Delivery Time Reduction Framework Development For Emergency, Make-to-order Replacement Parts

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Abstract: This research paper details how a manufacturer of make-to-order industrial gears reduced delivery lead-time for emergency customers, through the use of a modest amount of raw material inventory. The organization was able to eliminate procurement lead-time that translated into manufacturing lead-time reduction of 48-83% without any sacrifice of product quality.

Introduction

The time it takes to complete product development, manufacturing and delivery of a product to customers has been widely viewed as a source of competitive advantage in manufacturing strategy. [Ward, McCreery, Ritzman & Sharma, 1998; Ferdows & DeMeyer, 1990; Vickery, 1991; Vickery, Droge &, 1993; Vickery Dröge & Markland, 1994]. Studies have shown that organizations completing product development faster than their competitors were more likely to surpass competitors in the marketplace [Stalk, 1988, Stalk & Hout 1990; Wheelwright & Clark 1992 and Datar, Jordan, Kekre, Rajiv, & Srinivasan, 1997]. However, faster delivery time is likely to have little performance impact if resulting products do not meet customer demands for reliability, performance and other quality attributes. However, if reliability, performance and other quality attributes are relatively equal among possible suppliers, delivery time can be a determining factor in product sales, especially for make-to-order products.

Manufacturers with flexible flows tend to use a make-to-order process strategy. This allows for a great deal of flexibility in customer specifications resulting in a high degree of product uniqueness, flexible production processes and delivery times that can range from several days to several years. Due to the great divergence of manufacturing lead times within industries, lead-time reduction can be fertile ground for organizations seeking a competitive manufacturing posture. This is especially true if products are emergency replacement parts.

Emergency replacement parts for purposes of this paper can be defined as any resource that is necessary for the successful completion of an organization's mission. Lack of replacement part(s) can result in 1) loss of current and future sales, 2) decrease in customer service, 3) loss of customer good will, 4) additional setup costs necessitated by the use of alternate routings for products, 5) additional costs of rescheduling orders, 6) backorder costs or alternatively overtime or additional shift costs, 7) decline in labor and equipment utilization, resulting in additional manufacturing overhead and 8) added transportation costs. Given the critical nature of these situations and the additional costs resulting in a lack of replacement parts, delivery time reduction takes on added importance. In fact, delivery lead-time can be a primary determinant in selecting the organization for emergency part replacement (Wheelwright & Clark, 1992). An alternative scenario would require organizations to stock emergency parts, thus eliminating the risk of incurring the aforementioned costs; however, capital outlay for one part, similar to parts described in this paper, can easily reach costs of $50,000-$100,000 or more, which for most organizations is prohibitive. Consequently, organizations must rely on repair services that can produce quality replacement parts with minimum delivery lead-time.

Nature and Background of Business

This research focused on the Gear Repair Division (GRD) of Jewelcore Corporation (name changed); a Texas based manufacturing company operating in a long-standing traditional oriented industry. Gear Repair performs two basic functions – 1) repair of broken gearboxes, and 2) manufacture of interchangeable drop-in replacements for competitors' products. Products are marketed primarily in the petrochemical, power generation, and rubber and plastics industries.

The gear repair industry is highly competitive, based primarily on product quality and speed of delivery. Product quality is important because gear replacement is an expensive process. When customers replace gears they must be assured that replacements will last for an extended period of time. When a customer contacts Jewelcore, they are in one of two modes, anticipating replacement need or in an emergency situation with a down machine. In this second mode, with a down machine costing from $20,000 to $700,000 per day, that delivery time becomes an essential ancillary characteristic of the product.

Primary competition comes from three organizations, Eastern Gear, Makto Gear, and Saks Gear (name changes). Eastern and Makto both have locations in Houston, which makes them extremely competitive in the petrochemical market. All four companies produce quality products; therefore, competitive advantage is gained through quick delivery time. Due to the competitive nature of these companies, Jewelcore is always looking for ways to decrease total customer delivery time.

The Manufacturing System

The scope of this research study is limited to the repair of broken gearboxes. This limitation was imposed primarily because delivery speed is an essential characteristic in repair of broken gearboxes only. Customers requesting gears or gearboxes as inventory replacements will be willing to wait the normal manufacturing and delivery lead-time.

A review of company records revealed that the typical manufacturing lead-time to repair a broken gearbox (from customer order to product installation) ranges from 9 to 33 weeks as depicted below in Figure 1. The process is divided into 5 separate tasks, with materials procurement and gear manufacturing being the longest parts of the process. Material procurement time is the time for outside suppliers to get materials (gear rims) to Gear Repair. This stage is the bottleneck for the time element, taking from eight weeks to sixteen weeks from the initial time of sourcing. The gear rims (or rings) are assembled with hubs to form gear blanks. The hubs are either fabricated or cast at Jewelcore's own facilities, so lead-time for this component can be controlled in-house. The gear blanks are then machined into the final gear. Time to manufacture the gear is dependent on the size of the gear, material makeup, and intended use of the gear. The time frame can vary form five days to sixteen weeks. Shipping time is dependent solely on the distance of the customer from the manufacturing facility. Truck transportation of finished gears has been found to be the most economical mode of transportation for the Jewelcore Corporation and this can normally be accomplished in a week and often within a day. The GR Division installs 60 percent of its products and installation time is dependent on the size of the gear and the design of the gearbox. However, this can normally be accomplished in 2 days. Total time therefore can range from sixty three days to two hundred and thirty one days. Since this system is a job-shop and a finished gearbox is a very expensive inventory item, product inventories are rarely maintained. Therefore this up front time of a possible sixteen weeks for sourcing creates a total delivery time factor which is a potential competitive issue for the Jewelcore Corporation.

Problem at Hand

Primary concern is that material procurement is taking too long. The length of time is due to the higher quality of steel required for gearing applications. Currently, gears are designed and rim forgings are ordered based on the minimum amount of additional stock necessary to guarantee that the part can be finished to its design specifications. This minimizes both cost of the forging and the amount of time required to machine the part to its final dimensions. The current order process can take up to 10 times as long as the rest of the process combined. If material procurement could be shortened, the GR Division could gain a competitive advantage with its shortened delivery lead-time. This would allow the division to charge a premium price, thereby making gear repair more profitable and additionally gaining market share at the same time.

Shortening the Procurement Process: Alternatives

Initially, the researchers investigated various ways to shorten the materials procurement process. Three alternatives investigated were 1) Manufacture the gear rims in-house; 2) Find alternative suppliers; or 3) Carry an inventory of gear rims.

Manufacturing the Gear Rim

The researchers considered two new methods for manufacturing the gear rims. The first was to cut the ring out of a thick plate of 4145 modified steel. However, due to the process of rolling used in forming the steel plate, laminates would be oriented in a direction that would not be acceptable for the engineering and mechanical requirements of the gear. The problems associated with the laminates formed in the rolling process could be eliminated if the plate was forged. However suppliers stated that quality became an issue when forging thicker plates (6 inches or more) and that the cleanliness required by Jewelcore material specifications would be very difficult to meet.

The second method considered was to forge thinner plates, then mechanically roll the plate and weld the ends together to form a ring. This proposal eliminated the quality problem of laminates cited earlier but created some new unique problems. First, welded metal could not be located within the gear ring and a new process would have to be put in place to insure this did not occur. By engineering a new process and procedure, that included special welding electrodes and heat treating steps, the researchers eliminated any concerns about the welded area of the rim. The researchers contacted several companies that had the capabilities to actually roll the plates; however, procurement delivery was improved by only one week. Other problems inherent in this type of manufacturing included: 1) Cracking of the plate, 2) Poor welding procedures, and 3) limited variations in plate radii that the rollers could form. One company even refused any liability for material damage during the process. To summarize alternative #1, it was not mechanically sound in some cases. In the cases where the manufacture was sound, it was too risky and expensive for a significant benefit, that is reducing procurement lead-time. Therefore, the researchers rejected the option of manufacturing the gear ring itself.

Find Alternative Suppliers

The researchers contacted Jewelcore purchasing agents and they stated that it had been a long time since there was a concerted effort to identify new suppliers for ring manufacturing. The researchers contacted steel forgers that were familiar with Jewelcore's specifications for gear grade steel. Every forger contacted reiterated that Jewelcore specifications were so stringent, and quantities so small, that it would cost the forging companies too much to provide the rings. The researchers also contacted new suppliers; however, they also said they could only provide rings with a 6 to 8 week lead time, and could not guarantee quality of the gear grade steel. Therefore, this alternative was abandoned very quickly.

Carry an Inventory of Gear Rims

The more the researchers investigated options, carrying an inventory of gear rims became more and more attractive. Therefore, this is the alternative addressed in detail and presented in this research. Currently, Jewelcore maintains inventory to produce gear rims with outside diameters of 30 inches or less. This raw materials inventory policy allows the organization to cover a large portion of new sales and at the same time keep inventory of gear rims to a minimum. The researchers downloaded historical sales over the last five years and used the data as a basis for projecting sales frequency of various sizes of gears. A 95 percent confidence interval for the outside diameter of the downloaded data revealed that historical sales had outside diameters (OD) between 21.38 inches and 67.85 inches. Since current inventory carried for other products offered, covers all sizes 30 inches and under, this research focused on sizes above 30 inches. With current technology, Jewelcore can tool up to 6 inches off of the outside diameter and still meet all engineering requirements, so the researchers constructed a histogram for all sizes from 30.1 inches to 66 inches, with 6 inch bin ranges. These results show that six gear rims have an OD that can cover a 6" range. For example, the last gear rim has an OD of 66" which can be cut down to 60.1 to cover this range. Each of the six gear rims is handled in this manner so those projected sales are covered with six gear rim sizes. Orders that cannot be met with one of the six gear rims, specifically gear rims with OD greater than 66" will have to be made special order and will take the normal procurement lead-time. To figure the inside diameter (ID) of the six gear rims, two restrictions must be considered. The first is the pitch of the tooth cut on the gear. The largest cut is a one-pitch tooth that is about two inches high. According to an engineering handbook, this type of pitch requires at least four inches of steel under it for support. Considering the two inches from the tooth and the four inches of support, and multiplying that by two, provided a minimum ID required by engineering specifications. The second restriction that must be considered is the thickness. According to the Jewelcore Gear Design Manual, the maximum thickness (difference between the OD and ID) allowed is 14 inches. This must be followed for maintaining heat treatment properties in 4145 modified material. The division of 6" groupings for gear rim sizes allows for the rings to stay within the design guide to insure proper material hardness. In the previous example of the 66" OD gear rim, it would require at least a 54" ID so that the remaining 12" of steel meet the required specifications of support under each tooth. The researchers calculated the minimum ID for all six gear rims and looked at how many historical orders fell outside of our tentatively designed six gear rims. It was found that if the 66" OD gear had a 54" inch ID seven out of the forty-four orders taken would not be able to be manufactured. The inside diameter was decreased to a minimum required ID of 52" ID to allow the organization to service 98% of the orders in that range. Similar modifications with the remaining gear dimensions provide confidence in the ability to meet demand at the 99 percent level for gears two, three, and four and at the 100 percent level for gears one and five. It is only the gear six that would be at the 98 percent level.

Determining Gear Cost

To justify the maintenance of inventory for these gear rims, a cost analysis was performed. Gear costs were determined by getting a cost per pound for the gear rings purchased for the last five years. The purchase price of the gear ring was divided by its weight to get a unit price per pound of steel used for each of the rings. A linear regression analysis was done on this data and a regression equation was developed for determining unit cost based on the weight of the proposed rings. The statistical analysis used to determine the regression equation is available from the authors. The minimum price for steel used for the calculations was priced at a rate per pound as based on the historical pricing data contained in the firm's inventory records. The gear costs resulting from this analysis are available from the authors. In addition to the capital outlay of the additional inventory, the annual carrying cost of the capital was calculated based on a weighted cost of capital of the firm. The firm has a low ratio of debt to equity. It was also necessary to consider that by proposing the use of only 6 different sizes of rings to cover the production of 95 % of the gears that Jewelcore had historically produced, the machining costs would also increase. The total cost calculations were related to the cost savings.

The emergency mode of the customer gear replacement order should allow Jewelcore to realize an increase in revenue that will more than off set the costs. The additional revenue is based on assessing a premium (projected premium is 50 percent of the non-emergency rate) for service that gets the part to the customer approximately two to four months faster than normal. It is believed that the costs will be recouped with just one emergency repair job per year. Currently the organization is averaging five to six of these jobs per year.

Discussion

This research exemplified some very important points for organizations that want to use delivery time as a competitive weapon. Stalk and Hout (1990) cautioned that organizations using time as a competitive weapon should segment their customers into two groups: 1) Customers willing to wait, and 2) Customers that cannot wait for products. Customers that cannot wait for ordered items are candidates for lead-time reduction activities. Stalk and Hout (1990) stated that customers requiring lead-time reduction should be willing to pay a premium for the product, because of the product's time elasticity of price. The time elasticity of price was demonstrated in this research through the added margin. Closely associated with the elasticity of price is the quality of the product. Jewelcore Corporation was very careful in making sure that lead-time reduction was not going to sacrifice the quality image of products produced and delivered to emergency customers. Providing emergency customers quality products along with added service through reduced delivery lead-time, can also translate into more regular sales. Emergency customers will remember the quality and responsiveness of Jewelcore Corporation in emergency situations. When former emergency customers are looking for a manufacturer of products on a regular basis, Jewelcore will be the first organization called due to their customer service and responsiveness and product quality.

Stalk and Hout (1990) also indicated that to effectively use time as a competitive weapon, organizations must first identify non-value-added activities and seek to eliminate these activities. The greatest non-value-added activity in this research study was the procurement cycle for the gear blanks, see Figure 1. Through the use of a minimum amount of inventory, the gear blank procurement lead-time was essentially driven to zero, which translated into a decrease of 48-83% in manufacturing lead-time. However, it must be emphasized that Jewelcore should continue to seek ways to reduce manufacturing lead-time. Obvious areas that should be investigated are shipping and machining. Though shipping consumes only five days, Jewelcore should perform a complete analysis of the most economical and feasible way of transporting finished products to customers.

Though machining is a value-added activity, an analysis could be conducted to identify if any commonality of teeth pitch and size exists for replacement gears. If commonality can be identified, the organization could manufacture the replacement parts to a point and keep these semi-finished gears in inventory. This would reduce gear machining when an order is placed for a replacement gear, thus making the organization even more responsive and competitive with regard to delivery lead-time.

This research also indicated that the use of delivery lead-time reduction and elimination of non-value-added steps in manufacturing has a very short payback and no sunk costs. Jewelcore will recover all of the cost of capital associated with gear blank inventory through the sale of one emergency gear per year and purchase cost of the gear blank will be included in the price quoted customers.

Two small issues that must be resolved and not addressed in this research are housing of the emergency gear blank inventory and identification of emergency stock issuance by inventory custodians. It would be a good practice to keep emergency inventory separate from regular issue inventory. Access to this inventory should be limited to supply clerks/pickers. Identification of emergency stock issuance can be identified on the copy of the work order sent to inventory stores. For example, an E-prefix on the work-order-number could identify that this is an emergency situation calling for stock from the emergency store of gear blanks. An R-prefix on the work-order-number could identify that this is a regular situation calling for stock from the regular store of materials for gear production. In those situations where regular production called for the purchase of a gear blank, normal purchasing and inventory store issuance procedures could be followed to issue the gear blank to manufacturing.

Conclusion

This research study suggested that Jewelcore Corporation maintain an inventory of one unit for each of 6 different sizes of gear rings presented earlier in this research report made of 4145 modified material to Jewelcore's current specification. It was further recommended that gear rings be heat-treated to a final minimum hardness of 341 brinell, Jewelcore's maximum recommended design hardness. This hardness specification covers a broad spectrum of gear design speed and horsepower transmission. These two design specifications will maintain the quality of gears produced by Jewelcore Corporation. Historical records indicated that gear rings purchased in widths of 26 inches would cover over 95% of gears demanded. An ancillary benefit of purchasing gear rings in 26-inch widths was the original ring could be split into 2 gear rings of 13-inch widths (sixty to seventy percent of the gear rings were 13 inches in width or less). This inventory will give Jewelcore the capability to manufacture an extremely diverse array of gears and to reduce the manufacturing/ delivery lead-time by as much as one month.

Gear repair is typical of any other repair business. It is important to provide rapid service along with a quality product. Jewelcore Corporation has an excellent reputation for providing exceptional products but is continually looking for ways to improve the delivery of these products to customers. This research has developed a solution to the procurement time dilemma for Jewelcore Corporation. Though carrying additional inventory is not practical in all cases, this research demonstrated that a minimum investment in additional inventory significantly reduced delivery lead-time, and this solution did not sacrifice the excellent quality of finished products.

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