AN ABSTRACT OF THE THESIS OF

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Abstract Approved: ____

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The Global Formula Racing (GFR) team is an organization of student designers at Oregon State University (OSU) and at Duale Hochschule Baden-Württemberg (DHBW) in Germany working to create two race cars to compete in international competitions through the Society of Automotive Engineers (SAE). The large scope of this project necessitates the formation of organized management systems. This project sought to create an effective inventory management system for the GFR team. A database of the fasteners used by the team was created and includes information such as annual demand, inventory value, and lead times. This information was used, along with the appropriate formulas, to calculate the economic order quantity (EOQ), the total material cost (TMC) and the order point (OP) for each part. A comparison of two major vendors was also included, and the vendor with lowest TMC was recommended. Face to face communication methods to convey this new idea were recommended. Lean manufacturing techniques to help implement this new system were researched including 5S tools and a pokayoke. Student designers will now know exactly when to economically order a part, how many to order, and who to order from. This will save money, as well as increase productivity and professionalism.

Key words: Inventory management, lean, economic order quantity, reorder point.

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Inventory Management System for the Global Formula Racing Team

by

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I understand that my project will become part of the permanent collection of Oregon State University, University Honors College. My signature below authorizes release of my project to any reader upon request.

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Kimberly R. Daeschel, Author

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3. Fasteners Sheet:
https://docs.google.com/a/ba-racing-team.de/spreadsheet/ccc?key=0AslzGDylGg96dHlBeFIzQmpFM3lxVG41ZTFDQ0JtOGc#gid=0

Inventory Management System for the Global Formula Racing Team

INTRODUCTION

Background Information

The Global Formula Racing (GFR) team is comprised of students working at Oregon State University in Corvallis, Oregon and at Duale Hochschule Baden-Württemberg in Ravensburg, Germany. Each year the team builds a combustion engine and an electrical motor race car to compete in international competitions through the Society of Automotive Engineers (SAE). The highly rated vehicles produced are the result of a huge collaborative effort of over one hundred engineering students. The scope of this project necessitates an extensive management system, including a team of supply chain engineers. One important topic needing improvement is the inventory control and replenishment system. Parts tracking and reorder points have not been set for incidental parts such as fasteners. Communication between designers and management regarding ordering times, quantities, metric or English classifications, and current stock organization is lacking. An appropriate inventory management system is desired.

Inventory management is an extremely large area of current research in both academia and industry. Inventory is the lifeblood of many companies and must be managed appropriately to reduce costs and increase productivity. As organizations grow larger and more complicated, having an official inventory management system becomes more important. The GFR team is unique in that it is collaboration between two universities, separated by thousands of miles. This degree of complexity, which is increasing every year due to increased student involvement, makes GFR an ideal candidate for the transition into a formalized inventory management system.

An important outcome of creating an inventory management system is that correct reorder points and quantities will be created for common parts. An analysis will be completed on the current research in these areas and the best suited system will be applied to the GFR environment. The system for GFR will be focused on fasteners and other small parts that are needed in large quantities and multiple times throughout the year. Reorder points will allow the team to have a set date or other indicator (such as stock levels reaching a certain point) for exactly when is the best time to order more parts. The reorder quantity will be a logically determined number in which the most economical quantities are ordered. Both of these determinations will help the team reduce costs and increase productivity.

The reorder points and quantities cannot be set up simply using organizational information. The methods used to determine these numbers will most definitely involve information that can only be provided by suppliers, such as ordering costs and shipping lead times. This means that the reorder point and quantities will vary depending on which supplier is chosen. To choose the most efficient method, a supplier survey must therefore be completed. Different suppliers may be the most efficient for different parts. A supplier survey will ensure that optimal parameters are chosen. This survey will be part of the research and results. It is likely that a database will be used to best organize this information.

In addition to order quantity and point rules being implemented as standard team operating procedure, an inventory management system will include the physical improvements within the organization. The most popular and effective method of organizing inventory involves following lean manufacturing principles. These principles will guide the physical set up of the shop.

Lean manufacturing principles can be applied to elements of organizational processes. The lean principle related to inventory is very clear. Inventory is considered one of the “Seven Deadly Wastes” and the ultimate goal should be to eliminate inventory as much as possible. This is because inventory wastes space and capital and may become obsolete or damaged when left out. Inventory build ups in between operations, known as work in progress (WIP), is also disadvantageous because it drastically it can increase production lead times (Nicholas 60). Following the lean manufacturing principles, inventory will be kept as low as possible while still implementing the traditional rules for economic order points and quantities.

Lean manufacturing is also very useful for organizing the physical layout and storage of any inventory that will be necessary to have. One of the basic tools associated with lean manufacturing is following the steps of 5S. The five S’s in this acronym are Sort, Shine, Set in Order, Standardize, and Sustain. These are rules to follow during inventory organization. Sort means to only keep those parts which are actually necessary for production. Shine involves the actual cleaning of the workspace. Set in order means creating an orderly storage solution, such as labeled bins. Standardize involves defining a standard of what the previous three S’s should look like. Lastly, Sustain means defining a method to ensure these standards are followed on a regular basis to maintain them

(Nicholas 71). These rules and other lean techniques will be used as a guideline when plans are made for the physical inventory system set up.

Another area of research that will be useful during the creation of an inventory management system is team communication. With a large team that is spread out across time zones and countries, communication becomes both increasingly important and increasingly difficult. For the inventory management system standards to be effectively communicated amongst the team, some care must be put into how this communication is done. A secondary goal will be to discover which style of communication best meets the unique needs of the GFR team and to set up that method of communication with the overall inventory management project

Research Motivation

In preliminary discussions with GFR team members and after working with the team for several months in other capacities, it is clear that GFR is a hands-on, action-oriented organization. The usefulness of these inventory methods will be dependent on how well they actually perform in the GFR setting. For this reason, it will be important to involve GFR team members in various decisions made. This means, part of the research involves utilizing on GFR opinions of the best reorder quantities, points, vendors, management of said data, and the physical inventory set up. Because many of the current team members have been working in this environment for several years, they are truly the experts on what can actually meet their practical needs. Because many different options and methods may be discovered through the research, GFR opinion will be the final criteria when making decisions.

Before the major research was undertaken, an informal survey of team members was taken to establish a motivation and need for this new system as well as determine which topics are most important to the team.

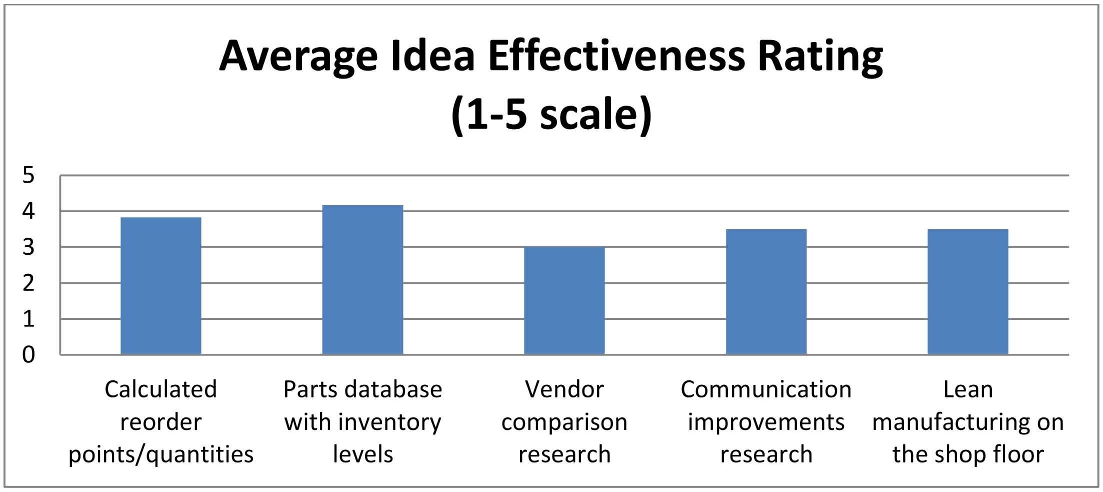

Figure 1. Average idea effectiveness rating. Column chart.

The topics that were higher rated, notably the “parts database with inventory levels” and “calculated reorder points and quantities”, as shown in Figure 1, were researched more thoroughly.

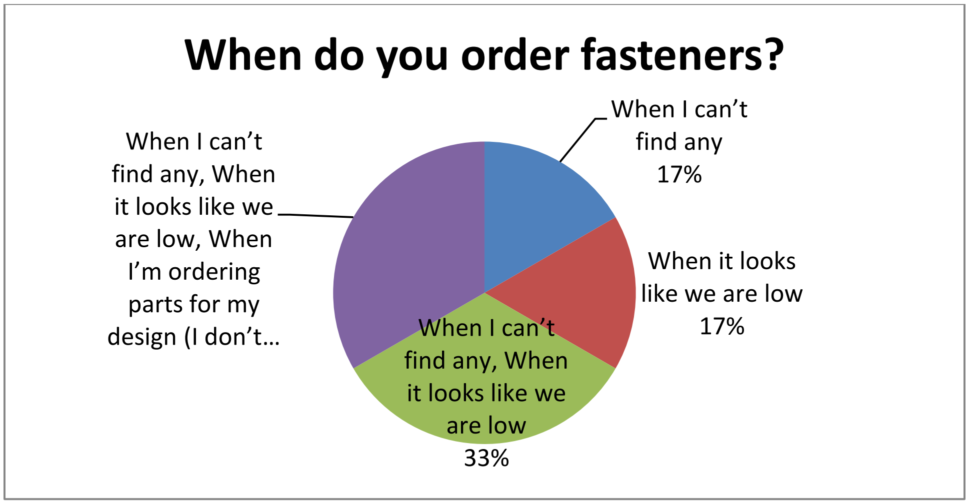

Figure 2. When do you order fasteners? Pie chart.

In addition, the confusion over when to order new parts was noted (see Figure 2) and a solution was proposed through the use of the bin labels, as well as the database in general. The survey also confirms the need for an inventory management system because most people rated the current system as either okay or poor, as shown in Figure 3.

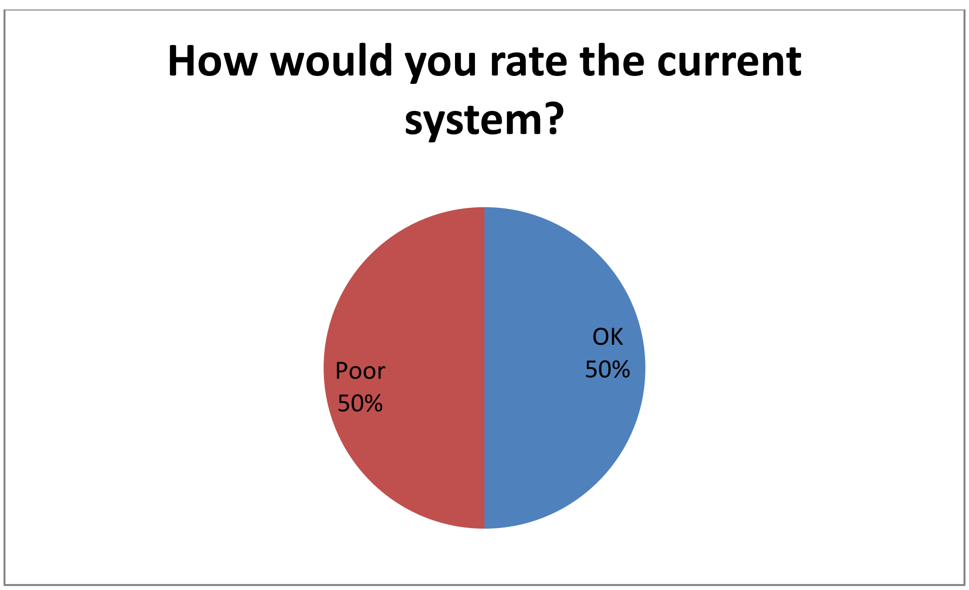

Figure 3. How would you rate the current system? Pie chart.

MATERIALS AND METHODOLOGY

The first step of this research project was to actually conduct the background research. Secondary research is the type of research that is gathered from other, already published, sources. Secondary research was used to form the basic inventory management system. Informal discussion with team members was also used at the same time to determine the basic needs of the management system from the standpoint of the customer as well as establish the motivation for this research, as discussed previously. Combining these two sources allowed a preliminary system to be created for testing.

The secondary research stage involved a literature review and summary. Various literary articles, books, and journals were read and analyzed to determine the top ideas in the topics being investigated. The topics searched for include the following: inventory management, reorder points, reorder quantities, vendor selection, databases, standard operating procedures, organizational communication, and lean manufacturing. When searching for research materials, these terms were modified as needed to expand the search results.

Inventory management was researched because this is the broad topic that was being addressed. The goal of the research is to create an inventory management system for the GFR team, and so the inventory management research is the overall category to be analyzed. Reorder points and reorder quantities were researched because these are the specific topics within the inventory management literature that the research was seeking to determine. The GFR team had no reorder points or quantities established for fasteners or for other small parts. Establishing this information was an integral part of creating an effective inventory management system and is a main subset within the subject of inventory management research.

Vendor selection was researched because a preliminary investigation into the environment that GFR operates in revealed that there is flexibility in terms of which vendors are used. There are multiple available vendors, especially for common parts such as fasteners. As such, vendor selection is an important part of the inventory management process. There are different parameters when purchasing from different vendors, such as product prices, ordering costs, and lead times. Therefore, the reorder points and quantities will vary based on this data. Vendor selection is an important process within inventory management that must be addressed in order to calculate proper reorder points and quantities.

Databases were researched because databases are important data management and storage tools. The information and processes defined in this project must be sustainable in order them to be useful in the future. That means the information must be easily accessible and useable. Databases provide a formal and useful location for information to be stored and retrieved. The inventory management system was planned to be stored in a database, so this research was critical.

Organizational communication was researched because during preliminary talks, it was clear that communication among the large GFR team was a challenge. Effective communication was a necessary precursor for implementing a successful inventory management system. The best communication style to use for communicating the new inventory management was researched and kept in mind when designing the database and standard operating procedures.

Lastly, lean manufacturing was researched because this is a very important manufacturing theory and will be very helpful in creating an inventory management system, most notably the physical layout of the inventory. Lean manufacturing strives to eliminate waste in the workplace and this includes non-value added inventory and effort relating to inventory. The 5S system or workplace organization provides guidelines on how to best organize inventory.

After the preceding research was analyzed and tabulated, it was time to actually create the system. This involved creating a database and entering the vendor survey information. The best order quantity and point formulas where chosen based on the information obtained from the primary research. The formulas were then applied to the list of fasteners and other parts to be included in the inventory management system. The best vendor was chosen based on quality, cost, and lead times. This created a database with the appropriate vendor and ordering information for each part.

LITERATURE REVIEW

EOQ Formulas

The first topic to be researched is the formulation of an appropriate economic order quantity and reorder point based on applying available research to the given situation. EOQ and OP theory has a long history and a review was conducted to determine which formulas and methodologies currently available would be most appropriate to apply to the GFR team and this inventory management system.

In discussing economic order quantities (EOQ), it is first important to note that EOQ theory assumes a fixed order quantity system. This means that the quantity of an order will be a fixed amount while the re-order point is allowed to vary (Gaither and Frazier 540). Another assumption made is that perpetual inventory accounting is used. This means that the organization’s inventory is constantly updated and an accurate inventory count is available at any time (Gaither and Frazier 541). In the small and labor-constrained GFR shop, this may not be always possible, especially since inventory is not controlled electronically. It can be assumed however that the inventory will be maintained fairly closely.

The formula for the basic model of EOQ is as follows:

$$EOQ = \sqrt{\frac{2DS}{C}} \qquad (1)$$

Where D = annual part demand

S = average order cost

C = average carrying cost (inventory holding cost)

This equation is derived from the formula for the total inventory cost, as shown in Gaither and Frazier. A second basic EOQ model is also available for inventory that is used to create production lots, but this does not apply to the GFR environment, which is a job shop (Gaither and Frazier 544). A third model is EOQ with quantity discounts. This model accounts for the fact that suppliers often provide discounts when larger quantities of parts are purchased. This model assumes that the orders are all received at once. To find the EOQ in this situation, one must first solve for the EOQ for all possible ordering cost brackets. The solutions should then be compared to the actual quantities needed to secure that price. Any non-feasible quantities should be eliminated. The total cost of the feasible quantities should then be compared with the lowest quantity to receive the cheapest order cost, as this may also be a minimum. The lowest cost option should then be chosen (Gaither and Frazier 547-9). It was discovered however that there are few quantity discounts for the fasteners being ordered (rather there are just minimum order quantities). This method of analysis is therefore unnecessary in this case.

An important equation related to EOQ is the equation for the total cost of a particular material. This equation will be useful in determining which vendor can provide the lowest cost material. The total material costs are as follows:

$$TMC = \left(\frac{Q}{2}\right)C + \left(\frac{D}{Q}\right)S + D(ac) \qquad (2)$$

Where Q = economic order quantity (EOQ)

C = average carrying cost (inventory holding cost)

D = annual part demand

S = average order cost

Ac= acquisition cost (per unit)

This is a more realistic model of actual inventory costs and optimization (Gaither and Frazier 550). The models presented thus far are a good starting point for determining realistic order quantities and points. However, more accuracy can be incorporated into the model by allowing backorders. A backorder is a situation where inventory stock is out and the organization must wait to receive parts. In the case of GFR, this means that student designers must wait in the case of an inventory backorder. This is clearly very undesirable. Including this variable in the EOQ equation will help avoid this possibility because when costs are assigned to backorders, the EOQ will increase. In a recent research paper, Kaj-Mikael Björk introduces the basic model with backorders (488). The formula for EOQ, y in this case, is as follows.

$$y = \sqrt{\frac{2KD}{h} + \frac{2KD}{p}} \qquad (3)$$

Where K= order cost

D = annual demand

h = carrying cost

p = shortage penalty

This work also provides a solution for the calculating the EOQ with uncertain lead times and demand (Björk 491). This is another method of increasing the accuracy, because the model will incorporate various possible outcomes and their probabilities. The quantities used for the lead times and demand would be given as “fuzzy numbers.” Fuzzy numbers are defined as uncertain parameters defined by a set of outcomes and their probabilities, as a sort of triangulation (Björk 486). While this extension of the model may be useful in the GFR setting, as GFR certainly has slightly uncertain demand and vendors may have variable lead times, the complexity of the model is not worth the additional accuracy. The quantities used in the GFR model are estimated to the best of the team’s ability and it is not likely that largely differing numbers are possible.

OP Formulas

The EOQ model mentioned above was thus decided as the final formula used in calculating re-order quantities for the GFR inventory management system. The next step was then to use similar methods to calculate the re-order point. The basic model for calculating an order point is the following equation (Gaither and Frazier 550):

$$OP = EDDLT + SS \tag{4}$$

Where EDDLT = expected demand during lead time

SS = safety stock

The order point is the quantity of parts that will signal when a replenishment order should be placed. There must be enough parts left to cover the time period between when the order is placed and when it arrives. This is the EDDLT term. There must also be a back-up quantity of parts in case the EDDLT is higher than estimated or for other emergency situations. This is the SS term. The demand during lead time is generally an uncertain term that can be described as a distribution. The EDDLT is then determined by statistically computing the expected value of the distribution (Gaither and Frazier 552). This can be done by evaluating the probability distribution functions (pdf). The EDDLT will vary based on the service level required. The service level is the probability that a back order will not occur and the EDDLT chosen will have a cumulative probability equal to the service level (Gaither and Frazier 552-4). In this case, the EDDLT data was estimated from annual demand and lead times and complex distributions were not deemed beneficial.

Another important related research topic is how to determine the safety stock (SS) level that is used in the reorder point formula. One method is to set the SS equal to the square root of the EDDLT. The formula for the re-order point then becomes:

$$Order\ point = EDDLT + \sqrt{EDDLT} \tag{5}$$

This method tends to set safety stocks quite low and is used when stock outs are not very harmful to the operation (Gaither and Frazier 558). In the case of GFR, stock outs could delay production of parts and the assembly of the vehicle. Because GFR operates on such a strict time schedule, stock outs are thus very undesirable. A more appropriate formula to use is:

$$Order\ point = EDDLT + j(EDDLT) \tag{6}$$

Where j = 0.1-3, depending on importance of the part (Gaither and Frazier 557).

Because of the factors already described, GFR parts were classified into the supercritical group. In this case, j is chosen to be 1.00 (Gaither and Frazier 558). The final order point formula used is therefore:

$$Order\ point = EDDLT + 1.00(EDDLT) \tag{7}$$

This was the formula used in the inventory management database to calculate each part's order point.

The lack of complex statistical methods (such as using distributions) used in these formulas may seem troubling because these methods can help improve accuracy; however it is justified due to the nature of the inventory being analyzed. This inventory management system is for fasteners and other small parts which are not high value parts inventory. This is because the GFR team already manages these parts carefully through use of the Part Evaluation System database as well as the Purchase Request database for purchased parts. The parts being analyzed here can be modeled using the ABC classification system. This system states that A parts account for 20% of inventory and 75% of value, B parts account for 30% of inventory and 20% of the value, and C parts are 50% of the inventory and 5% of the value (Gaither and Frazier 556). Clearly, fasteners and such will fall into the C category, as they are purchased in large quantities but are relatively cheap. According to the ABC system, C materials should be analyzed only minimally (Gaither and Frazier 556). Therefore, the EOQ and OP equations derived here are more than adequate.

Vendor Selection Theory

Vendor selection theories have evolved with increasing complexity. However, as with the EOQ/OP, there is little benefit to conducting a detailed analysis. The value of the parts being supplied is low, and the quantities are fairly low as well (since only two cars are built per year). Therefore, the approach to vendor analysis was fairly organic in nature. McMaster-Carr and Fastenal were selected as possible vendors based on use in the past. Both of these companies are large enough to supply virtually any fastener needed, and they both also offer direct sales to customers. That is, even though GFR is a small account (would be classified as a business to consumer sale rather than business to business), orders can be directly placed. While intense analysis was not performed on these companies, some criteria are needed as a basis for vendor selection. Cost, quality, and delivery are three important criteria that can be easily used to guide decisions (Chakraborty, Ghosh, and Dan 172). These parameters can be given different weights and a total score can be created per vendor per part. Cost can be calculated using the Total Material Cost (TMC) equation already discussed. Quality can be assessed based on reputations and any past experiences. Delivery is based on lead times, which is information that was previously gathered.

RESULTS

Data Collection

With the appropriate equations selected, the next step was to compile a list of the fasteners and other small parts, along with the necessary part information for each to complete the calculations. The needed information was annual demand, carrying costs, order costs, batch sizes (in case there are certain quantities that must be ordered through a vendor), order lead time, and demand during lead time. The part list as well as the annual demand was compiled using the Part Evaluation Sheet (PES), which is a database that lists all needed parts for the entire team. The fasteners and other small parts were extracted from this list. The annual demand was also determined from the PES because necessary quantities for each year are listed per part, in the second column of that document. During the collection of this information, it became clear that not all fasteners were included in the PES, though they should have been entered by the designers. Therefore to improve the quality of the fasteners list, two other sources were used to gather parts and annual demand information. A list of fasteners currently stored in the GFR shop was made (to be printed and used as labels) by GFR team member DJ Barnes. This list was used to identify possible parts for the inventory list. This document was especially useful because it listed the official Fastenal item number of the fastener, while often the PES would not. This information was helpful when collecting part prices, batch sizes, and ordering information from the vendor websites. The purchase request database was the second document used to gather inventory information. Some fasteners not listed in the PES could be found in the ordering records of this database. This also helped determine the most accurate annual demand numbers, because the PES does not always account for the proper number of spares; the purchase request database shows the actual numbers ordered this year. All items listed on the purchase request database that were identified as fasteners from the item description column, were added into the database. The annual demand was determined from the quantity column. The PES and purchase request database were cross-referenced to ensure that no fasteners were counted twice (by referencing the "person responsible" for a fastener listed on the PES and the "requestor" on the purchase request). Links to three web documents that were used to compile this data can be found in the "Web Data Sources List" preceding this text. These documents are constantly updated and contain multiple fields, view, or tabs, so further information can best be viewed by referencing these sites.

The carrying costs were estimated based on industry rules of thumb. Demand during lead time was derived from annual demand, as well as the vendor lead times. The batch sizes, order costs, and order lead times are dependent on which vendor is selected, which is part of the inventory management system's purpose. This information is thus stated for each possible vendor. This information was gathered during the vendor survey.

With the vendor specific information obtained from the vendor's website the database information was completed. This information was initially stored in an Excel spreadsheet for simplicity during the research process. However, Excel is not a viable option for storing this information because it will not be universally available for queries and updates. Microsoft Access is a database program that offers more options than Excel, but is again not easily accessible. Because the GFR team already uses the Google suite of online tools, it would be easiest to select a dataset option from that set. Google Fusion tables are interactive and provide useful filtering and look up function for users. However, they are more challenging to create, and the additional features were not found to benefit this type of database. Google spreadsheets were another option. Using Google spreadsheets will provide the same simplicity and ease of creation as Excel, but will be readily accessible online to the entire GFR team. The GFR team will also be more likely to use the database if it is in Google spreadsheets because everyone on the team is familiar with that program. This option provides adequate usability for the least degree of difficulty, and was thus chosen as the appropriate database.

Database Calculations

The database created is viewable in Appendix I. The list of appropriate fasteners and their annual demand was gathered from the PES as well as the purchase request database as previously mentioned. The next two columns are the batch costs for both McMaster and Fastenal. This information was collected from the Fastenal and McMaster websites. The next two values are the inventory value for the parts if they were ordered from McMaster or Fastenal. The inventory value is the total cost of the annual demand of the parts. This was calculated by dividing the batch cost by the batch size (a later column), to get a cost per part, and then multiplying by the annual demand of parts. The next two columns are the carrying costs of the inventory. This is the cost incurred by holding large amounts of inventory and can be attributed to such things as paying for storage costs, lost value if products become obsolete, etc. The carrying cost is usually calculated as a percentage of the total inventory value, and a good rule of thumb is 25% of the inventory value ("Methodology of Calculating" 3). This rule was used and so the carrying costs for both companies are calculated as 25% of their respective inventory values. The next two columns are the ordering costs for each company. These values are what must be paid each time an order is placed. This value, like all the information collected in the fasteners inventory database, is part of the information needed for the end goal; which is to calculate to the economic order quantity and order point of each part. The order costs will be equal to the shipping costs paid each time an order is placed and shipped from the companies' website. The shipping costs were estimated by placing sample orders of typical fasteners on the websites. The shipping costs relate to the amount of product added but it is also a tiered system. That is, it will cost the same to order one fastener as it will to order five. To mitigate the high initial ordering costs, the GFR team already tends to order about 4 different types of fasteners at the same time. This is accounted for in the estimated order costs so they are not unrealistically high (that is, shipping costs are split between multiple parts). Because this method is used, it is important to note that the order points calculated in this database are merely guidelines that can be slightly altered to maintain this practice of grouping some orders together.

The next two columns are the official McMaster and Fastenal part numbers, important for easily ordering the parts. The next two columns are the batch sizes, used in the inventory value calculation as previously mentioned. The next two columns are the lead times expected for each part. This is important because it is used to calculate the demand during lead time and thus the appropriate order point. The lead time for small packages from these two companies obviously varies and is difficult to estimate. The

Fastenal website mentions a standard delivery time (about 5 days) when parts are available to ship within one day. The parts that are not available to ship in one day were estimated to take about twice as long (10 days) based on anecdotal evidence. McMaster has a reputation for being very fast and so the lead time was estimated to be 2 days, also based on anecdotal evidence. The next two columns are demand during lead time, which is calculated by dividing the total (annual) demand by the number of days in a year to get a lead time per day and then multiplying by the lead time. The number of days in year used in this case was 30 (1 month) instead of 365. This is because most of the demand for GFR fasteners occurs during the actual building of the car, which occurs for about one month during winter term. By selecting this as the appropriate time period, the order point will accurately ensure parts a re-ordered in time to prevent stock outs during this period.

The next column is the penalty cost. This is used in the economic order quantity equation. It relates the increased costs associated with stock-outs. If stock-out costs are high, the EOQ will increase to try and prevent these costs from occurring. This was estimated to be $5, not very high, because while GFR stock-outs are very undesirable and this should increase the EOQ, there are already additional safeguards against this occurring by the high order points used. As mentioned before, a coefficient of 1 was selected for the order point formula, which corresponds to supercritical parts. So while the EOQ is not drastically increased, stock outs will be avoided by ordering sooner.

The next column is the actual computed EOQ. This was calculated using the equation selected from the research. All the needed information is pulled from the database. A key issue with this is that some parts, especially those ordered from

McMaster, have minimum order quantities, often 100 pieces. This means that in these while the EOQ may be smaller, the actual number used must be the minimum batch size or higher. Therefore, the formula used in these cells was the maximum of the actual EOQ and the minimum batch size. The EOQ numbers were also rounded because it is not possible to order a quantity of parts that is not a whole number.

The next columns calculated the total material cost of the ordering the EOQ (or minimum batch size) for each company. This was calculated usually the previously researched equation. This equation does not account for the penalty cost because that cost is really a fictitious cost (we are serving internal customers who have no choice but to wait for their parts) and is only meant to increase the EOQ. Further, the penalty cost is the same for vendors so it adds no value to a TMC comparison.

The TMC values were compared and the smallest cost was chosen as the appropriate company to order from, listed in the next column. Cost, quality, and lead times are the vendor selection criterion and are equally important in this scenario, and so should be weighted equally when making a decision. However both Fastenal and McMaster-Carr have equally excellent quality reputations. While McMaster does have better lead times, they are not that significant and choosing McMaster in these situations would often result in ordering more fasteners than needed (though not spending more money), which creates extra inventory waste. In addition, varying lead times are already accounted for in the OP formula. Of course, team members should use individual judgment when using this database and may select McMaster over Fastenal in cases where the database was not initially followed and a rush order is needed to prevent a stock-out.

The last column calculates the order point for each part, depending on which company is chosen. The order point depends on the expected demand during lead time, as previously calculated in the database, and a safety stock level (which is just the demand during lead time multiplied by the safety coefficient, which was chosen before to be 1.00) The numbers calculated represent the minimum number of parts remaining before an order is triggered. Higher demand parts have higher numbers so there will be adequate stock during the lead time while an order is filled. For parts that have a location in the GFR shop bins, these numbers (along with the EOQ – the quantity to order) should be printed on labels in the bins.

Part Name/Use	Annual Demand	Batch Cost (McMaster)	Batch Cost (Fastenal)	Inventory Value (McMaster)	Inventory Value (Fastenal)	Carrying Cost		Order Cost (shipping)		McMaster Number	Fastenal Number	Batch Size	
						McMaster	Fastenal	McMaster	Fastenal			McMaster	Fastenal
M8-1.25 x 20mm socket head cap	25	9.79	0.3616	4.895	9.04	1.22375	2.26	1.25	2.2025	91290A432	39587	50	1
M8-1.25 x 30mm socket head cap	25	9.9	0.4844	4.95	12.11	1.2375	3.0275	1.25	2.2025	91290A434	39589	50	1
M8-1.25 nylock nut	50	9.36	0.1816	4.68	9.08	1.17	2.27	1.25	2.2025	90576A117	40163	100	1
5/16" x 1" shoulder bolt	16	1.11	1.26	17.76	20.16	4.44	5.04	1.25	2.2025	91259A583	26318	1	1
M3-0.5 x 8mm socket head cap	14	4.48	0.0839	0.011746	1.1746	0.0029365	0.29365	1.25	2.2025	91290A113	39503	100	1
M3-0.5 x 25mm	12	8.17	0.109	0.9804	1.308	0.2451	0.327	1.25	2.2025	91290A125	39508	100	1
M4 x 0.80mm flat washer	40	1.89	0.1084	0.04336	4.336	0.01084	1.084	1.25	2.2025	91166A230	11103691	100	1
M4-0.7 x 16mm socket head cap	2	6.22	0.0799	0.001598	0.1598	0.0003995	0.03995	1.25	2.2025	91290A154	39526	100	1
M3-0.5 x 12mm socket head cap	12	5.26	0.1597	0.6312	1.9164	0.1578	0.4791	1.25	2.2025	91290A117	39505	100	1
M4-0.7 jam nut	50	2	0.0225	1	1.125	0.25	0.28125	1.25	2.2025	90695A035	0141486	100	1
M4-0.7 x 20mm socket head cap	4	6.63	0.1698	0.2652	0.6792	0.0663	0.1698	1.25	2.2025	91290A168	11103313	100	1
M3-0.5 nylock nut	4	3.09	0.0813	0.1236	0.3252	0.0309	0.0813	1.25	2.2025	90576A102	40143	100	1
M3-0.5 x 16mm socket head cap	4	5.6	0.1446	0.224	0.5784	0.056	0.1446	1.25	2.2025	91290A120	39506	100	1
M4-0.7 x 25mm socket head cap	4	8.14	0.1776	0.3256	0.7104	0.0814	0.1776	1.25	2.2025	91290A176	11103314	100	1
M3-0.5 x 20mm socket head cap	30	6.47	0.2701	1.941	8.103	0.48525	2.02575	1.25	2.2025	91290A123	39507	100	1
M4-0.7 nylock nut	14	3.73	0.1028	0.5222	1.4392	0.13055	0.3598	1.25	2.2025	90576A103	40147	100	1
M5-0.8 x 10mm socket head cap	50	6.47	0.1836	3.235	9.18	0.80875	2.295	1.25	2.2025	91290A224	39544	100	1
M5-0.8 x 25mm socket head cap	16	8.55	0.0996	1.368	1.5936	0.342	0.3984	1.25	2.2025	91290A252	39548	100	1
M5 x 1.10mm flat washer	200	2	2.31	4	4.62	1	1.155	1.25	2.2025	91166A240	1140354	100	100
M5-0.8 x 12mm socket head cap	6	7.42	0.1493	0.4452	0.8958	0.1113	0.22395	1.25	2.2025	91290A228	39545	100	1
M5-0.8 x 30mm socket head cap	26	9.47	0.223	2.4622	5.798	0.61555	1.4495	1.25	2.2025	91290A254	39549	100	1
M5-0.8 x 35mm socket head cap	16	12.3	0.1123	1.968	1.7968	0.492	0.4492	1.25	2.2025	91290A256	39550	100	1
M6-1.0 nylock nut	2	4.32	0.1451	0.0864	0.2902	0.0216	0.07255	1.25	2.2025	90576A115	40155	100	1
M6-1.0 x 25mm low height socket	16	9.56	0.2221	3.0592	3.5536	0.7648	0.8884	1.25	2.2025	93070A149	90590	50	1
M6 x 20mm shoulder bolt	20	1.15	1.47	23	29.4	5.75	7.35	1.25	2.2025	92981A103	40001	1	1
1/4" x 0.045" flat washer	150	6.8	0.141	10.2	21.15	2.55	5.2875	1.25	2.2025	93286A029	76357	100	1
M5-0.8 x 35mm low height socket	50	14.33	0.9574	28.66	47.87	7.165	11.9675	1.25	2.2025	92855A528	90581	25	1
M6-1.0 x 35mm low height socket	24	8.59	0.268	8.2464	6.432	2.0616	1.608	1.25	2.2025	93070A153	90592	25	1
M5-0.8 x 30mm thermal socket head cap	8	n/a	37.57	n/a	3.0056	n/a	0.7514	n/a	2.2025	n/a	86029	n/a	100
M5-0.8 zinc nylon insert lock nut	8	4.09	12.4	0.3272	0.992	0.0818	0.248	1.25	2.2025	90576A104	1140151	100	100
1/4"-20 zinc jam top lock nut	16	7.85	0.21	1.256	3.36	0.314	0.84	1.25	2.2025	91837A029	37261	100	1
M6 -1 zinc top lock nut	16	8.92	0.2228	1.4272	3.5648	0.3568	0.8912	1.25	2.2025	93795A220	90680	100	1
1/4"-20 nylon insert lock nut	16	3.23	0.069	0.5168	1.104	0.1292	0.276	1.25	2.2025	90640A129	37018	100	1
M5-0.8x25 socket head cap	16	8.55	9.96	1.368	1.5936	0.342	0.3984	1.25	2.2025	91290A252	1139548	100	100
M4-0.7x45 mm socket head cap blue	48	n/a	100	n/a	48	n/a	12	n/a	2.2025	n/a	0137223	n/a	100
M4-0.7x35 mm socket head cap	16	10.09	31.46	1.6144	5.0336	0.4036	1.2584	1.25	2.2025	91290A182	1139530	100	100
M3 Flat Washer	12	1.56	1.73	0.1872	0.2076	0.0468	0.0519	1.25	2.2025	93475A210	40217	100	100
M5x16 mm socket head cap	16	7.86	0.1722	1.2576	2.7552	0.3144	0.6888	1.25	2.2025	91290A232	11103325	100	1
M5 washer	16	2.57	0.0497	0.4112	0.7952	0.1028	0.1988	1.25	2.2025	93475A240	MW6350000BX000	100	1
M5 x 30 mm socket head cap	16	9.47	0.1868	1.5152	2.9888	0.3788	0.7472	1.25	2.2025	91290A254	11103330	100	1
M5-0.8 nylon insert lock nut	16	4.09	7.04	0.6544	2.2528	0.1636	0.5632	1.25	2.2025	90576A104	1L2540000A20000	100	50
M3 x 30 mm socket head cap	12	9.09	0.2579	1.0908	3.0948	0.2727	0.7737	1.25	2.2025	91290A130	11103304	100	1
3.2 ID x M2 x M8 OD washer	16	n/a	1.05	n/a	16.8	n/a	4.2	n/a	2.2025	n/a	11128379	n/a	1
M4-0.70 x 14mm socket head cap	12	10	0.2008	1.2	2.4096	0.3	0.6024	1.25	2.2025	91294A193	39941	100	1
M6-1.0 x 70mm socket head cap	48	7.75	0.5086	14.88	24.4128	3.72	6.1032	1.25	2.2025	91290A348	39577	25	1
M8-1.0x16mm socket head cap	20	7.2	0.3982	2.88	7.964	0.72	1.991	1.25	2.2025	91290A418	35750	50	1
M6-1.0 x 130mm cap	12	10.59	1.29	25.416	15.48	6.354	3.87	1.25	2.2025	91287A264	11113079	5	1
M8-1.25 zinc jam nut	25	4.69	0.0529	1.1725	1.3225	0.293125	0.330625	1.25	2.2025	90695A040	0141490	100	1
M4-0.7 x 12 mm socket head cap	50	5.58	0.1857	2.79	9.285	0.6975	2.32125	1.25	2.2025	91290A148	39525	100	1
M4 0.7 zinc lock nut	25	3.73	10.28	0.9325	2.57	0.233125	0.6425	1.25	2.2025	90576A103	1140147	100	100
M12-1.75 hex nut	10	13.15	0.1947	1.315	1.947	0.32875	0.48675	1.25	2.2025	90592A028	40170	100	1
1/4"-20 zinc heavy jam lock nut	50	7.91	0.2897	3.955	14.485	0.98875	3.62125	1.25	2.2025	90648A029	37197	100	1
M8-1.25 x 25mm zinc socket head cap	25	4.31	0.2377	10.775	5.9425	2.69375	1.485625	1.25	2.2025	95263A633	0135936	10	1
M4 Washer	100	1.86	2.3	1.86	2.3	0.465	0.575	1.25	2.2025	93475A230	MW6340000A2000(	100	100
M6 Washer	100	2.12	3.55	2.12	3.55	0.53	0.8875	1.25	2.2025	91166A250	1140355	100	100
1/4" Washer	100	3.21	0.035	3.21	3.5	0.8025	0.875	1.25	2.2025	90108A413	1133004	100	1
1/4"-20 nylock jam nut	50	5.01	0.2573	5.01	12.865	1.2525	3.21625	1.25	2.2025	91831A029	0129156	50	1
1/4-20 x 1 hex head bolt	2	11.94	0.2215	0.2388	0.443	0.0597	0.11075	1.25	2.2025	91286A111	0115005	100	1
M4-0.7x45 SS socket head cap	50	7.17	0.1991	7.17	9.955	1.7925	2.48875	1.25	2.2025	91292A133	MS2530045A20000	50	1
M8x1.25 Jam Nut Zinc	50	4.69	0.0529	2.345	2.645	0.58625	0.66125	1.25	2.2025	90695A040	110141490	100	1
M6x1.0 LH hex nut	14	3.94	0.7073	5.516	9.9022	1.379	2.47555	1.25	2.2025	93510A120	MN2550000A2LH0(	10	1
M5x0.8 LH hex nut	14	11.06	0.164	1.5484	2.296	0.3871	0.574	1.25	2.2025	93695A130	MN2540000ZPLH0(	100	1
M3 SS A4 Flat Washer	12	1.76	0.06	0.2112	0.72	0.0528	0.18	1.25	2.2025	90965A130	LZ6330000A40000	100	1
M8-1.25 x 15mm socket head cap	25	n/a	0.4354	n/a	10.885	n/a	2.72125	n/a	2.2025	n/a	0154265	n/a	1
M10-1.5 zinc lock nut	50	8.45	14.835	8.45	14.835	2.1125	3.70875	1.25	2.2025	90576A118	1140167	50	50
M10-1.5 zinc cap screw	20	8.92	0.4962	7.136	9.924	1.784	2.481	1.25	2.2025	91280A636	0145161	25	1
M10x 30 mm socket head cap	20	7.61	0.7095	15.22	14.19	3.805	3.5475	1.25	2.2025	91760A515	11103373	10	1
M3-0.5 x 10 mm socket head cap	50	4.65	0.1843	2.325	9.215	0.58125	2.30375	1.25	2.2025	91290A115	39504	100	1
M3-0.5 x 18 mm socket head cap	6	6.94	15.57	0.4164	0.9342	0.1041	0.23355	1.25	2.2025	91290A121	39515	100	100
M3-0.5 x 14mm socket head cap	20	7.15	0.152	1.43	3.04	0.3575	0.76	1.25	2.2025	91290A119	11103299	100	1

Table 1. Inventory Database.

Part Name/Use	Lead Time (days)		DDLT		Penalty Cost	EOQ		Total Cost		Vendor Selected	OP
	McMaster	Fastenal	McMaster	Fastenal		McMaster	Fastenal	McMaster	Fastenal		
M8-1.25 x 20mm socket head cap	2	5	1.67	4.17	5	50.00	8.00	36.11	24.96	Fastenal	9
M8-1.25 x 30mm socket head cap	2	10	1.67	8.33	5	50.00	8.00	36.51	31.10	Fastenal	17
M8-1.25 nylock nut	2	5	3.33	8.33	5	100.00	12.00	63.81	31.88	Fastenal	17
5/16" x 1" shoulder bolt	2	5	1.07	2.67	5	4.00	5.00	31.64	39.81	McMaster	3
M3-0.5 x 8mm socket head cap	2	5	0.93	2.33	5	109.00	15.00	0.33	5.43	McMaster	2
M3-0.5 x 25mm	2	5	0.80	2.00	5	100.00	13.00	13.39	5.47	Fastenal	4
M4 x 0.80mm flat washer	2	5	2.67	6.67	5	100.00	14.00	1.09	18.22	McMaster	6
M4-0.7 x 16mm socket head cap	2	5	0.13	0.33	5	112.00	15.00	0.05	0.75	McMaster	1
M3-0.5 x 12mm socket head cap	2	5	0.80	2.00	5	100.00	11.00	8.67	6.95	Fastenal	4
M4-0.7 jam nut	2	5	3.33	8.33	5	100.00	29.00	14.13	9.00	Fastenal	17
M4-0.7 x 20mm socket head cap	2	5	0.27	0.67	5	100.00	10.00	3.63	2.41	Fastenal	2
M3-0.5 nylock nut	2	5	0.27	0.67	5	100.00	15.00	1.72	1.52	Fastenal	2
M3-0.5 x 16mm socket head cap	2	5	0.27	0.67	5	100.00	11.00	3.07	2.17	Fastenal	2
M4-0.7 x 25mm socket head cap	2	5	0.27	0.67	5	100.00	10.00	4.45	2.48	Fastenal	2
M3-0.5 x 20mm socket head cap	2	5	2.00	5.00	5	100.00	10.00	26.58	24.84	Fastenal	10
M4-0.7 nylock nut	2	5	0.93	2.33	5	100.00	14.00	7.22	6.16	Fastenal	5
M5-0.8 x 10mm socket head cap	2	5	3.33	8.33	5	100.00	12.00	44.30	32.13	Fastenal	17
M5-0.8 x 25mm socket head cap	2	5	1.07	2.67	5	100.00	14.00	18.67	6.90	Fastenal	6
M5 x 1.10mm flat washer	2	5	13.33	33.33	5	100.00	100.00	56.50	66.78	McMaster	27
M5-0.8 x 12mm socket head cap	2	5	0.40	1.00	5	100.00	11.00	6.09	3.33	Fastenal	2
M5-0.8 x 30mm socket head cap	2	5	1.73	4.33	5	100.00	10.00	33.56	18.77	Fastenal	9
M5-0.8 x 35mm socket head cap	2	5	1.07	2.67	5	100.00	13.00	26.77	7.43	Fastenal	6
M6-1.0 nylock nut	2	5	0.13	0.33	5	100.00	11.00	1.19	1.09	Fastenal	1
M6-1.0 x 25mm low height socket	2	5	1.07	2.67	5	50.00	10.00	22.58	11.52	Fastenal	6
M6 x 20mm shoulder bolt	2	5	1.33	3.33	5	4.00	5.00	40.75	56.59	McMaster	3
1/4" x 0.045" flat washer	2	10	10.00	50.00	5	100.00	16.00	139.58	84.10	Fastenal	100
M5-0.8 x 35mm low height socket	2	5	3.33	8.33	5	25.00	8.00	120.72	109.51	Fastenal	17
M6-1.0 x 35mm low height socket	2	5	1.60	4.00	5	25.00	9.00	35.22	19.54	Fastenal	8
M5-0.8 x 30mm thermal socket head cap	n/a	5	n/a	1.33	5	n/a	100.00	n/a	40.75	Fastenal	3
M5-0.8 zinc nylon insert lock nut	2	5	0.53	1.33	5	100.00	100.00	4.52	13.57	McMaster	2
1/4"-20 zinc jam top lock nut	2	10	1.07	5.33	5	100.00	10.00	17.16	11.08	Fastenal	11
M6 -1 zinc top lock nut	2	5	1.07	2.67	5	100.00	10.00	19.47	11.54	Fastenal	6
1/4"-20 nylon insert lock nut	2	5	1.07	2.67	5	100.00	16.00	7.18	5.51	Fastenal	6
M5-0.8x25 socket head cap	2	5	1.07	2.67	5	100.00	100.00	18.67	21.87	McMaster	3
M4-0.7x45 mm socket head cap blue	n/a	10	n/a	16.00	5	n/a	100.00	n/a	649.06	Fastenal	32
M4-0.7x35 mm socket head cap	2	5	1.07	2.67	5	100.00	100.00	21.99	68.31	McMaster	3
M3 Flat Washer	2	5	0.80	2.00	5	100.00	100.00	2.68	3.07	McMaster	2
M5x16 mm socket head cap	2	5	1.07	2.67	5	100.00	11.00	17.18	9.75	Fastenal	6
M5 washer	2	10	1.07	5.33	5	100.00	19.00	5.75	4.54	Fastenal	11
M5 x 30 mm socket head cap	2	5	1.07	2.67	5	100.00	10.00	20.66	10.25	Fastenal	6
M5-0.8 nylon insert lock nut	2	5	1.07	2.67	5	100.00	50.00	9.03	17.04	McMaster	3
M3 x 30 mm socket head cap	2	5	0.80	2.00	5	100.00	9.00	14.88	9.51	Fastenal	4
3.2 ID x M2 x M8 OD washer	n/a	10	n/a	5.33	5	n/a	6.00	n/a	35.27	Fastenal	11
M4-0.70 x 14mm socket head cap	2	5	0.80	2.00	5	100.00	10.00	16.35	8.06	Fastenal	4
M6-1.0 x 70mm socket head cap	2	10	3.20	16.00	5	25.00	9.00	63.78	63.62	Fastenal	32
M8-1.0x16mm socket head cap	2	5	1.33	3.33	5	50.00	8.00	21.38	21.43	McMaster	3
M6-1.0 x 130mm cap	2	10	0.80	4.00	5	5.00	5.00	44.30	30.44	Fastenal	8
M8-1.25 zinc jam nut	2	5	1.67	4.17	5	100.00	19.00	16.14	7.36	Fastenal	9
M4-0.7 x 12 mm socket head cap	2	5	3.33	8.33	5	100.00	12.00	38.29	32.39	Fastenal	17
M4 0.7 zinc lock nut	2	5	1.67	4.17	5	100.00	100.00	12.90	35.25	McMaster	4
M12-1.75 hex nut	2	5	0.67	1.67	5	100.00	10.00	17.88	6.58	Fastenal	4
1/4"-20 zinc heavy jam lock nut	2	5	3.33	8.33	5	100.00	10.00	54.02	43.60	Fastenal	17
M8-1.25 x 25mm zinc socket head cap	2	5	1.67	4.17	5	10.00	10.00	27.37	18.88	Fastenal	9
M4 Washer	2	5	6.67	16.67	5	100.00	100.00	26.36	33.25	McMaster	14
M6 Washer	2	5	6.67	16.67	5	100.00	100.00	29.87	50.13	McMaster	14
1/4" Washer	2	5	6.67	16.67	5	100.00	24.00	44.59	23.18	Fastenal	34
1/4"-20 nylock jam nut	2	5	3.33	8.33	5	50.00	11.00	37.57	40.57	McMaster	7
1/4-20 x 1 hex head bolt	2	5	0.13	0.33	5	100.00	9.00	3.25	1.43	Fastenal	1
M4-0.7x45 SS socket head cap	2	5	3.33	8.33	5	50.00	12.00	53.23	34.06	Fastenal	17
M8x1.25 Jam Nut Zinc	2	5	3.33	8.33	5	100.00	19.00	32.28	14.72	Fastenal	17
M6x1.0 LH hex nut	2	5	0.93	2.33	5	10.00	6.00	14.16	22.47	McMaster	2
M5x0.8 LH hex nut	2	10	0.93	4.67	5	100.00	11.00	21.08	8.26	Fastenal	10
M3 SS A4 Flat Washer	2	10	0.80	4.00	5	100.00	17.00	3.00	3.80	McMaster	2
M8-1.25 x 15mm socket head cap	n/a	5	n/a	4.17	5	n/a	8.00	n/a	28.65	Fastenal	9
M10-1.5 zinc lock nut	2	5	3.33	8.33	5	50.00	50.00	62.51	109.76	McMaster	7
M10-1.5 zinc cap screw	2	5	1.33	3.33	5	25.00	7.00	30.44	24.90	Fastenal	7
M10x 30 mm socket head cap	2	8	1.33	5.33	5	10.00	7.00	36.75	32.90	Fastenal	11
M3-0.5 x 10 mm socket head cap	2	5	3.33	8.33	5	100.00	12.00	32.01	32.21	McMaster	7
M3-0.5 x 18 mm socket head cap	2	5	0.40	1.00	5	100.00	100.00	5.70	12.74	McMaster	1
M3-0.5 x 14mm socket head cap	2	5	1.33	3.33	5	100.00	12.00	19.56	11.27	Fastenal	7

Table 2. Inventory Database Continued.

Future Recommended Work

Besides the creation of a database to implement proper EOQ and OP calculations in the GFR environment, research was developed regarding communication theory as well as lean manufacturing. The work done on these topics, while valuable, is at a preliminary stage and is therefore recommended as possible future work for the GFR team. Communication was studied because the inventory management database is unique tool for the GFR team that needs to be communicated effectively for implementation to be successful. Lean manufacturing was researched because of its possible use in implementing the inventory management system on the shop floor. A summary of these research results is as follows.

The database was a brand-new tool that needed to be properly communicated to the team. Based on past communications, it had become clear that communication within the GFR team could be improved. Therefore, in order for this tool to become used and useful, proper communication methods needed to be used. GFR is a large organization that spans international boundaries. The team members are students who are not paid for their work, and therefore keep varying hours. This dynamic reduces face to face interactions between team members and classifies GFR as a partially virtual organization. This means, that communication techniques among the team are often electronic in nature. Indeed, Gmail, Google Docs, and Skype are widely used communication and collaboration tools used by the team. While these tools are highly useful, it has been proven that electronic communication is often less effective and efficient. Many studies have shown that electronic communication is lacking compared to face to face when the subject matter is within a non-established context (DeSanctis and Monge 697). This means that communication over new or innovative ideas should be first conducted face to face. This is because misconceptions may be high when a new idea is first implemented, and face to face communications can help establish the context of an idea. Furthermore, studies have shown that building consensus or resolving conflict is best conducted through non-virtual communication (DeSanctis and Monge 697). This is because the parties can better convey tone and make sure their opinion is heard. A new idea also falls into this category of building consensus, because the team must all agree on it and its usefulness.

In this case, the “new idea” that was implemented was the inventory management system. For this to be done most effectively, the preceding ideas on communication were applied. The database itself is a virtual method of communication, but because it is a new and innovative approach, communication about it needed to be done in a non-virtual manner when possible.

First, while the official team pre-survey was completed online due to convenience, there were also face-to-face interviews completed. Prior to the onset of this project, the idea and suggestions for improvements were discussed in person with several team members.

Second, once the system is implemented, communication regarding its expected should be carried out through e-mail, online tutorial and an in-person announcement. The intent of this system should be discussed during a (non-virtual) team meeting and any questions should be discussed in person.

While the research conducted on communication was limited in this case, it provided useful insights as to how to best communicate this specific type of project to the team. The implementation of the project will be likely more successful because of this. In the future, communication in general within the team would be a helpful topic for future projects to fully focus on.

After the inventory management database was completed some physical improvements to be made in the shop to better manage the inventory were researched. The techniques selected follow some of the basic ideas of lean manufacturing. The research results are thus summarized:

Lean manufacturing is primarily concerned with the elimination of waste in processes. There are many different tools that have been developed to accomplish this goal. One of the first tools many organizations just beginning their lean journey implement is known as “5S”. These are the guidelines for creating a clean and organized workplace and were discussed in the introduction. This was the perfect tool for organizing the inventory in the GFR shop. It is a simple tool, which is important because GFR is not very knowledgeable in lean, and it easily applies to inventory management. The main benefit of the 5S system is that it eliminates waste, the main goal of lean, by reducing time spent look for inventory. In the 5S system, everything is in its place, and will be readily available when needed. In addition, any problems such as low inventory will be easily seen in an organized system.

Another important lean concept discovered that would have benefits to the GFR shop is pokayoke. A pokayoke is a device or system that helps prevent defects from occurring. There are two types of pokayokes: regulatory and setting. Regulatory pokayokes automatically control or give warning if a defect occurs. Setting pokayokes check for the proper setting or counts in a device. Pokayokes will prevent human error and the waste that goes along with it. They can serve as a visual signal to an operator that something is wrong, or something needs to occur (Nicholson 340).

In the case of the GFR shop, a defect that could occur, that is preventable, is an operator selects the wrong fastener. The pokayoke device to prevent this is having the fasteners in separate, labeled bins. This is part of an organized 5S system and in fact was already in place for some fasteners in the shop. Another defect that could occur is that the stock of a part reaches a re-order point, as calculated previously, and then nobody re-orders it. To solve this problem, a setting pokayoke could be used to make it visually obvious when the count of a part necessitates a re-order. In this case, it was determined that it would work to measure how far up the bin each part would reach when it is at its critical inventory level (in need of a re-order). This fill level could then be marked, so it would be clear when it was reached. However, once the re-order points were calculated, it was determined that since the re-order points are very low quantities (often 1 fastener and always less than 10) this method would not be necessary. A simple label will be sufficient.

DISCUSSION

Research Impact

Through research and the actual database creation, an inventory management system has been started for the GFR team. The research stage was necessary to determine the appropriate formulas and methods to use in creating the database. Through various research methods, including vendor website and GFR team information gathering, enough information was compiled to actually populate the database. The database contains all the information needed to calculate which company to use when ordering a part (McMaster or Fastenal), what the proper order quantity should be, and when to order it. This information was calculated for each and every part, which required intensive research from both outside vendor sources as well as the GFR environment. The database will be most useful if all team members reference it when both ordering and consuming fasteners. It will be also useful as a future project for the fasteners with dedicated bins to be labeled with the EOQ and order point information, so it is easily viewable when team members use up parts. Of course, many of the fasteners are not stored in bins and so this information will only be referenced online.

Three main formulas were utilized in the inventory system: Economic Order Quantity, Total Material Cost, and Order Point. The EOQ will be directly used by team members when determining how many parts they should order at a time. The TMC is used to determine which company, Fastenal or McMaster, is best to order from. The OP will inform team members when to order parts. The goal of following all three of these formulas is the reduction of costs. The team will save money by ordering parts from the cheapest source, and by only ordering the most economical quantities at the proper time. The system weights ordering costs against the costs of stock-outs and carrying costs to optimize the ordering process. Holding a large amount of inventory will increase carrying costs but will reduce stock-out costs. Holding a small amount of inventory will do the opposite. Holding a small inventory but ordering parts more often will lower carrying and stock-out costs but increase order costs. It is clear that these three costs must be balanced to choose an optimal middle ground, and this is what the EOQ formula does.

In addition to these core formulas, preliminary research was done on lean techniques. The most useful of these for an environment without much experience in lean, such as the GFR shop, is 5S, which is a formalized process of workplace organization. While the research done was appropriate for the GFR environment, many of the labeling techniques promoted by 5S were already in place for the fasteners inventory. The inventory management system is a form of organization in itself, and can be classified as a lean improvement. This is especially true because the use of a formalized EOQ system will help reduce inventory, one of the fundamental wastes as defined by lean methodology.

Another important contribution of the inventory management system is how it can be easily adapted into a physical tool that reminds users to follow the EOQ rules. A simple label can be placed into the bins of the fasteners (those that have space to be in the bin system) that lists the EOQ and OP. This will serve as an error-proofing device, or pokayoke. The research conducted on pokayokes helped cement this idea of a useful application for the database. This is error-proofing because a label right on the bin will make it difficult for a team member to make an incorrect choice when deciding how many to order, or if more even need to be ordered. Pokayoke devices are an important part of lean manufacturing and were discussed in the research results.

System Limitations

While the set-up of this fasteners database is a good start towards an effective inventory management system, there are some limitations in the system that should be addressed. Firstly, the EOQ system works best in situations where the annual demand for parts is relatively smooth. That is, the annual demand is spread out evenly throughout the year. This pattern does not fit well with the GFR work schedule. During fall term, the majority of the work done is computer-based design and so the demand for parts is very low. During winter term, the parts are actually built and the majority of the annual demand occurs. During spring term, the cars are finished and tested, and so demand drops off again. The month within winter term when the car is physically being built is really the full year of demand; few parts need to be replenished during other times. However, it was possible to adjust the EOQ model for this unique situation. The season length was chosen as 1 month (30 days) rather than a full year when calculating the demand during lead time. This helped to increase the accuracy of the reorder points. However, the demand within winter term is also very uneven. A team member may require the entire “annual demand” of a fastener all at once, as they get ready to build their design. The designs are generally built only once per year, and so the fastener’s demand may be very uneven. However, most fasteners are required by more than one designer, and the designers are all on slightly different schedules when building their designs. That means, the demand for a fastener may be smoother and occur consistently throughout the season. There may also be repeated demands for a part due to testing, re-designing, and fasteners breaking. Other limitations of the system include the need to estimate several of the parameters, such as penalty cost and carrying cost, because data was not available for a complete calculation.

Sensitivity Analysis

The main limitations of this system arise from the fact that EOQ and OP results may be skewed if the season length (period of smooth demand) is estimated incorrectly, or the penalty cost and carrying costs are not appropriate. To show that these estimates do not have a large effect on the results, and that effect is diminished as the estimates become larger (and usually more inaccurate), a sensitivity analysis was performed on each. The sensitivity analysis was performed on the data from an example fastener in the database.

Season Length (days)	Log(Season Length)	DDLT	OP
1	0	125	250
7	0.84509804	17.85714	35.71429
15	1.176091259	8.333333	16.66667
30	1.477121255	4.166667	8.333333
60	1.77815125	2.083333	4.166667
180	2.255272505	0.694444	1.388889
365	2.562292864	0.342466	0.684932

Table 3. Sensitivity Analysis on Season Length

As shown in Table 3, the season length parameter was varied from 1 day to a full year. Probable time periods in between were tested such as 1 week, half a month, 1 month, 2 months, and half a year. The season length changed the demand during lead time (DDLT) variable, which in turn changed the order point. The values show that as season length increases the order point will decrease. This is because a longer season will spread out the demand more and thus the DDLT decreases, so the OP can decrease. However, the season length has less effect on the OP as it increases. The difference in OP between a half year and a year season is much less than the difference between one day and a week.

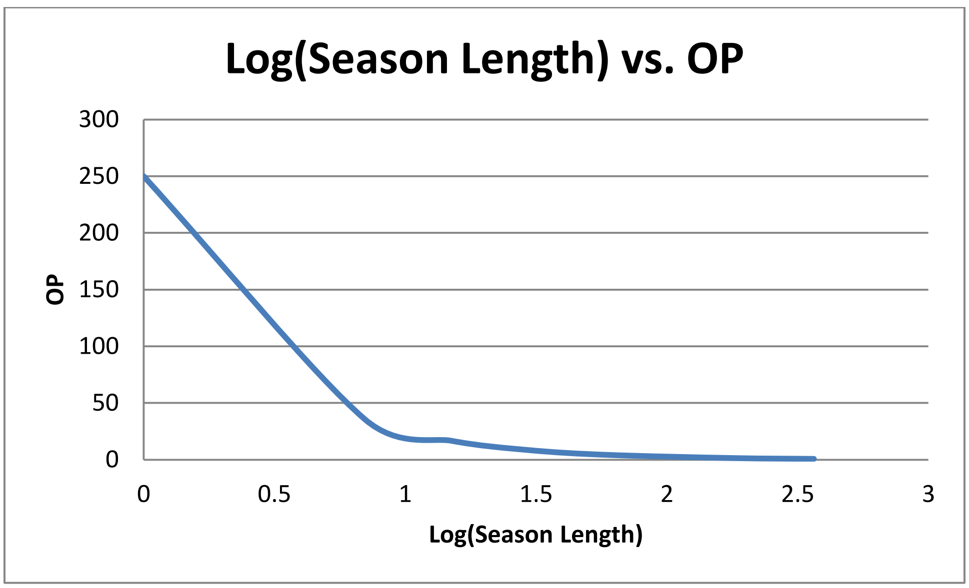

Figure 4. Log(Season Length) vs. OP

Figure 4 is a semi-log plot of the season length and the order point. The log of the season length is plotted because as it increases in orders of magnitude, the OP begins to level off. This chart shows that there is a negative linear relationship between OP and season length, but it becomes less important after about log(Season Length) = 1 or about

15 days. Therefore it would not be overly important if the season length was in fact greater than the chosen 30 days, because the OP would only decrease minimally. It is fairly important however if the season length is actually shorter. The relationship between these two variables is also moderately correlated, with an r-squared of 0.648. But based on information from experienced team members, 30 days is a good approximation of the season length. In cases where the season length for a certain fastener is less than this, for example 15 days, the OP should be twice as high. This can be covered without a stock-out though because the OP includes a safety stock, making it equal to double the DDLT. If the season length is less than 15 days, a stock-out may occur, but this is unlikely and designers should realize that the OP may need to be adjusted if such a tight schedule does occur.

Carrying Cost (% of Inventory)	Actual Value	Log (Carrying Cost)	EOQ
1	0.09	0	35
5	0.45	0.7	16
10	0.90	1	12
25	2.26	1.4	8
50	4.52	1.7	7
100	9.04	2	6
200	18.08	2.3	5
300	27.12	2.48	5
1000	90.40	3	5

Table 4. Sensitivity Analysis on Carrying Cost

Table 4 shows a similar analysis for the carrying cost. The carrying cost was varied from 1% of inventory value to 1000%. The actual value of the carrying cost is shown as well as the log, because the EOQ decreases very little as the carrying costs become much larger.

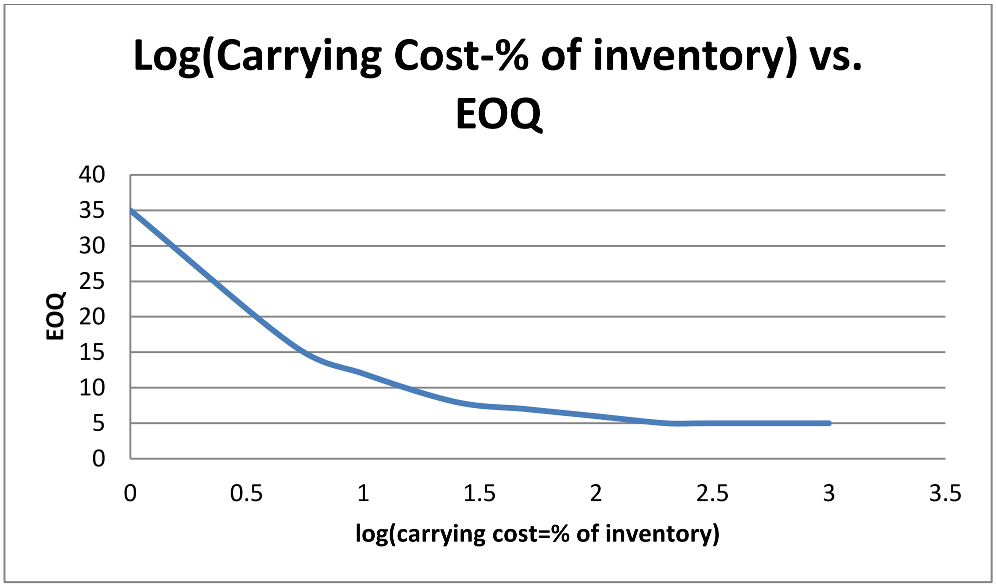

Figure 5. Log(Carrying Cost-% of inventory) vs. EOQ

Figure 5 is a plot of the log of the carrying costs and the EOQ. It is clear that as the carrying costs become exponentially larger, the EOQ flattens and reaches an asymptotic value of around 5. The current value of carrying cost is 25%, which is corresponds to an example EOQ of 8. This EOQ only decreases by around 3 if the carrying cost is drastically increased, so the possibility of a higher carrying cost is not that important to the calculation (and very unlikely as well). However, it is possible that the carrying costs should be estimated lower, especially since GFR uses technically “free” student labor and pays no rent for the storage space (though student labor moving inventory decreases labor that could be adding value elsewhere). It is feasible that carrying costs could be lower, such as 10%. This value however, only produces an EOQ of 12, which is not much higher than 8, especially since safety stock buffers are in place. Overall, the EOQ formula, while correlated fairly closely to carrying cost (the r-squared value is 0.733), is not highly sensitive to large changes in the carrying cost. The estimation of 25% can thus be held in more confidence.

Penalty Cost	Log(Penalty Cost)	EOQ
$0	$0	4
$1	$0	13
$2	$0	10
$3	$0	9
$4	$1	9
$5	$1	8
$10	$1	8
$100	$2	7
$10,000	$4	7
$1,000,000	$6	7
1,000,000,000	$9	7

Table 5. Sensitivity Analysis on Penalty Cost

Lastly, a similar analysis can be completed for the penalty cost. This is a particularly important analysis because the penalty cost was estimated to be $5 simply because that seemed to be a reasonable value. As seen in Table 5, adding a penalty cost actually increases the EOQ before it decreases and then levels off as it is increased beyond $5. The penalty cost initially increases the EOQ because an additional term is added to the formula, to account for the allowance of the back-orders associated with the penalty cost. When back-orders are allowed, the EOQ increases because when an order is received, a portion of the parts must be used to fill the back-orders, so more parts are needed. The EOQ then decreases as penalty cost increases because as the costs associated with back-orders are increased, less back-orders should be allowed, so the EOQ should be allowed to decrease again (Muckstadt and Sapra 14).

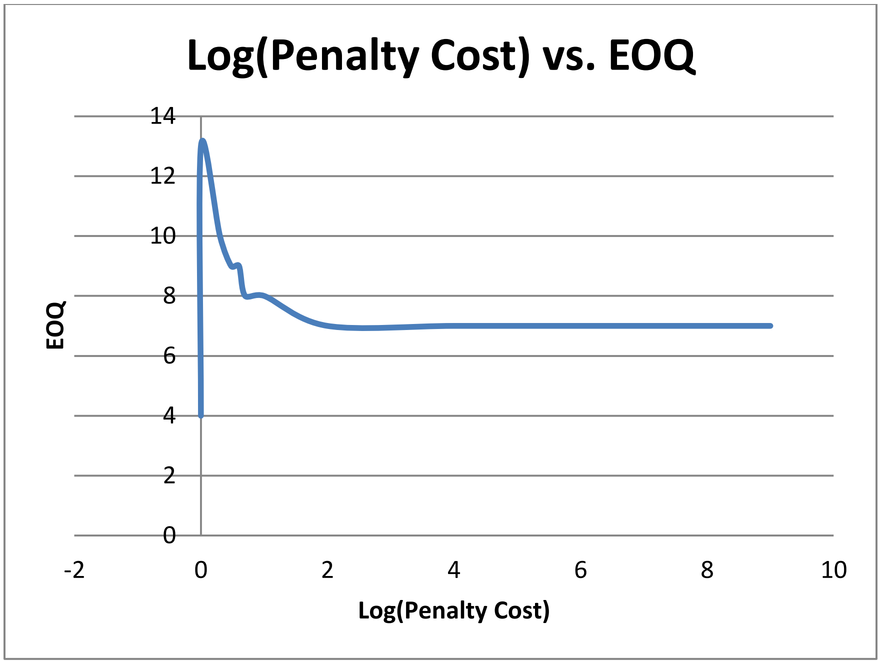

Figure 6. Log(Penalty Cost) vs. EOQ

This pattern can be seen in Figure 6, where the log of the penalty cost is plotted against the EOQ. In the case of the GFR team, back-orders are not desirable, and they rarely happen because of vendor reliability, but they should be included in the EOQ formula because they are possible. The chosen penalty cost is reasonable because the EOQ would barely change if it was increased, and it is not desirable to lower it any further because it is already quite low, and back-orders always cause some lost time and therefore value. In addition, the r-squared value for this relationship is 0.105, showing how little the penalty cost truly correlates with the EOQ. Overall, the estimation made of the penalty cost is acceptable and justifiable.

Through the use of sensitivity analysis on the model parameters, it has been shown that the EOQ and OP models are robust to those parameters which have been estimated, or which may vary as demand smoothness does (season length). This proves that even with data limitation, the EOQ and OP models are reasonable choices to be selected for implementation in the GFR inventory management system.

System Benefits

In discussions with team members, many do not know when to reorder fasteners that they have used, or the appropriate quantity to re-order. They may not realize another designer also requires the same part, and so they will not order enough. The database tracks all fasteners from all designers and so the appropriate order size and order point will be known. This will help prevent the costs of multiple orders of the same part, a poor practice that can be seen in the purchase request database records.

In addition, another benefit of this system is that it determines for the designers which vendor to use when ordering the part. Currently, most parts are ordered from Fastenal, because they allow fasteners to usually be purchased in small batch sizes (often times a batch size of 1). However, in many cases McMaster-Carr is actually cheaper (especially with parts where Fastenal does not allow small batch sizes). The inventory management system lists the appropriate vendor for each part, using total material cost as the deciding factor. If this system is used in the future, over $160 can be saved annually on fasteners just by ordering from McMaster-Carr when appropriate. As an added bonus, McMaster usually has shorter lead times than Fastenal.

While the database has some practical limitations, it shows team members that the GFR team is working towards a more reliable and organized inventory management system, and all fasteners must be accounted for. It provides the basis for creating a formalized system of inventory, which will reduce material costs and delays throughout the year. As a student organization with limited time and monetary resources, and strict deadlines to manage, there is no room for error. An inventory management system will allow the team to become more reliable and professional. Designers should always get the right part, in the right place, at the right time.

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