
# Management of the Design and Construction of the WPI Bamboo Bicycle

A Major Qualifying Project Submitted to the Faculty of Worcester Polytechnic Institute in Partial Fulfillment of the Requirements for the Degree of Bachelor of Science

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# Abstract

The goal of this project is to manage the design, assembly, testing, and marketing processes of a bamboo bicycle. This was achieved through the use of the axiomatic design method where each functional requirement is independent and the information content of the design is minimized. Additionally, the management team utilized tactical business techniques and analytics to coordinate the efforts of the overall MQP group.


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# 1. Introduction

The overall purpose of the MQP was to work with a group of nine management students, twelve mechanical engineers and three faculty advisors to create a bamboo bike and possibly prepare it for commercial production. We started off with a lot of enthusiasm and everyone was excited to get to work in A Term. As we progressed through A Term and early B term the designs were taking longer than expected. There were problems with communication, which resulted in ambiguity with who was making the decisions. As a result, these setbacks slowed our momentum. Problems with getting the necessary parts slowed us down even more, which led to a three term project becoming a four term project. There were several objectives that we, as a management team, wanted to address, the first and most important was to do everything we could to help the mechanical engineering students produce a fully functioning bamboo bicycle that could accommodate the average rider. After this we handled things like handling logistics of the materials, establishing a healthy team dynamic, enabling communication and identifying a target market to try and develop a marketing plan.

# 2. Literature Review

A quick internet search will reveal the many different types of bamboo bicycles that are readily available in today's market. These bicycles offer the same functionalities of a metal-framed bicycle, replacing metal with bamboo for the framing material. While this bike may be attractive to affluent consumers willing to spend more on a specialized bicycle, they currently do not meet the demands for a functional and affordable means of transportation. The use of more available resources, sourced in developing nations (i.e. bamboo), may help to lower the selling price. The ability to create a process of producing inexpensive and functional bamboo bicycles would meet the demand of consumers looking for inexpensive transportation as well as

providing a product that has an essence of style and flare. Many benefits and concerns, which will be examined in the following paragraphs, are apparent in the bamboo bike design. The key is to examine the benefits and costs in order to produce a bicycle that simultaneously maximizes the benefits while minimizing any negative concerns.

One of the first benefits of the bamboo bike design is the utilization of readily available and renewable resources for material compared to a potentially more expensive industrial product. The use of renewable resources is more environmentally friendly, as the materials needed to produce the bicycle do not need to be extracted from mines and manufactured. The bamboo can simply be harvested and replanted where necessary in order to ensure an unlimited and infinite bamboo supply. In other words, the carbon footprint for each bamboo bike is much less when compared to the carbon footprint made from a traditional aluminum, steel, titanium or carbon frame (GoGreenTravel, 2015).

The bamboo bicycle could be more ideal than a typical metal bike in developing countries due to the availability of local resources. Many developing countries, such as Ghana, do not have a matured industrial infrastructure in order to power tools and machinery for the production of metal bicycles at a consistent rate (Kho, 2008). Therefore, many of these countries must rely on other resources that are more readily available. When kiln dried properly, bamboo can provide an excellent substitute for metal frames. In fact, there are individuals who claim that the bamboo bicycle actually provides a smoother ride for users since the bamboo is capable of absorbing vibrations during travel in a different way than a metal bike frame could (Kho, 2008).

In developed nations like the United States, the main selling point for the bamboo bicycle is the style that it offers to potential customers. Consumers looking for a bicycle that offers a unique style and will turn heads, the bamboo bicycle is the bike that they have been searching

for. This could explain why the bicycles currently on the market today are so highly priced. After a thorough search for inexpensive bamboo bicycles, it can be concluded that one should expect to pay no less than $500 for a fully functioning bamboo bicycle. In a culture where everyone strives to be different and social status is a priority, the bamboo bicycle can progress into a hot commodity if the proper marketing strategy is conducted to inform consumers why they need this bicycle.

The qualities that bamboo possesses are what make it an attractive material alternative for building bicycles. Bamboo is an extremely light and strong material that absorbs vibrations well, and is often used for scaffolding in many Asian nations. Many avid bicycle riders are trying to avoid buying bikes that are heavy, as it decreases the overall riding experiences. Many consumers are often in the market in search of a light bike that can be easily picked up and transported, as well as a light to ride (Sparkes, 2009).

A major concern for a bamboo bike is the frame's durability over a long time period. If the bamboo is not properly treated or the joints are poorly designed, the bicycle may not be able to transfer loads properly ultimately resulting in a split bicycle frame. For this reason alone, it is critical that good engineering design takes place to ensure that the bamboo bicycle is strong and the joints are appropriately designed and constructed. Assuming that the bikes can be produced inexpensively and will be popular in developing nations, it is important that the bicycle can handle the loads and subsequent stress that is placed on it from the rider as well as the stress from the road conditions. In many developing nations, infrastructure may not be suitable for bicycles. Therefore, it is critical that the frame can handle bumpy road conditions, potholes, and any other kind of rough terrain that a bike rider might encounter while riding.

As mentioned previously, the price of the bicycle could be another major concern. The ability to produce a bamboo bicycle that can be sold at approximately the same price as a metal frame bicycle has yet to be done, making it a major barrier in the advancement of the bamboo bicycle on the main stream market. One of the functional requirements of the bamboo bicycle project is to create a bike that can be sold to developing nations. It can be assumed that very few people in developing nations could currently be able to afford a bicycle that is in the $500 price range; we believe that our bike could be sold for as low as $50 (Wysocky, 2014). Using the bare essentials, while maintaining the structural integrity of the bicycle frame, appears to be the most efficient manner to create an inexpensive bamboo bike. However, safety is the number one priority and must always be monitored in the attempt to cut down on the overall cost to produce bamboo bicycles.

## 2.1 Bamboo Bike History and Modern Relevancy

The first bamboo bicycle was invented in 1894 by the Bamboo Cycle Company Ltd. in London, England (English Patent No.8274). First displayed at the London Stanley Show, the bicycle caused quite a ripple and drew large interest towards the company. As a marketing ploy, the company decided to give a number of the bicycles to wealthy families in the area. In return, they requested the families to review the products and provide feedback. The testimonials were later featured in the company's 1897 catalogue, which can be seen on the next page in Figure 1 (Old Bike Europe, 2014).


*Figure 1 - Bamboo Cycle Co. Catalog*


*Figure 2 - 1896 Bamboo Bicycle*

Also pictured above, in figure 2, is the 1896 model by the Bamboo Cycle Company Ltd., which is on display to this day in the National Cycle Museum in Wales. The frames were designed from bamboo due to the combination of unique qualities of strength, corrosion resistance, and lightweight. Unfortunately for the Bamboo Cycle Company, the product was too expensive to reach the majority of the market. At the time bicycles made from steel were more financially affordable for the masses, forcing the declining business to close in 1899 (Bamboo Bicycle Company, 2015).

Fast-forward a century later and the bamboo bicycle trend has sparked once again. All over the globe, including the United States, Latin America, Africa, and Asia, companies have opened in an attempt to utilize strong and inexpensive bamboo. In 2007, one of the more prominent groups opened, the Bamboo Bike Project that is run by the Earth Institute of Columbia University. One of the main objectives of the project is to build higher quality bikes for members of rural communities within poor nations. Coinciding with their objectives, the group also hopes to create a sustainable model of the bamboo bicycle industry. Overall, these efforts are taking

place in order to provide transportation at a low manufacturing cost by utilizing local resources (Bamboo Bicycle Company, 2015)

The project was mainly funded by industry leader Calfee Design. Calfee Design rose to prominence after creating high end carbon fiber bicycles for Tour De France winner Greg Lemond. They utilized the success from the carbon fiber design to branch out to other experimental markets, one of which included their bamboo bicycle design in 1995. Calfee Design's owner Craig Calfee toured Africa shortly following the completion of their first bamboo bicycle and identified it as potential target market. In particular, Ghana had a surplus of bamboo and a shortage of bicycles; therefore Calfee decided to develop a package that instructed the people to build their own. He took his idea and partnered with the Bamboo Bike project in an attempt to meet both of their individual goals (Calfee Design, 2014).

On the other side of the pricing spectrum resides Erba Cycles Inc., who creates high-end bamboo bicycles and are headquartered in Boston, Massachusetts. Their bikes are designed with renewable resources in mind, in addition to the attractive aesthetic properties of bamboo. The company cites other benefits of bamboo including the dense cell structure, which dulls vibrations and creates a smoother ride. They claim the key to success is designing strong joints that can handle the load transfers associated with riding a bicycle. Erba's solution is to join the bamboo pieces with epoxy-resin treated hemp or flax fibers. The frame itself contains specialized heat-treated bamboo, which is then coated with water resistant polyurethanes. Their bikes are considered high-end, with a retail price that is over $2500. This price excludes the company from the price range for the average consumer and for Calfee's Ghanaian market (Erba Cycles, 2014).

## 2.2 Managing Large Groups

The WPI Bamboo-Bike MQP of 2014-15 is one of the larger MQP groups in WPI history. Nine management students are paired with thirteen mechanical engineering students,

which in itself poses a number of potential challenges to overcome due to sheer size of the group. Managing a large group of individuals requires effective communication, leadership, and agreement from the entire team. In order to support the management portion of the project, we have researched strategies and examples of how to and how not to conduct a project with this many members.

WPI's project based curriculum provides a number of opportunities for students to work on teams, and each student has faced difficulties associated with that. One major challenge often faced in group projects is determining how to hold team members accountable while ensuring everyone is pulling their own weight and contributing. In an attempt to solve this problem, the team created an online Google document which allows each person to record the work they did on a particular day. This also allowed the team to manage how time is being allotted and determine which areas need more people working on them. The management team also identified the importance of communication, as sharing information and ideas within the team is pertinent to advance the project's development.

While conducting group management research the team discovered the work of Andreas Wettre of Ramboll Management Consulting, who defines six factors that lead to dynamic management (Wettre, 2014).

1. Set a clear purpose
2. Prioritize projects
3. Utilize group diversity
4. Reflect on own role
5. Focus your communication and dialogue
6. Facilitate effective meetings

*Table 1- Six Factors*

Setting a clear purpose is critical because it is necessary to define a mission statement and set goals and objectives in order to provide direction for the project. Once the direction is

defined, the process of obtaining buy in from the whole group can begin. This process ensures that time and effort is efficiently being put in to achieve the projects purpose and to avoid non-value adding time. Wettre also harps on the utilization of group diversity, which directly applies to this project due to the wide variety of skills the members can offer to the team. By building upon different member's strengths for specific tasks, the project will likely experience a more successful outcome. A third lesson to be learned from these six factors is the importance of facilitating effective group meetings. This MQP mimics a real world business due to its multi-disciplinary approach; therefore we must use resources as effectively as possible. Time is the most abundant resource, therefore determining the most efficient ways to use our time, especially in group meetings, is a top priority (Wettre, 2014).

## 2.3 Managing Group Meetings

Meetings were ranked the number one productivity killer in the work place based on a survey given to professionals by Survey.com in 2013 (Smith, 2013). The problems faced in our group meetings are similar to others in working industry; they take too much time to complete, participants are distracted by technologies, the meeting often gets hijacked by one or two group members, and often it leaves everyone wondering why they attended the meeting. There are three main standards that one can use to gauge the effectiveness of a meeting;

1. Were the goals achieved?
2. Was the least amount of time possible used?
3. Did everyone walk away feeling it was a productive and sensibly run process?

*Table 2- Three Main Standards*

Neal Hartman, an expert on meetings from the MIT Sloan School of Management wrote an article in Forbes regarding running an effective meeting (Hartman, 2015). He states the first

step is to make sure the objectives of the meeting are clear. What will the end result be? Is the purpose of the meeting to make a decision, generate ideas, or even just the exchange of status reports from subgroups and individuals? If the objectives are made clear at the beginning of the meeting, then everyone should know what is trying to be accomplished and be provided with more focus. The following steps aid in addressing the second measure of efficiency, which is using the least amount of time possible to achieve goals; if something is not fulfill one of the objectives than it is considered superfluous and it should not be focused on.

Hartman's second step considers the invitees and ensures everyone in attendance is necessary to working on the problem, eliminating the unnecessary personal. Next, he states one needs to create a meeting agenda with a timeline. This should be created prior to the start of the meeting and circulated amongst invitees in order to gain feedback and make necessary adjusts. At the meeting, the agenda should be displayed where all members can see so everyone is aware of the timeline, helping the group can remain on task. The fourth piece of advice makes sure that no one dominates the meeting by talking more than their fair share. As a leader, it is the meeting chair's responsibility to attempt to get everyone involved and avoid listening to only one person's opinion for a lengthy period of time. The fifth piece of advice ensures the utilization of time as efficiently as possible, making sure the meeting starts and ends on time. Another suggestion provided is increasing meeting effectiveness by banning all technologies and any other distractions that people may use.

The seventh step advised is following up the meeting with an e-mail or in person conversation to verify everyone remains on task and works on the next steps. Some other suggestions to improve effectiveness at the end and post meeting is to summarize what was discussed in the meeting and confirming everyone agrees. There should also be a designated

secretary who is responsible for taking notes throughout the meeting and summarizing the next steps to be taken before the next meeting and circulate it to the group (Hartman, 2015).

## 2.4 Why have meetings?

A question that we have all asked during a meeting at one point or another is "what am I even doing here?" Most meeting experts agree on two things, that there are too many meetings in today's workplace and too many of them are a waste of time. This establishes a cycle for failure, people expect meetings to be unproductive and therefore they are. However, when a meeting is effective, it provides a number of benefits. At an effective meeting, there can be an exchange of expertise and perspectives, complex organization issues can be addressed, and people participate and buy in to the decisions concluded. These decisions tend to be more sustainable than decisions made without group consensus.

One of the main reasons for having meetings is that they tend to lead to better decisions, however, at many meetings this does not take place. People can get caught up in "group thinking" (where all think the same way) and just agree with what the most senior member believes. In a good meeting, the issue being decided receives input from numerous individuals with different experiences and perspectives. These varying inputs can bring up topics or ideas that one would have never thought of alone. Even the disagreements that arise in a group meeting can promote better decisions because they set the stage for creative solutions that may have gone unexplored.

Another reason to have group meetings is that it may result in more buy-in and consensus from all participants, two signs of having an involved workplace. When an individual provides input during the decision making process, they tend to feel their contributions are acknowledged and will likely work harder, this is why buy-in is imperative. When there is total consensus regarding a decision, it indicates that everyone agrees with the basic tenets of the idea even if

they didn't get exactly everything they originally desired. It is important that members of the group support the final decision concluded. If it is difficult to gain consensus, as a manager, it is imperative to have a face-to-face meeting in order to attain the buy-in desired. Group meetings also help everyone develop a better understanding of complex issues that arise.

In today's workplace, problems tend to be more complex and interconnected, having many different dimensions. Productive meetings expand everyone's understanding of organizational challenges because everyone can listen to other members' concerns regarding project issues, but from different perspectives. There will inevitably be conflict at every workplace. Some conflict may be constructive and result in group growth, but if the conflict goes unresolved, it can develop into a major problem, putting the company or group in jeopardy. For this reason, it is crucial that conflicts are resolved as quickly and thoroughly as possible.

A meeting is intended to be a safe session where concerns, issues, and emotions can be freely shared amongst the group members who then work on solutions to resolve any issues (American Management Association, 2014). One of the major benefits of meetings actually occurs after the meeting is finished. When a meeting ends with clear steps to be taken, people are put in a position to accomplish more before the next meeting. When a follow up email or a to-do list is sent to the group, people are informed with what it is that is expected and how it fits into the larger picture of the project. This also helps promote collaboration across the whole project team because they are aware of what others are working on and how it compliments their part. Meetings also provide individuals with the opportunity to practice a plethora of skills such as interpersonal communication, presentation skills, articulating ideas, asking meaningful questions, critical listening, working in a team, managing conflict and showing professional respect (American Management Association, 2014)

Although meetings have many benefits, they only occur when the meetings are efficient, productive and take place according to the predetermined agenda. Meetings are often held for no reason other than to have a meeting (Pittampalli, 2011). Repetitive, unnecessary, and unproductive practices should be minimized; not only do they increase costs to the company, but they also waste one of the most precious resources, time. An example of these practices occurred when Jack Welch became GE's CEO and began receiving a daily report of all the worldwide sales and inventory of the company. When Welch asked someone why he was receiving these reports they responded that they didn't know and that's how was always done like so; he deemed these reports as unnecessary information for his responsibilities and canceled them the next day.

Many meetings the project team has are unnecessary, but which ones are necessary and which one are not still needs to be determined. According to *Productivity Magazine*, we have meetings for three main reasons; to make decisions, pass along critical information, and for socialization purposes (Pittampalli, 2011). Most times in large groups individuals end up either disagreeing or all agreeing with one viewpoint, rarely is an important decision made. In terms of exchanging critical information, meetings work except they tend to be long, expensive and consist of a good amount of socializing; meetings can also prevent certain people from doing useful and value-adding work.

When individuals can make decisions on his or her own without input from the group, it proves to be more effective, but if an individual cannot make a decision on their own, then a meeting should be called in order to figure it out. It is also possible to communicate vital information using other methods such as e-mail, audio, video, text message, or wiki. These methods also have the added benefit of allowing individuals to process the information at their own rate in their own timeframe. By holding specific social events for the office one can stop

wasting meeting time for this. It is important to determine what actions need to take place in a meeting and what can be done using other processes.

# 3. Discussion

## 3.1 Axiomatic Design

A key element throughout our work during the Bamboo Bike project was the utilization of the Axiomatic Design method (Suh, 1990). Axiomatic design is an analytics tool, similar to planning or organizing, and is applicable to the work of engineers and managers. The rules or axioms can be applied to any design effort, they do not have to be applied specifically to an engineering project. The purpose of the axioms is to create plans and systems for the progress advancement of the project. The MQP team employed the axiomatic design method not only for the engineering elements of the project, but also the management aspects as well. The application of axiomatic design method simultaneously aided in keeping the entire group on task while increasing production.

Axiomatic design consists of three main elements: axioms, structures, and processes. Each function has secondary characteristics that must be included (Brown, 2012). Axioms require maximum independence with minimal information, while structures require design domains along with design hierarchies, and processes require zigzagging decomposition with physical integration (Brown, 2012). Below is a table that illustrates the purpose of each function's characteristics:

| | |
|---|---|
| **1.1 Maximum Independence** | *Avoids iteration and unintended consequences* |
| **1.2 Minimum Information** | *Maximizes chance of success* |
| **2.1 Design Domains** | *Decomposes laterally by type* |
| **2.2 Design Hierarchies** | *Decomposes vertically by level of detail* |
| **3.1 Zigzagging decomposition** | *Developing detail down through the hierarchic domains* |
| **3.2 Physical integration** | *Integrating detail up through the physical domain* |

*Table 3 - Axiomatic Design*

As seen above, each function possesses distinct purposes that help fulfill the entire setup. The first axiom function, maximum independence, is the most vital piece to having an effective setup (Brown, 2012). This feature permits the design to be controllable and adjustable while avoiding unwanted coupling. Unwanted coupling creates consequences not expected and does not allow each function of the process to work the way they were intended. Coupling occurs when two aspects of the design are interdependent of each other (Brown, 2012); therefore if one task is not completed, the other task cannot be completed either. This is a determining factor when planning or designing because it prioritizes the order in which actions need to be completed for success. The status of coupling is determined through Functional Requirement (FR's) & Design Parameter (DP's). The two are not always independent, but it is part of the axiomatic design process to determine which ones are forced to be interdependent for the greater good of the design (Brown, 2012). Minimizing information involves maximizing success; this is represented by the ratio of results based from FR, displayed in DP, compared to the actual number of outcomes that can be utilized to move on to the next FR (Brown, 2012). This ratio guarantees success because it filters unnecessary information, which allows for more time and less waste. The structure allows for the design to be communicated and created effectively. The domains of the structure are descriptions of the design, typically physical (Brown, 2012). They are typically different kinds of entities that make up the design. The hierarchies of the structure

bring classification to the descriptions of the design (Brown, 2012); both of them work together to make the design effective. Finally, the process is how the structure is created and set up. Zigzagging decomposition is part of the process that develops the detail for the hierarchies (Brown, 2012). The structures it creates are necessary for the axioms to work. The physical integration is putting everything together and giving detail to physical domain (Brown, 2012).

As management students, the use of the axiomatic design process was used differently as compared with that of the mechanical engineers. The method was found to be most effective when there was a need for organizing a meeting or a specific task. For example, axiomatic design was used to create and deploy a survey regarding potential customers of the Bamboo Bike. Axiomatic design was effective for this process because it provided a closer examination of each survey question. The group discovered the intended purpose behind every question and gained an understanding of why specific information was needed. The FR's consisted of the subject information we wanted to obtain, while the DP's included the actual wording content of the question; this format eliminated waste from the survey. The axiomatic design process was also applied to help setup the meetings. The entire project group consisting of management and mechanical students as well as advisors, met every Tuesday. As management students, we found it effective to assess the meetings in order to find value that the meetings added to the project. Below is the axiomatic decomposition for the Tuesday meetings:

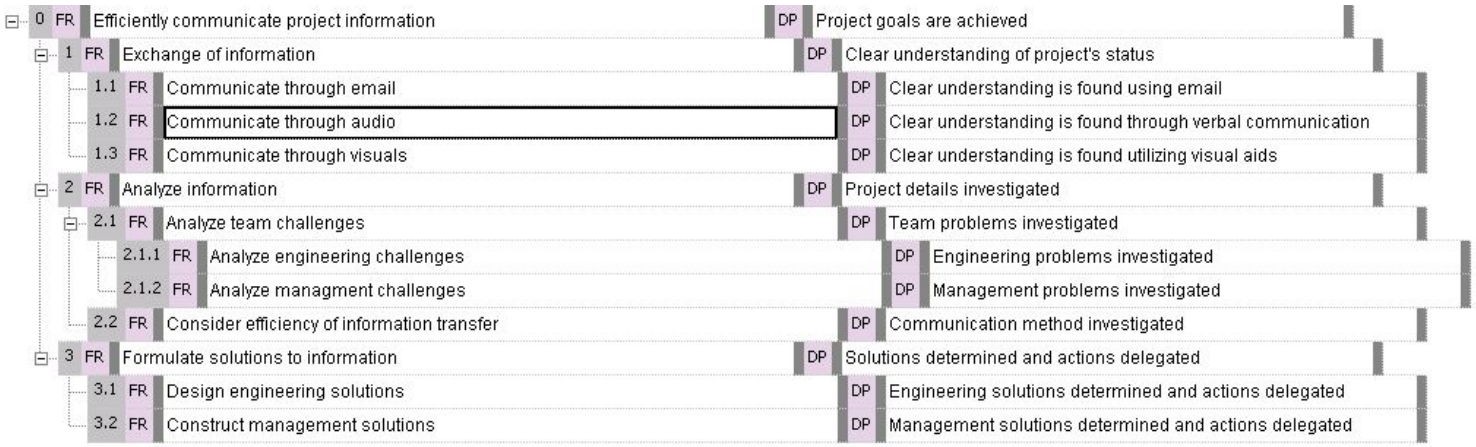


*Figure 3 - FR DP of Group Meetings*

The construction of the axiomatic design for meetings kept the agenda simple yet extremely effective. The FR's were goals from the meetings that could be given a solution via the DP's. The communication outlets were completely laid out and resulted in a quicker transfer of information than being presented at big meetings. The axiomatic design process not only produced consistent results with the mechanical students, but it also helped management students grasp control of specific components of the project and furthering progress.

## 3.2 Supply Chain

### 3.2.1 Materials Requirement Planning

#### *3.2.1.1 Overview of the MRP system*

In manufacturing environments it is crucial to track the amount of available and consumed resources in order to maintain efficient operations. Many businesses utilize the Material Requirements Planning (MRP) system, which is a computer-based inventory management system designed to assist production managers in scheduling and placing orders for items of dependent demand. In a production oriented business, dependent demand items are the components of finished goods such as raw materials, component parts, and subassemblies. The amount of inventory requested depends on the level of production of the final product

(Encyclopedia of Small Business , 2007). In other words, the utilization of the MRP system depends on the level of production of the product(s) along with the amount of materials needed.

For the bamboo bike MQP, the dependent demand inventory items includes materials such as aluminum and steel, as well as joints, fixturing components, tires, seats, sprockets, chains, and the bamboo that would be used for frame construction.

Determining what is essential to produce the bamboo bike requires a need to develop an MRP system, which yields the manufacturing plan. The MRP system consists of a schedule for finished goods that is then scheduled backwards into requirements for the component parts and raw materials needed to produce the finished bamboo bike within the predetermined schedule. When the MRP system was examined, we started from the finished goods stage and worked backwards, determining the raw materials requirements and labor request. Using an MRP system will quantify and realize our production goals because the intent of MRP is to approach the questions in mind of: “what is needed, how much is needed, and when is it needed?" (Encyclopedia of Small Business , 2007).

#### *3.2.1.2 Preliminary internet research*

With respect to the MRP system, it must be understood what exactly is being made and what materials the mechanical engineers intend to use to construct the final product with. We knew that a bamboo bike would be our final product, but the ambiguities that were ahead of us were the exact materials needed to construct the components of the bike, and ultimately, the bike design itself. As managers, we aimed to maintain effective communication with the mechanical engineer teams to learn how the bike was to be made and what would be needed in order to accomplish the manufacturing goals. Once the concrete criteria of what was needed was established, basic research on the material selection could begin.

Of course, the research would take longer than necessary if the criteria are not completely understood. Such criteria includes the size and thickness of the bamboo, the type of metal needed to construct the joints as well as its dimensions, in addition to other essential components. As research was conducted, it was kept in mind that price discrepancies and part variations exist, since all materials and parts possess different characteristics. This includes quality finishes, which lead to different costs. Ultimately, the materials and parts chosen most closely aligned with the design requirements that maximized quality while also being cost effective in procurement.

One aspect of our research that proved to be very useful throughout the MQP was communicating with local bike shops. Local Worcester bike store, Barney's Bicycles, had useful information as to where the raw materials could be obtained and how to distinguish the different criteria (Howard, 2014). For example, an expert could provide information on material stresses, manufacturing tolerances, durability and manufacturability. The manufacturability is important because the ease of manufacturing determines the cost. The criteria that the mechanical design engineers deliver and recommendations received from experts would determine what can be ordered. The goal was to have a variety of options to choose from, ultimately selecting the most efficient options that satisfy the MRP system developed.

Sourcing various national and international suppliers is another helpful strategy in development of a working MRP schedule, since each supplier possesses their own pros and cons. For example, one particular supplier may be very good in producing high quality bamboo, however it may be too costly or the shipment time period may be too long. Another supplier may offer the lowest quotes on raw bamboo; however the quality of the bamboo may be unacceptable. Once the suppliers' information is gathered and rated, accurate reports such as order schedules

can be implemented. Even though there may not be a fully developed business plan at that point, having an order schedule could be a useful factor in determining the length of time it would take to have the final product produced and readily available for the consumers.

#### *3.2.1.3 General application of the MRP*

While looking to minimize the time used in producing a bamboo bike, having a variety of prototype options is crucial in determining what criteria is most crucial and how it can translate to fulfilling public demand and satisfaction. While there are external factors such as marketing that impact the final product, internal operational factors determine production capabilities. Developing good reports in the MRP system can help address problems such as excessive scrap rates, late orders, or stock outs and help forecast and determine future inventory capacities and requirements (Encyclopedia of Small Business , 2007). Overall, having an MRP system could be beneficial in developing and optimizing a business process for the MQP.

### 3.2.2 Logistics

Managing the supply chain in any company is vital to saving money and time, which in turn allows for the best opportunity to develop a competitive advantage. There are a myriad of different principles that fall under the umbrella of Supply Chain Management. Perhaps the most important, that is found along every step of the supply chain in the planning and coordinating of details of the operation and serving as the engine that provides the optimal efficiency and effectiveness, is logistics. In simpler terms, logistics has an effect on all parts of the supply chain, but most importantly in terms of inventory management and transportation (The Growing Importance of Logistics, 1995). The areas of inventory management and transportation are also vital parts of the logistics planning. The overall process, from designing the bicycle all the way to the final product, the behind the scenes of how building the Bamboo Bike was achieved were imperative points of logistics that required a lot of focus and time to execute correctly.

Effective supply chain management and logistics do not promise direct success of a company, but they can have a major influence. Companies such as Amazon, Walmart, and UPS have used strong logistics to achieve a competitive advantage in their respective markets. Poor logistics can harm a company in the form of unnecessary costs, waste, and damage to customer relationships.

### 3.2.3 Manufacturing Process

#### *3.2.3.1 Value-stream mapping of the bamboo bike production system*

In lean manufacturing environments, it is vital that managers outline a clear process on paper in order to pinpoint the status of company operations as well as optimization paths that can be pursued. Ultimately, the levels of quality and price range are critical criteria that managers should keep in mind when manufacturing any product. In many cases value stream mapping (VSM), which is also known as material and information flow mapping, is an effective continuous improvement method of providing the skeleton of manufacturing operations. This mapping tool uses the techniques of lean manufacturing to analyze and evaluate certain work processes in one or multiple manufacturing operations. Through this method, waste is identified and reduced, and thus flow is improved in the manufacturing process. Having a customer driven information flow can help determine whether the process will be reliable or if it is absent of type II problems while also enabling the company to address the customers' wants. As defined by the Cambridge Dictionary of Statistics, a type II error is an instance that the null hypothesis is falsely accepted (Everitt, 2010). In a manufacturing environment for instance, it is measured by the probability of a batch of defective parts being accepted, which is also known as consumer's risk; the higher the probability is above the lot tolerance percent defective (LTPD), the more likely it is that the defective parts will be accepted. Factors such as timely delivery, changing customer demands and advances in innovation can influence customer satisfaction, therefore, determining

whether the process should be altered or left intact. One MQP goal is to determine the desired value of the bamboo bike in terms of quality and price by utilizing the VSM tool, which would, in turn, increase the chances of customer satisfaction and retention.

To produce an accurate VSM, managers must have these factors in mind; identify the product, create and evaluate a current-state VSM, identify problem areas, create a future state VSM and implement the final plan. For the MQP, the bamboo bicycle is the chosen product that the VSM will represent. In order to determine the current state of the VSM process, it is necessary to identify the items in the process; for instance the raw materials of the bike, equipment, inventory, human resources and parts in various stages are the flowing items. Design elements of the process such as logistics (i.e. shipping and receiving), production stages or machining operations, and inspection stations was then determined. Lastly, the customer service venues (i.e. front desk) outside the internal operations complete the VSM. Following the completion of the current map, there was an evaluation of the process and the steps involved; on a typical VSM every step of the process was included. For each step, production parameters include cycle time, TAKT time, work in progress (WIP), set up time, down time, number of workers, and scrap rate; these parameters were dependent on existing consumer demand on the product. For instance, to maximize output while retaining product quality to meet high consumer demand, the parameters would be minimized. A VSM also identifies where value was added in the manufacturing process, as well all other steps where there was non-added value, such as repetitive inspection of parts reworked. After analyzing and evaluating the current process of the product, any existing problem areas can be identified. It is crucial to be mindful that some problems in the system may come up as type I problems, which result when the null hypothesis is falsely rejected, as defined by the Cambridge Dictionary of Statistics (Everitt, 2010). In other

words, type I errors, also known as producer's risk, are defined by the probability that a lot of acceptable parts will be rejected; these naturally occur and thus should not be fixed. If the process was modified to address these issues, then consequences such as reduced quality, increased defects and scrap rate may result. On the other hand, type II problems, which occur as a result of a flaw in the process, should be eliminated. Unreliable machinery equipment or poor raw materials shipment from the supplier are such examples. Due to limited capital however, it may not be possible to fix all problems. Therefore, an analysis of each problem would be conducted, outlining the different pros and cons of each of them being solved. When type II problems are eliminated, KPIs would be installed at the changed spots of the process, which monitor the different parameters and quality output resulted from the improved system. Once the current process is changed to minimize problem areas completely, a future state VSM can thus be created. The last step of the value stream mapping process is to implement the new ideas, which will in turn create a more efficient lean manufacturing process.

#### *3.2.3.2 Lean Manufacturing*

While working on the bamboo bike project we were asked to look at it from several viewpoints; what managing a large group was like, facilitating the mechanical engineers, and what it would be like if the project was working as a small factory. Unfortunately we were only able to produce a limited quantity of bicycles, but we can still observe and attempt to apply the principles of lean manufacturing. Lean is an idea that can be applied to almost any process and its main principle is eliminating anything that does not add value (Chase, 2013). Something can only be said to add value if the customer is willing to pay for it, the activity changes the product bringing it closer to the finished product, or if it is done correctly on the first try. This is important because waste is defined as all non-value-added activities, therefore it is important to clearly understand the difference so we know what to eradicate and what to maintain and look to

improve. Specifically in a manufacturing operation, lean is when one identifies and eliminates the waste (non-value-added activities) through continuous incremental improvements and attempting to have products flowing at exactly the same rate that the customers pull it in pursuit of perfection (Chase, 2013).

When examining the definition of lean, one can notice that lean manufacturing is a relatively straightforward process with many different characteristics. One aspect is the flow of the product and its relationship to the pull of the customer for it (Chase, 2013). The 'flow' of the product is the movement between value adding processes and the 'pull' is the activating of a process when the customer wants to receive the product. In an ideal perfectly lean system, one would produce exactly the amount need at any given time and would operate with a zero inventory because there would be no reason to store the product. As an MQP team, it was decided how many bicycles were going to be 'ordered' from the team based on time and resources so the exact amount of bicycles will be made with little excess inventory.

If we were a business open to the public we would be producing less than the projected demand, however this means there is room for continuous improvements in the pursuit of perfection. The hypothetical point of perfection in lean manufacturing is the point where every action adds value; there is no wasted time or resources. This is the status that is being aimed for through continuous work on the process, usually during a Kaizen event (Chase, 2013). This is where a group of people work on a specific problem for a short time until solutions or counter measures is developed. Group assignments where the whole management team works together to achieve a goal, are similar to the Kaizen events. The most specific examples of the team working on a Kaizen event is working on the improvement of the group meetings. Solution ideas included having management students attend the mechanical student's meetings and other small changes.

The Six Sigma process was first developed by Motorola in 1986 and was later introduced to G.E. by Jack Welsh years later. During his tenure, the company's value rose 4000% in large part due to the use of Six Sigma (Welch, 2005). Many other companies utilize the process including: Amazon, Bank of America, Boeing, Caterpillar, Dell, Ford, Sears and even the United States Military (Wikipedia, 2014). Clearly, if all these organizations successfully use the technique, it is worth considering. Subscribers to Six Sigma thinking believe that each step is yet another opportunity for defects to occur, so it seeks to reduce variation in the process as a way to reduce the number of defects. "Variation is the enemy of quality (Deming, 2000). Although this seems like something said by mindless worker in a sci-fi film working on a factory line there is a reason for that, because it is correct. With variation comes defects, and products fall out of the acceptable range. A Six Sigma process is one in which 99.99966% of all opportunities to produce some feature of a part are statistically expected to be free of defects and fall within the expectable range. Three to four parts per million opportunities will have defects, even when producing at this range, which usually falls in about a four to five sigma level (Chase, 2013). Six Sigma is a goal that was set and has become part of the lingo. There is more to Six Sigma then simply trying to limit waste and reduce the number of defects; there are many analytical tools used to look at the process, evaluate it against a standard and take steps to improve the processes.

### 3.2.4 Learning Curve

The purpose of a learning curve is to model the relationship between efficiency and effort given (Chase, 2013). Experience generally shortens the time a task takes to be completed; this was observed in 1936 by the Wright Air Force base, where every time aircraft production was doubled, the total labor time decreased. Mathematicians have come up with different equations to fit the model of a learning curve (Chase, 2013).

Additionally to the learning curve, the experience curve should also be utilized. The experience curve models periods of “experience”, which is the result of production doubling while labor was in reduction. The bamboo bike manufacturing process would be able to display experience, once we have doubled our bikes in record time. The experience curve is very accurate in determining how trained a company is with their production process.

To gain experience, it is vital that every worker be trained properly with the tools and machining of the manufacturing process. Training is a part of work culture and allows a new comer to gain some “experience” before ever being hands-on. The difficult decision revolves around time allocated towards training; workers need initial experience but too much time becomes a distraction for actual production. As a bamboo bike company, workers will need proper machining training as well as tool knowledge. After the machines and tools are covered, the actual assembly needs to be properly taught and replicated. Once the assembly is finalized, experience can be gained through repeating the process on a daily basis.

## 3.3 The Critical Path Method for Project Management

In larger engineering projects, where there are many diverse activities involved, it is especially important to have a tool to help coordinate all involved towards a common goal. An effective tool commonly used in project management is the Critical Path Method (CPM), which is a procedure for scheduling that determines all the time and dependency information about each task in a project in order to calculate the critical path. Calculating the critical path means finding the sequence of activities that take the longest time to complete. If any other activities on the critical path are delayed, then the project will not be completed on time. In other words, activities on the critical path have no slack time (Kelley & Walker, 1959).

The steps for applying the critical path method are:

1. Determine all the activities involved in the project and estimate the completion time of each activity.
2. Determine the order of activities, i.e. which activities are dependent on other activities.
3. Map out the sequence of activities in a diagram.
4. Find the critical path (the path with the longest completion time).
5. Determine the earliest start/finish and the latest start/finish times for each activity.

*Table 4 - Steps for Critical Path*

Appendix E illustrates the information gathered from each of the four steps in the CPM. Step 1 is shown in the "Activity" and "Time (weeks)" columns. The "Designation" column simply assigns each letter their own letter in order to more easily identify activities in the critical path diagram. The results from step 2 are shown in the "Immediate Predecessors" column. The third step also shown in appendix E depicts the format of each circle representing a separate activity in the diagram. After mapping it out, the results of step 4 show the activities that are on the critical path, which is indicated by a "Y" in the "Critical Path" column. Finally in order to complete the fifth step, one must start from the beginning and calculate the early start and early finish numbers. When at the last activity, the process calls for working backwards to the beginning again. The critical path diagram for the bamboo bike project is shown in Figure 4. The blue circles are the activities on the critical path (Chase, 2013).

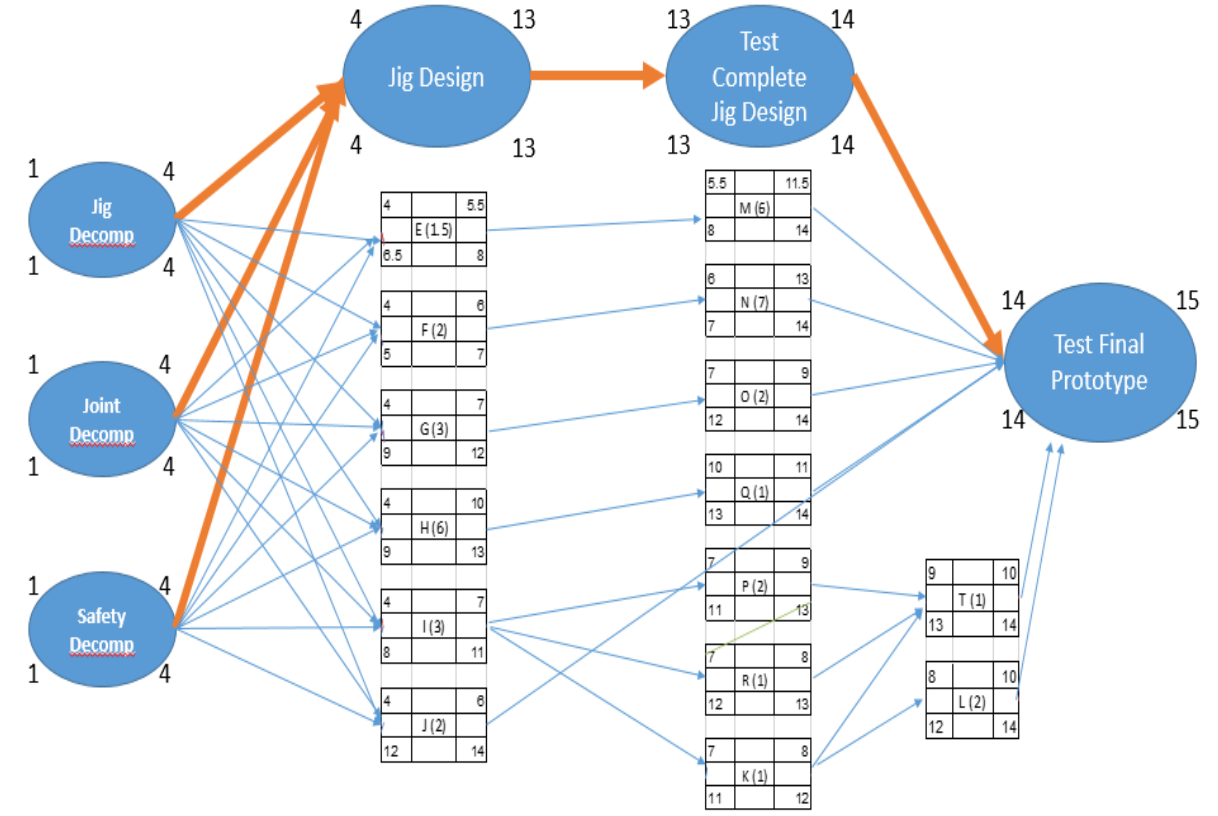


*Figure 4 - Critical Path of the Bike*

The benefits of the critical path method includes the promotion of proactive planning, allocating resources such as time, and continuously monitoring progress in comparison to timelines. Using the CPM sponsors more efficiency and productivity, reduces uncertainty, and increases the chances that tasks will be completed on time (Critical Path Method, 2015).

Some of the disadvantages of using the CPM includes that it requires an estimate of how long each activity should take, which can be very difficult to accurately determine. The critical path method also does not necessarily fix problems; it is merely used to inform project members of primary tasks with no slack time (Critical Path Method, 2015).

# 4. Marketing

## 4.1 Target Market

A key part of a corporation's business unit strategy is the marketing segment. Marketing is an organizational function and set of processes for creating, communicating, and delivering value to customers and for managing customers' relationships in ways that benefit the organization and its stakeholders (Shah, 2014). When referring to the value that is being delivered to customers, we are referring to the benefits that the customer receives from buying a product or service. In creating a marketing strategy, it is important to first identify a target market. After the target market is identified, the next step usually consists of using the marketing mix, commonly referred to as "the 4 Ps of marketing," to introduce the target market to the product or service that is being offered (Shah, 2014). These steps will be discussed in more detail.

As briefly mentioned before, the recognition of a potential target market is the first steps in creating a marketing strategy. By definition, a target market is a specific group of consumers at which a company aims their products or services (Shah, 2014). In order to identify a target market, it is important to first understand the customers' value needs. There are three main tactics used to help identify the target market and they include segmentation, targeting, and positioning.

## 4.2 Segmenting Strategies

Market segmentation is the process of dividing a marketing into relatively similar, or homogenous, identifiable segments or subgroups (Shah, 2014). These segments or subgroups consist of people sharing one or more characteristics that cause them to have similar needs. The fundamental bases of segmenting customers' needs are geographic, demographic, psychographic, and behavioral characteristics (Shah, 2014). The geographic location segmentation of subgroups

can be impacted by physical location such as continent, country, size of region (urban or rural), or other factors such as political boundaries, market size and density, and climate. Age, gender, income or social class, and ethnicity are just some of the factors in demographic segmentation, which focuses mainly on the characteristics of the customers. Psychographic segmentation is based on lifestyle variances such as social class, personality, lifestyle, and opinions or attitudes. Behavioral segmentation is defined by customer behaviors such as usage rates, loyalty status, brand preferences and most importantly perceived benefits.

## 4.3 Targeting Strategies

After the subgroups are determined, whether there are only two or several, it is important to decide which segments will be targeted. This is when the targeting strategies should be considered. While there is not just one strategy that is right for all consumer groups, strategies can be developed to tailor the specific requirements needed. There are several general targeting strategies that can be useful for selecting target markets, all of which fall under either a single-segment or multi-segment marketing strategy (Shah, 2014). The first and simplest targeting strategy is the single segment or concentrated approach. In this strategy, a single product is marketed to a single market segmentation and is often used by small companies with limited resources. An individual marketing approach is another strategy that can be used, although it is considered rather impractical in past practices, proving to be very time and resource consuming. In this tactic, the marketing mix is tailored on an individual consumer basis. The remainder of the marketing strategies fall under multi-segment marketing. A product specialization approach is used when a specific product is tailored to appeal to several market segments. Market specialization is the opposite of product specialization, where one market segment is selected and offered a selection of different products. Selective specialization is a combination of the two

previous approaches where different marketing mixes are offered to different market segments. Although the actual product may not to be different in this technique, it is the promotional messages that are altered. Finally, the largest and most broad approach is the full market coverage. This technique attempts to appeal to the entire market by using one of two means. The first, mass marketing, uses a single differentiated marketing mix and offers this to the entire market. The second is a differentiated strategy where a separate marketing mix is offered to each different segment, appealing to each in a different way.

Targeting strategies is best decided after performing a cost benefit analysis of all available strategies and comparing the results, determining which will be most appropriate for the situation (Shah, 2014). Besides performing the cost benefit analysis, there are other factors that can help eliminate segments with less promise. First, the segment should be similar and dissimilar. This ultimately means that the segment should be internally homogenous (similar) and externally heterogeneous (dissimilar) from the competing segments. The segment should also be substantial, or large enough to warrant a special marketing mix. The selected segment should also be identifiable and measureable in size, as well as accessible. By being accessible, the members of the targeted segment must be reachable with the marketing mix. The segment should ideally be responsive, meaning that the potential consumers are responsive to the marketing mix; the various segments tend to respond differently to different marketing mixes. Upon entering a market, a company should often target the most promising segment that matches its capabilities. Once there is a strong establishment and the beginning of growth within the market, the company can look to expand by pursing different additional strategies.

## 4.4 Positioning

Once the segmenting and targeting tasks are complete, the final step in selecting a target market is positioning. Positioning is the act of developing a strategy to influence how consumers

perceive a particular product or brand image (Shah, 2014). Perception by targeted customer segments can be influenced and improved by a company through strategic promotional activities and marketing mixes. There are several categories that serve as positioning bases, which essentially outlines the services or goods offered by the company (Shah, 2014). The categories include attribute, price and quality, application, product user, product class, competition, emotion, as well as others. Companies can focus on specific bases in order to appeal to consumer's needs. Based on previous results, it is typical that the most effective marketing strategies for companies tend to be more intense than less effect ones. A promotional strategy is usually considered effective when it is able to elevate marketing efforts as well as leading a consumer from knowledge to purchase of a product.

The target market that we have decided to focus upon for the Bamboo Bike is the student population of WPI. Based on the subgroups within the market that we have determined, the targeting strategy chosen is the product specialization strategy by offering the same product, with some customizable options, to different groups that make up the WPI student population. The positioning approach to reach potential customers will look to emphasize the low price and high quality, as well as the environmentally friendly benefits.

## 4.5 4 P's of Marketing

The marketing mix, commonly referred to as the Four P's of marketing, is a tool used to help determine marketing strategies for a new product or service entrant into the market. The Four P's consist of product, price, place, and promotion; controllable parameters that are subject to constraints (Solomon, Marshall, & Stuart, 2012). The key objective to create perceived value and generate positive reception by revolving the four parameters around the customers in the chosen target market.

### 4.5.1 Product

The first term, product, is a reference to the tangible (goods) or intangible (services) being offered to customers (Solomon, Marshall, & Stuart, 2012). The actual product itself, the bamboo bike, consists of three levels. The first level, the core product, is the benefits that the product offers. The second level is the actual product, which is the physical product itself and the final level is the augmented product, or the added value. The core product of the bamboo bike includes transportation, exercise, and any other benefits. Finally, the augmented product of the bicycle includes the saving of gas money instead of driving a vehicle and time saved compared to walking. The classifications of the bamboo bike as a specialty good that is durable for multiple uses helps in determining how to brand the product. The branding of the bamboo bike as an individual brand geared towards young, active, and eco-friendly college students looking for an easier means of transportation. While the product will not be available in national mainstream stores, it is intended to be available at the local WPI bookstore. The packaging of the bamboo bike will be rather compact and inexpensive with little environmental impact, for it will be produced right on campus. This will eliminate a lengthy transportation route of the finished product, cutting costs and excessive packaging.

### 4.5.2 Price

The second term, pricing, includes the many decisions regarding prices. The first step in price planning is to set the pricing objectives (Solomon, Marshall, & Stuart, 2012). Many key objectives that should be determined include maximization of profit, revenue, and profit margin, as well as customer satisfaction, image management, and company survival (Solomon, Marshall, & Stuart, 2012). Next the estimated demand should be performed, accounting for the change in unit sale that will result from a price percentage change. After demands are estimated, costs should be determined taking into account fixed and variable costs and the pricing environment.

The pricing environment is the trends of the economy and consumers, as well as the competition pricings. Once these tasks have been completed, it is appropriate to determine which pricing strategy will be used. A cost-based pricing strategy is based upon how much profit will be made after taking into account the cost of production and distribution.

Value-based pricing bases the price on effective value to customers relative to competing products (Solomon, Marshall, & Stuart, 2012). When a company sets prices in comparison to competitors, it is considered a competition-pricing tactic. The final strategy, new product-based pricing, has two approaches. The first, skimming pricing, aims to skim profits of the market layer by layer; the initial price is high and slowly lowers to make the product available to a larger market (Solomon, Marshall, & Stuart, 2012). Penetration pricing aims to gain a large market share initially with low prices and the anticipation of high sales numbers. The company will then increase prices once the market share is captured. Once the pricing strategy is determined implementation must occur.

### 4.5.3 Placement

The third Term, placement, is all about getting the product to the customer. Objectives that need to be met include, but are not limited to: distribution channels, market coverage, inventory management, warehousing, distribution, order processing, transportation, and reverse logistics (Shah, 2014). The desired structure of distribution would go from the manufacturer to the retailer to the customer. Since this company is part of the project, we would manufacture and distribute the products at WPI. Since this is where our target market is, it makes the most sense for us to manufacture our bicycles closest to the customer to cut down on distribution costs. However, if we end up with an inventory so large that we can no longer fit on campus, we would then need to look into other storage facilities and factor in that new cost into the cost of the bicycle. If we decided to move our production and storage off campus, new costs would include,

inventory costs, processing costs, and shipping and handling costs. As we are not currently using a space off campus, we do not yet have a projected expense.

If the business were strong enough that the bicycles could be sold in retail stores, the stores would most likely be specialty stores. A bamboo bicycle is a unique product and would attract very specific customers.

### 4.5.4 Promotion

The fourth and final ‘p’ of marketing is promotion. Promotion represents anything related to communicating information about the product to the customers; the goal of this is to generate a positive customer response (Shah, 2014). We would need to utilize as many marketing methods as possible and appropriate to have the most successful business.

Our first tactic would be to use direct marketing. These advertising techniques involve communicating directly with the customer. This can include things such as TV or radio commercials, newspaper or magazine advertisements, fliers, and catalog distribution. Along with this type of advertising, we would have to keep a database of all of the people we distribute our catalogs to. In this database we might include name, contact information, order history, and demographic information. All of these will help us improve our marketing techniques and make sure we are meeting customer demands.

We would also use the push and pull strategy of sales promotion. The push strategy would mean making sure the customer knows about our product and selling the brand. This involves creating unique and appropriate packaging, sale displays, and working with retailers to make sure they are stocking our product. The pull strategy involves getting the customer to come to us. This would mean advertising everywhere possible, generating good customer/management relationships so that they tell their friends about our product, and offering sales and discounts.

Utilizing both the push and pull strategies together is important because you can't really have a successful business with only one or the other.

## 4.6 Marketing Survey

At the beginning of the project, the team created a survey to send out to the WPI campus. The goal of the survey was to not only gauge interest in the bamboo bicycle itself, but also to see what the potential customers would want from the bicycle. The survey was sent to as many people as possible.

The survey included 16 questions and was answered by 368 people. The questions as well as the response data can be found in Appendix C. From those responses, the team discovered a lot about the potential customer base. For instance, 91% of the people who answered the survey are between the ages of 18 and 30 and 94% of the responses were from students. This means that if we were going to market this bicycle, the target market would be students and young professionals between the ages of 18 and 30.

While the survey results yielded that 83% of respondents would purchase a bicycle made out of bamboo, 83% also said that they did not currently own a bicycle on campus. The reasons for this vary, but the largest response at 44% said that they had a "lack of interest/no use" for it. This leads us to believe that perhaps Worcester is not the most bicycle friendly city and that our potential customers may be more willing to purchase our bicycle if they lived elsewhere.

From these results we know that these respondents utilize bicycles mainly for recreation, they bike less than once a month, and typically ride between one and five miles. We also learned that the top three things they consider when purchasing a bike are: 1) durability, 2) weight of the bicycle, and 3) aesthetics of the bicycle. Our potential customer's ideal bike, is a multispeed mountain bike that costs $200 or less.

# 5. Financing a Bamboo Bike Startup

## 5.1 Financial Analysis

The chances of a startup company in any industry achieving Fortune 500 status, is minimal at best. With the number of companies that attempt to achieve millionaire capital value, the percentages that achieve that goal are staggeringly low. The reason for this boils down to the number of obstacles that prevent critical progress forward. The successful startup companies are those that can overcome the first obstacles successfully and make it to profitability relatively unscathed from business expenses. This project has revealed challenges that startups will face on a daily basis.

One of those challenges that we were confronted with from the onset of the project was the difficulty in managing subdivisions of the overall team as one management division. Often times when the entire bamboo bike team has been separated for a period of time, the individual subdivisions needed to be brought together and communicate openly about their progress within their section of the entire project. Once all of the members of the bamboo bike team were on the same page, the project progressed more smoothly. Managing people is a major issue that large startup companies will be forced to face and overcome if they want to attempt at building a successful company?

With startup companies there are large expenses incurred while attempting to become profitable; every startup will be cash flow negative for a while until they can turn positive. Therefore, the objective is to have the ability to withstand the expenses long enough to help get the company off the ground. With a budget set at $2060.00, we were fortunate to have working capital to spend on bicycle supplies to be used at a future date. The majority of startups will not have the working capital to fund their “business child” and will be forced to take out a loan and often times enter debt.

Budgeting was still important to consider and reconsider overtime, due to the fact that we were still a startup company with an imperfect method at making the bamboo bikes. We would need to keep necessary funds on hand to deal with emergency situations if extra bicycle supplies need to be bought. The need to budget sparked the need to meticulously find suppliers who would give the greatest value for their goods.

The management team was successful in managing the money we had wisely, knowing that we had no additional sources of income available. We cannot gain any income until we successfully sell a bicycle, and the ability to obtain any disposable income from that sale would be near impossible. If our team failed to manage the budget wisely, the whole project could stall due to insufficient funds to buy needed tools, supplies, etc. The management team felt that maintaining the funds to keep the project running was a major priority. The team was able to spend just under $300 for all of the bamboo that would be needed for testing and building of the first prototype. This allowed for extra capital with great liquidity in order to buy supplies and parts when needed.

## 5.2 Break-Even Analysis

### 5.2.1 Fixed Costs

Fixed costs are costs incurred independent of number of units sold; typical including costs such as rent, utilities, salaries, insurance, etc. At the start, there will be no fixed costs for the bamboo bike because they are being manufactured in Washburn Labs, and therefore rent and utilities will not be an applied cost. In the future, however, in order to mass-produce bamboo bikes these will become applied costs.

### 5.2.2 Variable Costs

Variable costs are costs incurred dependent on the number of units sold. In other words, an increase in the number of units sold correlates to an increase in variable costs. The variable costs for the bamboo bike include bamboo, brakes, sprocket, wheels, derailleurs, and tires.

### 5.2.3 Revenue

Revenue is the selling price per unit. For the bamboo bike, we have determined the sale price to be $50 based on the campus survey results on what price most were willing to pay for it.

| **Per Unit** | $ |
|---|---|
| **Fixed Cost** | 0.00 |
| **Variable Cost** | 27.00 |
| Bamboo | 2.00 |
| Brakes | 3.00 |
| Sprocket | 4.00 |
| Wheels | 5.00 |
| Deraileurs | 6.00 |
| Tires | 7.00 |
| **Sale Price** | 50.00 |

*Table 5 - Survey Result Pricing*

The following is the formula used to calculate the number of units sold in order to cover your costs. Because there are no fixed costs at this point, we start making profit with the first bamboo bike sold.

$$\text{Break-even Sales Units} = \frac{\text{Fixed costs}}{\text{Sale price} - \text{Variable costs}}$$

$$\text{Break-even Sales Units} = \frac{0.00}{50.00 - 27.00} = 0 \text{ units}$$

*Equation 1: Break-Even Sales*

## 5.3 Discounted Cash Flow Analysis

The purpose of the discounted cash flow analysis is to determine the value of the company today based on future projections. The reason why it is called "discounted" is because a dollar is worth more today than a dollar tomorrow (McClure, 2006).

We begin with calculating the WACC (Weighted Average Cost of Capital), which is the company's weighted borrowing rate (Table 5). In the case of the bamboo bicycle, since we do not have any equity outstanding, our WACC consists solely of the incremental cost of debt financing. Although we do not actually have a loan for this project, in reality we would finance the prototyping and initial manufacturing costs. We assumed that this loan would have a loan rate of 8% and our tax bracket was a minimum of 25% because our income from operations in our first year will be less than $50,000 (McClure, 2006).

| WACC | | 6.00% |
|---|---|---|
| Debt | Formula | W*(r*(1-tr)) |
| | Loan Rate | 8% |
| | Tax Rate | 25% |
| | After Tax Rate | 6% |
| | Weight | 100% |
| | Weighted AT Rate | 6.00% |

*Table 6 - WACC*

To calculate the after tax rate, you multiply the loan rate by subtracting the tax rate from one. The reason why we do this is because interest paid on debt is tax deductible thus reducing the borrowing cost for companies. Because we would solely use debt financing, the weight is 100% and the WACC is equal to the weighted after tax rate, which in this case is 6%.

The next step was to come up with the projections to perform the discounted cash flow analysis. To be conservative, we chose to grow sales by 5% each year as well as choosing to have 3 different sales forecasts (each having a 33% probability). These three projections allow us to take the average of the three discounted cash flows where we have a net present value that incorporates different sales forecasts. Each table starts with the $23 contribution margin and multiplies it by the amount of bikes expected to be sole in Year 0. Each successive year 1-3, the amount of bikes sold is increased by 5% over the prior year's amount. With the projected CM dollar amount for Years 0-3, we then discounted the future amounts in Years 1-3 to present value using the weighted average cost of capital of 6%. Year 0 does not need to be discounted as it is the current year and thus at present value to begin with (McClure, 2006).

Thus in Projection 1, we started with 20 bikes sold during year 0 and with the 5% growth rate in sales, we have a total present value of $1,814 (Table 6).

| Projection 1 | | 0.05 | | |
|---|---|---|---|---|
| **Year** | **0** | **1** | **2** | **3** |
| **Projected CFs** | $460 | $483 | $507 | $533 |
| **PV** | $460 | $456 | $451 | $447 |
| **Total PV** | $1,814 | | | |
| **Initial Cost** | $300 | | | |
| **Net Present Value** | **$2,114** | | Probability | |
| | **$698** | | 33% | |

*Table 7 - Projection 1*

In Projection 2, we started with 30 bikes sold during year 0 and with the 5% growth rate in sales, we have a total present value of $2,721 (Table 7).

| Projection 2 | | 0.05 | | |
|---|---|---|---|---|
| **Year** | **0** | **1** | **2** | **3** |
| **Projected CFs** | $690 | $725 | $761 | $799 |
| **PV** | $690 | $683 | $677 | $671 |
| **Total PV** | $2,721 | | | |
| **Initial Cost** | $300 | | | |
| **Net Present Value** | **$3,021** | | Probability | |
| | **$1,007** | | 33% | |

*Table 8 - Projection 2*

In Projection 3, we started with 40 bikes sold during year 0 and with the 5% growth rate in sales, we have a total present value of $3,628 (Table 8).

| Projection 3 | | 0.05 | | |
|---|---|---|---|---|
| **Year** | **0** | **1** | **2** | **3** |
| **Projected CFs** | $920 | $966 | $1,014 | $1,065 |
| **PV** | $920 | $911 | $903 | $894 |
| **Total PV** | $3,628 | | | |
| **Initial Cost** | $300 | | | |
| **Net Present Value** | **$3,928** | | Probability | |
| | **$1,309** | | 33% | |

*Table 9 - Projection 3*

By multiplying all three Net Present Values by their respective probabilities of 33.33%, we get total NPV of $3,014.

## 5.4 Part Sourcing

Divulging deeper into the specifics of the project, it was crucial that we take an aggressive approach to our supply chain management and the logistics behind it based on the nature of our MQP. Beginning in A14' term, things got off to a slow start. The mechanical students were not quite sure what the management students were helping them with, and we

management students not quite sure what the mechanical students required help with. We initially made a few attempts at sourcing some bike parts and bamboo for them with poor results. We did not have specifics, and parts were essentially chosen at random as a result of a Google search.

What transpired after that at the beginning of B14' term was a significant rise in the level of communication, which allowed both sides of the project, mechanical and management students to become more valuable to each other, and, ultimately, enhanced our services to each another. This improved communication led to smaller meetings, more detail, better relationships across disciplines and ultimately a heightened ability to help each other. Specifically, we met with the safety and testing group of mechanical students and determined the specific elements of bamboo they were looking to test, and learned a lot about the diversity of bamboo and how vast the options really are.

Learning exactly what supplies were needed by increasing our attention to detail helped tremendously and gave us a jump on supply chain management, reduced wasted materials or money, and took full advantage of our limited time. Next came ordering the parts, which involved taking into account lead time on shipping, cost, and the possibility of some parts not passing our safety and testing groups tests, which would lead to re-ordering new parts.

Previously we mentioned the absolute importance of logistics planning as it pertains to supply chain management along every step of the way. This was something we knew about coming in to the beginning of the project based on our academic experience, but as we progressed through the project, and dealing with logistics in a real operation it became more and more apparent that logistics are incredibly essential to the total operation. While our logistics

planning did very little to directly design and build the vision of the mechanical engineering design teams, without it the bike could not be build (Sachdev, 2009).

The process of ordering parts for MQPs at WPI requires students to go through their respective schools to obtain the funding. Due to the mechanical students being allotted more funds per person we chose to order through the mechanical engineering department. The process includes filling out a purchase order form (Appendix B), calling the company to determine if they accept purchase orders, and then submitting the form to the Mechanical Engineering Department. Generally, the process went smoothly, but some companies do not accept purchase orders and there was one major hiccup.

The parts ordered included the jig frame and components, pedals, seat, brake and wheel set, pre-peg wrap, handlebars, and the bamboo itself. See table 9 for the list of expenses. Please note that additional items were laser cut free of charge due to connections in the industry.

| Company | Description of Order | Price |
|---|---|---|
| Air Incorporated | Jig Frame | $228 |
| Albracobra Metals | Jig Components | $25 |
| Bike Nashbar | Pedals&Seat | $288 |
| Coasties | Brake and Wheel Set | $290 |
| Hoff Company | Pre-Peg Wrap | $250 |
| Performance Bicycle | Headset | $43 |
| Sunset Bamboo | Bamboo Poles | $528 |

*Table 10 – Part Sourcing*

The particularly difficult item to order was the shipment of the bamboo. The supplier sold the bamboo poles at over 8 feet long and as a result they had to be specially shipped which created an additional cost. Next we were notified that the poles after being shipped from California had returned to the sender after one attempted delivery because the company had the wrong phone number on hand. We had placed the order December 15$^{th}$ and by February the poles were still

not in our possession. To counter the shipping costs again we asked the company to cut the poles in size so that they may be three day UPS shipped to us. Finally in early March the poles arrived, but at this point the project had to be delayed to D Term.

# 6. Company Direction

## 6.1 Organizational Behavior and Change

### 6.1.1 Decomposition of the Group Meeting Process

Organizational behavior is essentially the study of the impact an individual, a group, or a structure can have on human behavior within organizations (Boundless Management, 2014). Organizational change is when a company or organization goes through a transformation or modification of management structures or business processes (Basu, 2013). Organizational behavior and change, as it applies to our project, requires us to look at what we want to achieve during the course of this project, how we are structuring our team, and what we can all individually contribute to the final product.

The project started out by having weekly meetings on Tuesday nights at 9pm. The Mechanical Engineering students would gather on one side of the room, and the Management students on the other, a visual division of the roles we play within the scope of this project. We were asked to create a decomposition of the weekly meeting and determine why we should or should not have it. The task at first seemed confusing and a little overwhelming. Why do we really need to have this meeting every week? What are we gaining from being in a room together every week?

In an attempt to answer these questions, we came up with a few pro/con lists. The first list is the pros and cons of the weekly meeting.

### Weekly Tuesday Meeting

Pros:

- Address the issues that need to be heard in person by everyone in the group
- Bring about discussion with both advisors
- Implement new ideas with detail

Cons:

- Time efficiency
- Glancing over many details instead of focusing on specifics
- Redundancy and circulating back to the same topic
- Ineffective communication due to 25 people being in a room
- Left with more questions than answers
- Cannot form a clear consensus due to so many opinions
- Only form of face to face communication all week

After noticing that there were a lot of cons associated with the weekly meetings, we decided to change the structure of communication. We created two other pro/con lists to help us think of what we could do instead of the weekly meeting. The first one evaluated Management students going to Mechanical students' meetings to get information from them and help answer any questions they may have. And the second one evaluated only having weekly meetings twice A Term.

### MG's at Smaller Meeting with ME's

Pros:

- Get greater detail of ME progress and how MG's can help
- Clearer understanding of the schedule
- Increase the frequency of contact between MGs and MEs
- Working as a cohesive unit as opposed to 2 different groups

Cons:

- Not everyone in project gets details at meeting
- Less face time with advisors
- Possible MG interference

**Twice A Term Tuesday Meetings**

Pros:

- Plenty of progress to go over
- Progress that applies to whole group
- Saving time, by disregarding smaller tasks handled at smaller meetings.
- Updating the Advisors

Cons:

- Possibly longer meeting due to lapse of time together as big group.
- Big changes might not be addressed in a timely manner

After much discussion, it was concluded by the group as a whole that it would be beneficial for management students to sit in on mechanical student's meetings and that we would only hold weekly Tuesday night meetings if we agreed that we had enough to talk about at them and some progress could be presented.

### 6.1.2 Company Structure

Our company's management structure is from the center out, much like Helgesen's "web of inclusion". This structure allows for the members of the company to relate individual parts back to the greater goal. Helgesen teaches us that this structure is much like a spider's web.

> "The architect of the web works as the spider does, by ceaselessly spinning new tendrils of connection, while also continually strengthening those that already exist. The architect's tools are not force, not the ability to issue commands, but rather providing access and engaging in constant dialogue" (Mistifier, 1995)

We believe that this is the best way to foster leadership within our company as well as keep the lines of communication open. This web puts the managers in the middle so that people who report back to management don't feel like they have to go through chain of people to communicate. Each part of the web has responsibilities and with this structure, we are constantly

going back and forth about our advancements or setbacks. Our company structure can be shown in the following chart:

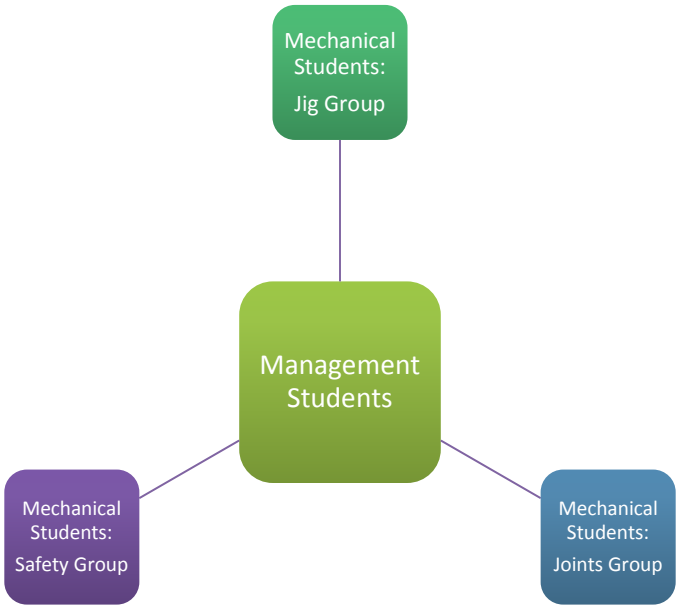


*Figure 5 - Company Structure*

### 6.1.3 Cross Business Functions

The unique thing about this project is that we are combining both management students with mechanical engineering students. This is unique because most Major Qualifying Projects are structured within one's own major. We combined these two groups together to try to utilize the talents and skills of students of different disciplines, much like the Interactive Qualifying Project, to realize the goal of building and mass producing bamboo bicycles. While the mechanical students bring to the table the knowledge to design and test a bike, the management students bring knowledge about finance, organizational structure, marketing, operations, and supply chain management. In the real world, generally, businesses are more successful by combining people with different levels of experience and skill sets. This allows the goal to be seen from different points of view and increases the problem solving power.

### 6.1.4 Accountability

Accountability in this project refers to the responsibility of team members to complete their assigned tasks on time and with quality results. Upholding accountability is important to the success of the project because each person needs to be contributing their part to the project so that no resources are wasted. Common ways to increase the accountability of team members are to track time spent and attendance, having individual team members create SMART goals, creating incentive programs to motivate individuals to have higher accountability for their work, prioritizing individuals' tasks, and monitoring progress. The ways management has chosen to increase accountability for this MQP is by tracking time and attendance, as well as monitoring progress. By taking attendance at weekly group meetings, we can better evaluate individual's participation levels in the project. We have also asked team members to input time spent on the project daily in order to improve time management within the project and monitor individual productivity levels so that management can see more specifically where resources are not be used most effectively (TimeWellScheduled, 2015)..

One of the downsides to our attendance management is that attendance was only taken at the weekly group meetings and may not accurate depiction of an individual's willingness to participate because the weekly meeting time does not fit the schedule of every person involved in the project. Also the downside to the system we implemented for tracking individual's time spent daily on the project is that it has not been adequately used; most team members do not input their time spent and therefore the data is not accurate. The purpose is to compare the amount of work done with the amount of time contributed to more accurately gauge how effective our time management is and how productive an individual is. Because the data we've gathered is insufficient, it is difficult to apply individual accountability.

## 6.2 Company Direction

### 6.2.1 Company Mission Statement

The Worcester Polytechnic Institute Bamboo Bicycle Company (WPI BBC) is committed to creating high quality bamboo products by utilizing axiomatic design, and business principles rooted in the WPI curriculum. The WPI BBC is a cross functional student organization adept at maximizing resources and innovation. Our bicycles are created while considering efficiency, global technology, and societal impact.

### 6.2.2 Project Goals

1. Demonstrate mechanical and managements students' knowledge through a senior capstone project.
2. Establish the foundation for a potential future business.
3. Develop industry leading bamboo bicycles designs by utilizing the axiomatic design method.

### 6.2.3 Project Objectives

1. Author final Major Qualifying Project report by end of term C 2015.
2. Create a working prototype by the end of term C 2015.
   Establish on going communication efficiency to maximize the project's effectiveness.

# 7. Results and Conclusions

Over the course of the project timeline, our team has overcome a number of challenges to complete the project. The major challenges faced include communication, logistics, and team organization as a whole. The anticipated completion time of C Term was extended into D Term in order to provide the team with the opportunity to produce a final project with a higher quality. Although this extension was not intended, it was necessary and the extra time allowed the team to come together. The bicycle prototype was completed before project presentation day, however our initial projection of producing five to ten prototypes was not met.

One of the major reasons the project took longer than expected was due to the lack of communication between and within disciplines. Initially, the management group held weekly meetings that lasted over an hour and often little was accomplished. Discussed topics were irrelevant to all members of the team and the management students quickly realized that we were wasting the most precious resource, time. In order to communicate objectives more effectively the team devised a new method for the meetings. This method consisted of limiting discussion topics to those that were crucial for the entire group to hear, and holding the meeting chair responsible for running the meeting according to the preapproved agenda. Other information was communicated via focus groups and email. Focus groups were a successful approach to get smaller topics accomplished, while email was at times ineffective. The management students found that meeting face-to-face was more effective than exchanging emails back and forth.

Communication proved to be a challenge when attempting to organize the entire Bamboo Bicycle team. It took a long time to determine who was responsible for the individual parts of the project, especially because there were over 20 members working on this project. It was necessary to find way to make sure each team member was contributing meaningful work while checking that different individuals did not repeat the same work. As management students it was our responsibility to determine deadlines, but it often occurred that tasks were not completed on time; ultimately resulting in the extension into D Term. It was problematic to hold individuals accountable, even after the institution of the time sheet as discussed in section 7.1.4. If WPI was to conduct an MQP project of this magnitude again it would be in that team's best interest to devise an effective way to hold members responsible for delivering their work in a timelier manner.

Other obstacles also arose during the course of the project, specifically as it relates to logistics. Parts sourcing appeared to be a simple process, however we found that some of the supplier choices were hindering progress. For example, the first bamboo order was placed in early December but the shipment did not arrive until March. Problems occurred with the shipment and as a result the safety team was forced to wait to test the bamboo. It was discovered that when ordering from more well-known suppliers, such as McMaster, the materials arrived more quickly and with less trouble. In addition to parts logistics, scheduling logistics were also a problem. Due to the size of the team, it proved to be difficult to schedule meetings when everyone was available, which led to individuals missing out on important information and decisions. To help remedy this, the team used resources such as When2meet, Google Docs, and Dropbox that were pertinent to the transfer of information.

Despite the challenges highlighted in this section, overall the project was a successful learning process. Over the course of the year, the students gained valuable knowledge about managing large-scaled projects. The MQP exposed the team to real-world situations, providing experiences that can be applied to the students' future careers. As a result of the MQP, group members acquired the skills to indicate the warning signals of a large-scale project falling off schedule. These forewarning signs include miscommunication amongst the group, missing deadlines or due dates, little to no overall project advancement, as well as others. Learning from the mistakes of mismanaging project time, group members also attained knowledge regarding different processes and procedures that can be utilized in a large project to avoid wasting valuable time. The project also taught the group that challenges presented by bosses or leaders, in this case the advising professors, could hinder project progress and illustrated the importance of managing not only the self-directed team, but also the project bosses or leaders.

Some of the major takeaways from the MQP include how to communicate effectively, inter-disciplinary collaboration, delegation skills, and the ability to run a well-organized meeting. Overall, the management team is confident that as a result of the MQP experience that each member will be effective in future employments when assigned to lead such an effort in respective work fields.

# Appendices

## Appendix A – Weekly Journals

This appendix features a weekly narrative of the process to complete the 2014-2015 Bamboo Bicycle MQP from the point of view of the management students. We have documented the process in order to highlight the challenges associated with such a large teams. The process began in the summer of 2014 as students began the axiomatic design learning process. As A14' started we instituted weekly meetings of all members and advisors to keep the project focused and moving the right direction. Additionally the mechanical students were divided into three groups: joints, jig, and safety. The management students determined which areas they would focus on but did not directly divide like the mechanicals. In the following sections you can see how the project transformed throughout the process and what the feelings of the students involved were.

### Week of 9/9/13 – 9/15/14

During this week the management students find themselves beginning to get a grasp on the project. After early troubles including ambiguity and communication problems, the project is starting to get some structure. The initial Gant chart is coming together which should effectively schedule the major tasks. Unfortunately only two of the ME groups have responded with their own personal Gant charts. In addition to the lack of responses for the Gant chart, we also asked for a list of the parts that need to be sourced in order to build the bike. This has also not been returned so we have created our own parts list. We have created a Dropbox folder to share information within in the group and it is working well so far. The management students have decided to meet on Wednesday and Sunday nights to go over weekly problems and delegate tasks.

In the future we will need to build more effective communication between the two groups, because without their input for us or vice versa the factory will never produce any bikes. This will be brought up during the Tuesday 9pm meeting which we hope will be more efficient than the first two weeks.

### Week of 9/16/14 – 9/22/14

This week the Bamboo Bike Management team worked mostly on continuing to improve what we have done and motivating the Mechanical Engineers to do the same. The ME's have been doing AD decompositions to help them with their part design process, the MG's are also using AD to help us complete the tasks we need to. We started work on a decomposition for the meeting and a survey we plan to send to the WPI community. Along with the decomposition we worked on making the critical path easier to understand for the ME's, refining what questions we will be using and how we will be asking them for the survey, and keeping the Gantt chart up to date. We have been focusing on how to better relate to the ME's what we want and what our works mean to them, like how the critical path and Gantt chart are there to help them keep on pace and which tasks they should be focusing on and when. Another reason we are doing decompositions is so that we can understand what the ME's are presenting when they talk about theirs.

### Week of 9/23/14 – 9/29/14

This week proved to be a very effective week for the Bamboo Bike Management and Mechanical Engineering teams. Communication has improved drastically after making a point of mentioning communication issues at the September 16$^{th}$ meeting. The three mechanical engineering teams completed their assigned task of finishing their initial decompositions and their presentations to the larger group were above satisfactory. A few revisions are necessary of all of the decompositions but the overall framework of each decompositions is solid. The

management team decided to focus on developing a critical path diagram to demonstrate the available slack time on each of our objectives outlined in the Gantt chart.

As the designing stages begin for the bamboo bike, the management team will have to have strong communication with the mechanical engineering teams to ensure that the ME's have everything they need to complete their initial designs.

### Week of 9/30/14 – 10/6/14

This week has proved to be productive on both the MG's and ME's parts. The collective group came to the conclusion that the initial designs will created with room for flexibilities and prohibit as many restricting factors as possible. The decision to present decompositions for all items/actions (MG's and ME's) prior to presenting to the entire group was also made.

The MG's focused on completing a final version of the Critical Path that provided a target pathway with no afforded lag time as well as several other pathways that allowed time for variation. Changes and updates were also made to the Gantt chart to reflect progress that has been made in the project. The MG's also met with Professor Brown to discuss the draft decompositions for the goal of the collective meetings and the survey. The suggestions given by Professor Brown were utilized to make edits and additions to both decompositions.

The ME's and advisors provided a clearer guide for sourcing parts, in order for the MG's to divulge deeper into research. The ME's updated the collective group on the progress of part designs; the Jig Group presented their first draft for the Bamboo Clamp, which they will continue to improve.

### Week of 10/7/14 – 10/13/14

There was a lot that needed to be accomplished this week to make sure that the production of the bamboo bike stayed on task. The previous team meeting on October 7$^{th}$ proved to be a challenging one. Both management and engineers were at odds about who should take

initiative in deciding the parts needed to put together the initial prototype design and what the "part parameters" would be for each piece. There was a great deal of emphasis that was placed on strong decompositions using axiomatic design, which actually led to a few heated discussions on the importance of axiomatic design in this project. Clarification has been achieved on how much axiomatic design is going to be used in the creation of our final product. The management decompositions, including the survey and part sourcing will need work so that the tasks that need to be addressed are fully understood. Production of the Bamboo bike is still on track according to the critical path and Gantt chart. As we move into B Term, the actual designs being proposed by the Bamboo Bike engineering groups will be ever more important as we hope to have a working prototype within the next term. Minimal work on this project will be conducted over the term break.

### Week of 10/14 – A Term break

A tumultuous week for the Bamboo bike project. At this point in time, minimal progress has been made on the design of the bike, and this caused a bit of unrest at our weekly meeting. Some folks in the audience tonight had serious questions about how much the MG's are really doing in order to help the ME's progress, and what value the MG's added to the project. So far, our attempts at decompositions, parts sourcing and almost everything besides chairing the meetings has been met with conflict from the ME side. This is all well and good, it is important for some friction in a project because that brings about the most honesty. It also gives the MG's a time to reflect and self-evaluate, and ultimately gives us an opportunity to prove ourselves and show the significant value we can add come B Term and the real big parts of this project.

I anticipate some serious, real discussions to come forth as we start B Term, about what exactly we are doing to help the ME's, how we can better establish a relationship throughout the

week, not just on Tuesday nights, and also what can be done to communicate most effectively, whether it be in an argument on Tuesday nights, or if we need to meet as a big group at all.

### Week of 10/28/14 – 11/3/14

After the last meeting of A Term the management team realized some major changes needed to be implemented. We started B Term with a meeting with professors Towner and Vassallo, we talked about some of the improvements we planned to implement as well as began thinking about the final paper we are writing, like what we are going to be putting in it as well as how we should began outlining it. One of the improvements we began was having a management student or two go to the ME meetings, we believe that this will help increase communication and understanding between the two and allow us to better assist them in what they need to do. Hopefully this allows the project to move along at a greater rate as well as reduce the length of the big group meetings. Another reason for this is the Gantt chart needs to be more detailed and have a way to measure progress, with this increased communication it will be easier for the management students to create a better chart. One of the management tasks was to create a survey to send out to the campus and we put the final touches on the decomposition and the survey and will be sending it out for final suggestion and then hopefully to the whole school. We also continued to work on the meeting decomposition with the hope that it will make the meetings shorter or maybe even not have to have a big group meeting every week.

### Week of 11/4/14 – 11/10/14

This particular week was focused on strengthening relations with the engineering group and outlining our paper. Last week the management group had a meeting apart from the engineers on what was expected to be accomplished for the management aspect of the MQP. In order for us to reach our goals, we had to have better understanding of why are we in this MQP and bring to the project our [business] knowledge to help the engineers on what we envision. We

also had to tackle the problem of operation efficiency within the group; one aspect that was being worked on was the notion that we are wasting time at our general meeting on Tuesday nights. In other words, we felt like we as a full group did not accomplish much; a lot of what was discussed at the meetings were categorized as asynchronous. Such items that are labeled this way are Gantt charts; in order to increase efficiency, it is best that communication between the groups is increased in what needs to get done and what progress has been made on certain tasks. Therefore, a decomposition on "the meeting" was done and once it is considered put into a proposal, we hope that we can eliminate non-value added time. To address the joint group relations, two select members were chosen to attend the ME meeting on Friday 11/7 and assess the current status of the engineering group. Continuously updated Gantt charts were needed and certain criteria like material requirements (management will source the desired materials) and manufacturing practices are needed from them in order to figure out the cost efficiency of the project in the future. Overall, more consistent communication is needed [by email] in order to keep the engineering group connected and to ensure they stay on task.

### Week of 11/11/14 – 11/17/14

This week we were able to get our survey approved by the IRB and WPI to have it sent out to all of the students and employees. Over the next few weeks we should be able to gather analytic information from the results of the survey. The safety team sent us different specs of bamboo we can source. There are three different demographics of bamboo and it is our job to determine which bamboo we can get in bulk and is cost efficient. Our Gantt chart is constantly being adjusted according to the progress of the ME's. The Joint and Jig design have both made significant strides and should be complete by the end of the month. We have been keeping an MG student in the ME meetings so that we have an idea of their discussion and next step actions. We have also created an hour logging document so all of our work towards the project can be

documented and noted. The whole team has decided not to meet before Thanksgiving, however each separate team has their own tasks to be completed : ME students are finalizing their CAD designs, as well as planning out different safety tests, and MG students are making a more detailed Gantt chart and we are beginning to write our report.

### Week of 11/25/14 – 12/1/14

During this week we discovered that even with IRB approval our survey cannot be sent to the all WPI students email alias. We also found that students are not allowed to mass email the faculty alias. In order to counter these measures we have individual emailed aliases by major and by grade and we have asked Professor Towner to send the survey to the faculty. Additionally any member of the MQP team that is part of a student organization has been sending out the survey link to their organizations (ex. Fraternities & Sports Teams).

The hour logging which was started last week has been identified as a priority by the professors in order to determine how much time individuals have spent on the project. We recommended that individuals save the link to their favorites tab in order to remember to fill it out. Due to thanksgiving there was no large group meeting but the management majors did meet as a smaller team. Each person was assigned a topic in the outline to research and began writing small sections. The mechanical students are slated to report on the status of the final jig design, the joint CAD drawings, and the safety team will discuss bamboo selection.

### Week of 1/20/15 – 1/26/15

This week marks the first full week back from winter vacation. There was no major work conducted on the project during break, so the teams timeline has shrank. Realizing that there is only 7 weeks left to complete the project the group held an impromptu meeting on MLK day in order to set some goals moving forward. It was determined that realistically our overall goal for the project will be to create at least one functioning prototype by March 4$^{th}$. Everyone agreed that

the design process and management portion will have a large amount of information, but we also wanted a tangible goal. Smaller goals were also scheduled for both groups of students. The mechanical students are to create their paper outlines for each group by January 26th. The joints group expects to have a final design and the jig group expects to determine which parts they need to buy or make by the same date. Unfortunately the bamboo order did not process through the mechanical department meaning the bamboo testing will be pushed back a couple weeks. The management students met with Professor Towner to discuss goals, and the first rough draft will be due on January 26th. With so many students on this project and specific goals being set, the project scope is much more detailed than it was in the early stages. The team will need to put in a full effort during this last term but we all expect a strong final project.

### Week of 1/27/15 – 2/2/15

This week was big for progress and looking at the full scope of our project. It was our first full week back in C Term, and after a long break it was important that we all re opened the lines of communication and figured out how we can really gain some momentum. Overall, it felt as if we actually did make a big step, as the ME's began discussing their Bills of Material which allowed us MG's to further understand what parts we need to get this bike completed, as well as begin our budgeting discussions, which seem to be difficult to figure out with so many students on board.

Additionally, we developed a concrete solution to our accountability, opening a "Googledoc" where students are to log the hours and describe how they work on the project as we move forward. Admittedly, this may be an aspect of the project we overlooked as MG's at the beginning and likely should have implemented much earlier in order to keep everyone on task and accountable for their work.

### Week of 2/3/15 – 2/9/15

The week proved to be productive for the writing and editing process of the term paper. The MG's met separately and assigned responsibilities for preparation of the first paper draft. Members both edited and reformatted the paper. Progress for the overall building process of the prototype remained stagnant over the week. Due to the delay of part delivery the production lingered at a halt. The ME's did however make advancements in the writing of their sections for the paper.

Establishment of objectives to be met during the following week was also composed. All project group members plan to read Professor Towner's writings on Manufacturing Systems and Design and emulate the language and writing style into the paper. The ME's made the goals to complete and submit their sections for the first draft submission and update the dates for the new Critical Path. The MG's made the goal to have the first draft of the paper completed for submission to the advisors.

### Week of 2/10/15 – 2/16/15

This week was another big writing week for the MG's. We had just gotten through our first work of edits and now we are fine tuning and anticipating a ME slot. Along with writing, we have been contacting bamboo suppliers as well as other part sourcing and it all should be ready before break. The issue has been processing the transactions in a timely manner.

Once the parts come in, the ME design is almost completely finish. We have decided that the project might run into D Term but as long as we're confident going into the term this will be appropriate. During our big meeting we developed a new critical path for the upcoming 3 weeks before break. Our plan is to produce as much work as possible so that the D Term load will be easy. The ME's are going to begin writing towards the end of the term, and by that time MG's should almost be all set with their material and ready to input the ME's.

### Week of 2/17/15 – 2/23/15

There was a lot that needed to be accomplished this week to make sure that the production of the bamboo bike stayed on task. All the parts have been ordered for the Bamboo Bike to be built according to design instructions. The bamboo will be tested this weekend to ensure the bamboo has the tension strength to support significant loads. Any additional parts that need to be ordered in the future can be requested to the management team who has agreed to swiftly move the purchase orders along as fast as possible.

The meeting this week was extremely important as the entire group had to come to a consensus on the best way to finish the Bamboo Bike Project. The options at this point were either to end the project at the end of C Term and scramble to earn a final grade, or to continue the project into D Term and finish the year with a finished product. After a long debate, the team came to the single thought that adding A Term onto the MQP project would be the best option in order to allow the three terms of previous work to have some substantial meaning at the end of the project.

The issue of communication was also discussed briefly, as some mechanical engineers felt that communication between the entire group was breaking down. As a result, emails will be sent more frequently to deal with this problem.

### Week of 2/24/15 – 3/2/15

In this, the final week of C Term a few major decisions have been made by the group. The most prominent of which is that the project will be forced to be extended into D Term. This is due to supplies not being ordered in time, and a general lack of adherence to deadlines. The project is not moving at the pace we initially predicted and as such we will be continuing into D Term.

Some interesting talks took place regarding the decision to move into D Term with the advisors. Overall the point was stressed that although the management students could finish their portion of the project before the deadline of the e-CDR, it wouldn't be right to leave the mechanicals on their own. It would also be a failure on the management portion because it is an inter-disciplinary project so both groups must see it to its completion. The team is confident that the additional time will yield a much better final project.

## Appendix B – Purchase Order Form

| | | | | |
|---|---|---|---|---|
| *PURCHASE ORDER REQUEST FORM* | | | | |
| Mechanical Engineering Department | *This form must be filled out completely see attached sample* | | | |
| | | | | |
| Company Information: | Requested by: | | | |
| | | | | |
| Co. Name: | Name: | | | |
| Street Address: | Email Address: | | | |
| City, State: | | | | |
| | MQP Name: | | | |
| Contact Person: | (if applicable) | | | |
| (If you speak to someone at co.) | | | | |
| Phone #: | Account to Charge: | | | |
| Fax #: | (Professor will provide this) | | | |
| | | | Unit | Total |
| Model or Part # | Item Description: | Qty: | Price: | Price: |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| Total: | | | | |
| | | | | |
| Faculty Advisor Signature: | | | | |

## Appendix C – Survey Data

**Q1 What is your age?**

| # | Answer | Response | % |
|---|---|---|---|
| 1 | Under 18 | 5 | 1% |
| 2 | 18-30 | 334 | 91% |
| 3 | 31-45 | 22 | 6% |
| 4 | 46-55 | 6 | 2% |
| 5 | 55+ | 1 | 0% |
| | Total | 368 | 100% |

**Q2 What is your gender?**

| # | Answer | Response | % |
|---|---|---|---|
| 1 | Male | 225 | 61% |
| 2 | Female | 140 | 38% |
| 3 | Other (please specify) | 3 | 1% |
| | Total | 368 | 100% |

**Q3 Where do you live?**

| # | Answer | Response | % |
|---|---|---|---|
| 1 | Off Campus (w/in 1 mile of WPI) | 199 | 54% |
| 2 | On Campus | 114 | 31% |
| 3 | Commuter | 55 | 15% |
| | Total | 368 | 100% |

**Q4 Check all that apply**

| # | Answer | Response | % |
|---|---|---|---|
| 1 | Student | 361 | 94% |
| 2 | Faculty | 4 | 1% |
| 3 | Staff | 16 | 4% |
| 4 | Facilities | 2 | 1% |
| 5 | Other (please specify) | 2 | 1% |
| | Total | 385 | 100% |

**Q5 Do you currently own a bike (on campus)**

| # | Answer | Response | % |
|---|---|---|---|
| 1 | Yes | 63 | 17% |
| 2 | No | 305 | 83% |
| | Total | 368 | 100% |

**Q6 What has prevented you from owning one?**

| # | Answer | Response | % |
|---|---|---|---|
| 1 | Lack of interest/no use for it | 163 | 44% |
| 2 | Too expensive | 43 | 12% |
| 3 | Not easily accessible | 46 | 13% |
| 4 | Don't know how to ride | 8 | 2% |
| 5 | Other (please specify) | 108 | 29% |
| | Total | 368 | 100% |

**Q7 I am interested in biking for (check all that apply):**

| # | Answer | Response | % |
|---|---|---|---|
| 1 | Recreation or Fitness | 273 | 43% |
| 2 | Transportation to school or work | 185 | 29% |
| 3 | Run errands or shopping | 126 | 20% |
| 4 | I am not interested in biking | 51 | 8% |
| 5 | Other (please specify) | 6 | 1% |
| | Total | 641 | 100% |

**Q8 How often do you bike?**

| # | Answer | Response | % |
|---|---|---|---|
| 1 | Once a year or less | 126 | 34% |
| 2 | Less than once a month | 114 | 31% |
| 3 | Once a month | 26 | 7% |
| 4 | 2-3 times a month | 47 | 13% |
| 5 | once a week | 20 | 5% |
| 6 | 2-3 times a week | 25 | 7% |
| 7 | Daily | 9 | 2% |
| | Total | 367 | 100% |

**Q9 What distance do you typically cover when riding?**

| # | Answer | Response | % |
|---|---|---|---|
| 1 | Less than 1 mile | 68 | 19% |
| 2 | 1-5 miles | 213 | 59% |
| 3 | 5-10 miles | 42 | 12% |
| 4 | 10+ miles | 40 | 11% |
| | Total | 363 | 100% |

**Q10 What do you consider when buying a bicycle? (check all that apply)**

| # | Answer | Response | % |
|---|---|---|---|
| 1 | Weight of bike | 240 | 25% |
| 2 | Load capacity | 84 | 9% |
| 3 | Stiffness | 87 | 9% |
| 4 | Aesthetics | 222 | 24% |
| 5 | Durability | 311 | 33% |
| | Total | 944 | 100% |

**Q11 Choose your preferred option:**

| # | Answer | Response | % |
|---|---|---|---|
| 1 | Mountain bike | 204 | 56% |
| 2 | Road bike | 163 | 44% |
| | Total | 367 | 100% |

**Q12 Choose your preferred option:**

| # | Answer | Response | % |
|---|---|---|---|
| 1 | One Speed | 46 | 13% |
| 2 | Multispeed | 321 | 87% |
| | Total | 367 | 100% |

**Q13 Choose your preferred option:**

| # | Answer | Response | % |
|---|---|---|---|
| 1 | Pedal brakes | 28 | 8% |
| 2 | Hand brakes | 337 | 92% |
| | Total | 365 | 100% |

**Q14 Choose your preferred option:**

| # | Answer | Response | % |
|---|---|---|---|
| 1 | Racing handle bars | 68 | 19% |
| 2 | Normal handle bars | 255 | 69% |
| 3 | Leisure bike handle bars | 44 | 12% |
| | Total | 367 | 100% |

**Q15 How much are you willing to spend towards a new bike?**

| # | Answer | Response | % |
|---|---|---|---|
| 1 | Under $100 | 118 | 32% |
| 2 | $100-$200 | 135 | 37% |
| 3 | $200-$300 | 49 | 13% |
| 4 | $300-$400 | 20 | 5% |
| 5 | $400-$500 | 8 | 2% |
| 6 | $500+ | 37 | 10% |
| | Total | 367 | 100% |

**Q16 Would you ever buy a bike made out of bamboo?**

| # | Answer | Response | % |
|---|---|---|---|
| 1 | Yes | 305 | 83% |
| 2 | No | 62 | 17% |
| | Total | 367 | 100% |

## Appendix D – Strategic Plan

| WPI Bamboo Bicycle Company Strategic Plan | | | | | | |
|---|---|---|---|---|---|---|
| **Overall** | **Management** | | | **Mechanical Engineering** | | |
| **Our Mission:** Complete a cross functional Major Qualifying Project<br><br>**Our Vision:** Develop a bamboo bicycle company. | **Mission:** Utilize business knowledge to assist the mechanical team in the production of a bamboo bicycle. | | | **Mission:** Utilize Axiomatic design principles to design a bamboo bicycle. | | |
| | **Financials & Marketing** | **Management Process** | **Manufacturing & Supply Chain** | **Jig Group** | **Joint Group** | **Safety Group** |
| | **Priority:** Develop financial and marketing plan. | **Priority:** Manage the development of the team dynamic. | **Priority:** Incorporate manufacturing, logistics and supply chain into project. | **Priority:** Design a jig system for the bamboo bicycle. | **Priority:** Design a joint system for the bamboo bicycle. | **Priority:** Design and conduct safety tests for the bamboo bicycle. |
| | **Objectives** | **Objectives** | **Objectives** | **Objectives** | **Objectives** | **Objectives** |
| | • Startup costs<br>• Break even analysis<br>• NPV<br>• Discount Cash Flow<br>• Target Market<br>• Survey<br>• 4 Ps | • Communication<br>• OBC<br>• Company Direction<br>• Group Journal | • Part sourcing<br>• Value Stream Analysis<br>• Critical Path | • | • | • |

## Appendix E – Critical Path

Bamboo Bike Scheduling Activity

| ACTIVITY | DESIGNATION | IMMEDIATE PREDECESSORS | TIME (WEEKS) | LF | EF | LS-ES (SLACK) | ON CRITICAL PATH |
|---|---|---|---|---|---|---|---|
| **DECOMPOSITION** | | | | | | | |
| Jig | A | none | 3 | 4 | 4 | 0 | Y |
| Joints | B | none | 3 | 4 | 4 | 0 | Y |
| Safety and Testing | C | none | 3 | 4 | 4 | 0 | Y |
| **DESIGN BAMBOO BIKE** | | | | | | | |
| Jig | D | A,B,C | 9 | 13 | 13 | 0 | Y |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Bamboo Clamp | E | A,B,C | 1.5 | 8 | 5.5 | 2.5 | |
| Crank Clamp | F | A,B,C | 2 | 7 | 6 | 1 | |
| Head Tube Clamp | G | A,B,C | 3 | 12 | 7 | 5 | |
| Rear Wheel Setup | H | A,B,C | 6 | 13 | 10 | 3 | |
| Joints | I | A,B,C | 3 | 11 | 7 | 4 | |
| Test for each specific part/design | J | A,B,C | 2 | 14 | 12 | 2 | |
| **DESIGN MFG PROCESS** | | | | | | | |
| Joints | K | I | 1 | 12 | 8 | 4 | |
| **BUILD PROTOTYPE** | | | | | | | |
| Joints | L | K | 2 | 14 | 10 | 4 | |
| **SAFETY TESTS** | | | | | | | |
| Test Bamboo clamp | M | E | 6 | 14 | 11.5 | 2.5 | |
| Test Crank clamp | N | F | 7 | 14 | 13 | 1 | |
| Test Head Tube Clamp | O | G | 2 | 14 | 9 | 5 | |
| Test Initial Joint Design/Model | P | I | 2 | 13 | 9 | 4 | |
| Test Rear Wheel Setup | Q | H | 1 | 14 | 11 | 3 | |
| Test Different Joint Material | R | I | 1 | 13 | 8 | 5 | |
| Test Complete Jig Design as a whole | S | D | 1 | 14 | 14 | 0 | Y |
| Test Final Joint Design as a whole | T | K,P,R | 1 | 14 | 10 | 4 | |
| Test Final Prototype | U | L,M,N,O,Q,S,T | 1 | 15 | 15 | 0 | Y |

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