the inevitable scheduling problems or parts delivery problems arise, customers must be kept informed (Zeithaml and Bitner, 2003). Research on service failures and recovery strategies clearly indicates that one of the most important drivers of customer satisfaction is what is termed "interactive fairness." Even when service failures occur, communicating with customers throughout the process and keeping them informed has significant positive effects on customer perceptions of service quality (Tax et al., 1998).

Negotiating with customers who have unrealistic expectations for repair services is also an important tool for managing customers' repair service expectations. For example, a negotiation process with Alpha customers in remote locations might be initiated to study the possibilities of a different repair service cycle time goal.

Yet another strategy for managing customer service expectations involves resetting customer expectations by, for example, offering several levels of repair service cycle times, at different prices. Another important aspect of resetting customers' repair service expectations involves educating customers to the realities and complexities of the two repair service supply chains. Research has shown that helping customers understand and appreciate the processes involved in service delivery can have positive effects on their satisfaction (Zeithaml and Bitner, 1996). Effectively managing customers repair service expectations on a consistent basis is and will continue to be an important issue as the number of Alpha installations increases and the product moves through its life cycle.

4. Conclusions and managerial implications

The preceding case study demonstrated how an effective and profitable reverse logistics operation for a RSSC was designed for a MDM whose customers' operations demanded a short cycle time repair service. The MDM in this case study found that repair cycle times significantly longer than 6 hours created unacceptably low customer satisfaction, while repair cycle times significantly shorter than 6 hours moved out of the realm of feasibility.

Given the cycle time goal, the supply chain must be designed to support that goal in a reliable and efficient manner. For this reason, the probabilistic nature of events must be accounted for. These include the random manner in which product failures "arrive" with the time of day, day of the week, and geographical repair locations that vary randomly. In addition, once a part has been used from inventory, the lead-time of replenishing that part is often random. The interaction of possible random events must be considered when making inventory strategy decisions such as reorder frequency and stocking levels. Computer simulation is one way to test the performance of a candidate supply chain. Problems can be identified and corrected while in the design phase. For the MDM in this case study, a decision support system was created that accounted for the various probabilistic behaviors in this system to assist managers in identifying minimal stocking levels for achieving the desired service level.

The reverse logistics operations and supply chains (Repair Part Supply Chain and Service Crews Supply Chain) required for the medical diagnostic manufacturer's short cycle time repair services were complex to design and manage. However, precisely because of their complexity, they represent a formidable advantage for the medical diagnostic manufacturer with respect to its competitors. The repair service supply chain designed for the medical diagnostic manufacturer will positively impact its customers' total cost of ownership, thus increasing customer loyalty. The repair service supply chain also gives the medical diagnostic manufacturer an opportunity to realize additional profit streams from the short cycle time repair services, as well as the potential for repeat purchases from satisfied customers who have benefited from the short cycle repair services for their existing equipment.

Although the focus of the case study in this paper involved a relatively innovative product, the Alpha, the methodology presented throughout the paper is also applicable for products that are less innovative. Short cycle time repair strategy for innovative products, such as the Alpha, speeds the rate of adoption, as well as increasing customer loyalty. Similar strategies for products that are in later stages of their life cycles also increase customer loyalty, thus granting an organization the opportunity to develop a sustainable competitive advantage.

Appendix A. General binary linear programming model for service crew domicile determination

Let be the m be the number of alpha installations, n the number of potential service crew domiciles, x_{ij} the binary decision variable, where $x_{ij} = 1$, if Alpha installation i is assigned to service crew domicile j, and $x_{ij} = 0$, otherwise.

The modeling process starts with determining the Alpha installations within a 6-hour travel distance from each potential service crew domicile. The model allows consideration of alternative service coverage by multiple potential service crew domiciles, when the 6-hour time window permits, to enhance the repair supply chain reliability at the design phase.

The objective function seeks a minimum number of service crew domiciles. The set of constraints ensure that each Alpha installation receives a 6-hour service coverage from *at least* one service crew domicile.

The repair supply chain design model may be stated as a binary linear programming model:

$$\text{Minimize} \sum_{i=1}^{m} \sum_{j=1}^{n} x_{ij}$$

subject to:

$$\sum_{j=1}^{n} x_{ij} \geqslant 1, \text{ for each } i = 1, \ldots, m,$$

$$x_{ij} = \{0, 1\}, \text{ for } i = 1, \ldots, m \text{ and } j = 1, \ldots, n.$$

Note that, if the linear relationship for the constraint set is changed from greater-than-or-equal to equal, then the model allows only one service crew domicile being assigned to each alpha installation. This minor change reduces the reliability of the service supply chain by eliminating the possibility of multiple domiciles coverage that could be taken advantage of in the post-hoc analysis, conducted frequently by the company, where adjusting the number of service crews at each domicile is being considered.

References

Abernathy, W.J., Hershey, J.C., 1972. A spatial-allocation model for regional health-services planning. Operations Research 20, 629–642.

Amini, M.M., Retzlaff-Roberts, D., 1999. Multifacility location decisions for meeting customer service commitments. Cycle Time Research 5, 13–20.

Beasley, J.E., 1988. An algorithm for solving large capacitated warehouse location problems. European Journal of Operational Research 33, 314–325.

Blumberg, D.F., 1999. Strategic examination of reverse logistics & repair service requirements, needs, market size, and opportunities. Journal of Business Logistics 20 (2), 141–159.

Brown, L.A., Williams, F.B., Youngmann, C.E., Holmes, J., Walby, K., 1974. The location of urban population service facilities: A strategy and its applications. Social Science Quarterly 54, 784–799.

Chajed, D., Francis, R.L., Lowe, T.J., 1993. Contributions of operations research to location analysis. Location Sciences 1, 263–287.

Cohen, M.A., Lee, H.L., 1990. Out of touch with customer needs? Spare parts and after sales service. Sloan Management Review (Winter), 55–66.

Cohen, M.A., Whang, S., 1997. Competing in product and service: A product life-cycle model. Management Science 43 (4), 535–537.

Cohen, M. A., Cull, C., Lee, H.L., Willen, D., 2000. Saturn's supply chain innovation: High value in after-sales service. Sloan Management Review (Summer), 93–101.

Craig, C.S., Gosh, A., McLafferty, S., 1984. Models of retail location process: A review. Journal of Retailing 60, 5–36.

Dennis, M.J., Kambil, A., 2003. Service management: Building profits after the sale. Supply Chain Management Review (January/February), 42–48.

Drezner, Z., 1995. Facility Location: A Survey of Application and Methods. Springler-Verlag, New York.

Ellram, L.M., 1993. Total cost of ownership: Elements and implementation. International Journal of Purchasing and Materials Management (Fall), 3–11.

Ellram, L.M., Siferd, S.P., 1993. Purchasing: The cornerstone of the total cost of ownership concept. Journal of Business Logistics 14 (1), 163–184.

Famighetti, R. (Ed.), 1997. The World Almanac and Book of Facts, World Almanac Books, Mahwah, NJ.

Fitzsimmons, J.A., 1973. A methodology for emergency ambulance deployment. Management Science 19, 627–636.

Fitzsimmons, J.A., Fitzsimmons, M.J., 1998. Service Management: Operations, Strategy, and Information Technology. McGraw-Hill, New York.

Gelb, B.D., Khumawala, B.M., 1984. Reconfiguration of an insurance company's sales regions. Interfaces 14, 87–94.

Handfield, R.B., Nichols, E.L., 1999. Introduction to supply chain management. Prentice-Hall, Upper Saddle River, NJ.

Heskett, J.L., Jones, T.O., Loveman, G.W., Sasser Jr., E.W., 1994. Putting the service-profit chain to work. Harvard Business Review 72 (2), 164–174.

Kimes, S.E., Fitzsimmons, J.A., 1990. Selecting profitable hotel sites at La Quinta motor inns. Interfaces 20, 12–20.

Lambert, D.M., Stock, J.R., 1993. Strategic Logistics Management, Third ed. Irwin, Boston.

Meyer, H., 1999. Many happy returns. Journal of Business Strategy 20 (4), 27–31.

Min, H., 1995. Location planning of airport facilities using the analytic hierarchy process. Logistics and Transportation Review 30, 79–94.

Price, W.L., Turcotte, M., 1986. Locating a blood bank. Interfaces 16, 17–26.

Retzlaff-Roberts, D., Amini, M.M., 1998. A decision support system for integrated inventory management. Cycle Time Research 4, 33–42.

Rogers, D.S., Tibben-Lembke, R., 2001. An examination of reverse logistics practices. Journal of Business Logistics 22 (2), 129–148.

Schrage, L., 1991. LINDO: Manual and Software, Release 5.0. The Scientific Press, San Francisco.

Swersey, A.J., Thakur, L.S., 1995. An integer programming model for locating vehicle emission testing stations. Management Science 41, 496–512.

Tax, S.S., Brown, S.W., Chandrashekaran, M., 1998. Customer evaluations of service complaint experiences: Implications for relationship marketing. Journal of Marketing 62 (2), 60–76.

Tibben-Lembke, R.S., 1998. The impact of reverse logistics on the total cost of ownership. Journal of Marketing Theory and Practice 6 (4), 51–66.

Verter, V., Dincer, M.C., 1992. An integrated evaluation of facility location, capacity acquisition and technology selection for designing global manufacturing strategies. European Journal of Operational Research 60, 1–18.

Wagner, K.A., Mittal, M., de Rosa, F., Mazzon, J.A., 2002. Assessing the service-profit chain. Marketing Science 21 (3), 294–317.

Zeithaml, V.A., Bitner, M.J., 1996. Services Marketing, first ed. McGraw-Hill, New York.

Zeithaml, V.A., Bitner, M.J., 2003. Services Marketing, third ed. McGraw-Hill, New York.