A Detailed Approach for Concept Generation and Evaluation in a Technology Push Product Development Environment

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A DETAILED APPROACH FOR CONCEPT GENERATION AND EVALUATION IN A TECHNOLOGY PUSH PRODUCT DEVELOPMENT ENVIRONMENT

by

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ABSTRACT

A DETAILED APPROACH FOR CONCEPT GENERATION AND
EVALUATION IN A TECHNOLOGY PUSH PRODUCT
DEVELOPMENT ENVIRONMENT

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Many companies rely on successful product development as a means to increase their revenues and expand their operations. Market pull, the most common form of product development, begins with a specific customer, and focuses on how to satisfy that customer's needs. Technology push is a product development process where a technology is first discovered, then embodied in products that may be marketed to specific customers. Technology push presents several obstacles not encountered in market pull processes, such as a lack of a defined market, lack of established processes and difficulty in execution. These complications keep technology push from being more widely used. However, when successful, technology push also presents opportunity for

rapid innovation, the discovery of disruptive technologies, and the ability to produce several products from a single R&D effort.

The existing literature for accomplishing technology push product development is presented at a high level. The research for this thesis provides a step-by-step method for generating and evaluating concepts in the technology push product development process. The model for accomplishing these steps was generated by taking the existing Technology Application Selection (TAS) process and supplying the necessary detail to allow product developers to complete the necessary steps. It also explains in detail several of the steps outlined in existing technology push processes.

In order to lend credence to the process presented in this thesis, a number of experiments were conducted, with the participants being asked to evaluate the process steps. Their feedback was used to ensure that the process met the predetermined success criteria for the product development process.

ACKNOWLEDGMENTS

My sincere gratitude goes to Spencer Magleby, Larry Howell, and Alan Parkinson, for their time and efforts that have made this work possible. My deepest gratitude also goes to my wife Mara, for her devotion and patience throughout the course of this work, and to our daughter Amanda, whose presence has multiplied our joy.

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Chapter 1 Introduction

Technology Push (TP) product development is a term used to describe a process where a technology is first discovered, then embodied in a product or products that may be marketed. There has been very little written on the subject of technology push product development. What has been written has merely scratched the surface, and gives a general outline of how to accomplish the process, yet does not delve into the specifics of how the process may be completed with optimal results. This thesis will develop a system that explains how to carry out the detailed steps generating and evaluating concepts in an environment where TP is the dominant mode of product development. The process will guide product developers in generating the greatest variety of potential products that will utilize the new technology, and help the developers determine which of the prospective products have the greatest likelihood of commercial success.

Traditional, or “market-pull”, product development is often seen as the preferred method of product development, and has been well documented in published literature. Different authors prescribe slightly different processes, but the steps generally flow as follows:

1. Identifying customer needs
2. Generating product specifications
3. Concept generation and selection

4. Concept testing
5. Prototype development.

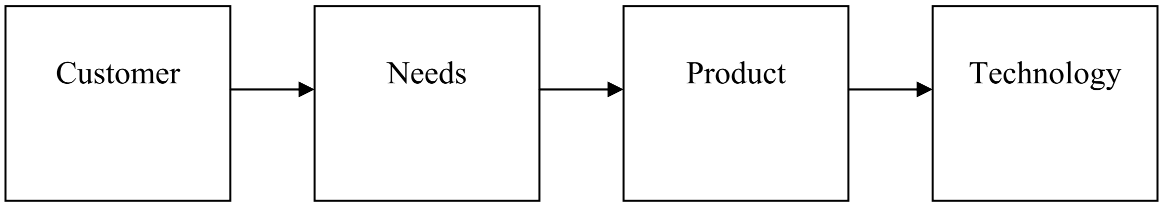

Figure 1.1 Information Flow In A Market-Pull Environment

The flow of information in market-pull product development clearly flows from the customer, whose needs are then translated into product specifications. The product developers then search out technologies and configurations that will satisfy the product specifications. It can then be seen that the customer, or market, "pulls" the product development process along.

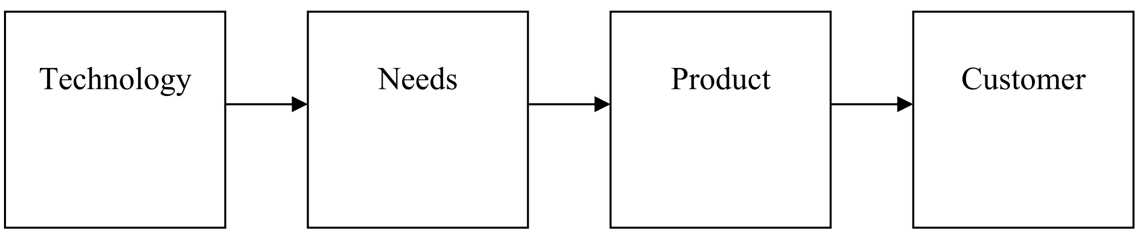

Figure 1.2 Information Flow In A Technology Push Environment

In TP product development the information flows from the technology to the customer. The technology is developed first. When the technology is fully understood, it is determined which customer needs it can satisfy. Once these needs are understood, the technology can be embodied in a product to be sold to the customer. Thus the technology "pushes" the development of the product.

The TP method of product development is especially useful for small companies and startups for several reasons, including the following [13] [20].

- The knowledge of a small company is more focused on a particular process or piece of knowledge than on a set customer base.
- Small companies may lack the product development resources available to larger companies.
- Small companies often target smaller or periphery markets that are shown to be more successful using TP product development

It is important to note that TP product development does not exclude the necessity of knowing the customer needs, it simply moves that step in the development process further down the chain.

There are also cases, such as university settings and other research groups, where a group discovers a new technology. Their purpose in finding the technology may have been research based, but they are now faced with the potential of creating profitable products from their findings. These groups may not develop products as their primary function, but have the opportunity to use a TP development process as a means to profit from their newfound knowledge.

This thesis builds upon the work of John Larsen [11] and Greg Bishop [2] in formalizing a method for generating and evaluating concepts in a technology push environment. Larsen's thesis laid out a general framework for TP product development, and explained some of the steps within this framework. He termed this the Technology Application Selection (TAS) process (see Figure 1.3). This thesis will describe in detail the steps in this process, namely the technology characterization, application identification and application evaluation stages.

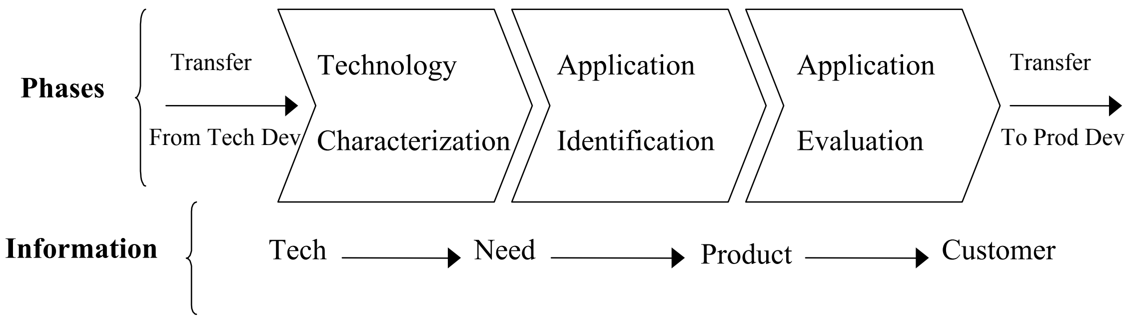

Figure 1.3 Larsen's Technology Application Selection Process

Portions of Bishop's work [2] were built on conclusions from the preliminary work in this thesis. He greatly expanded the scope of the TP product development beyond the TAS process to include steps such as prototyping, developing the potential market, as well as several steps specific to managers of product developers. The Concept Generation and Evaluation (CG&E) process developed in this thesis is designed to provide the specific steps needed to complete the comprehensive process laid out by Bishop.

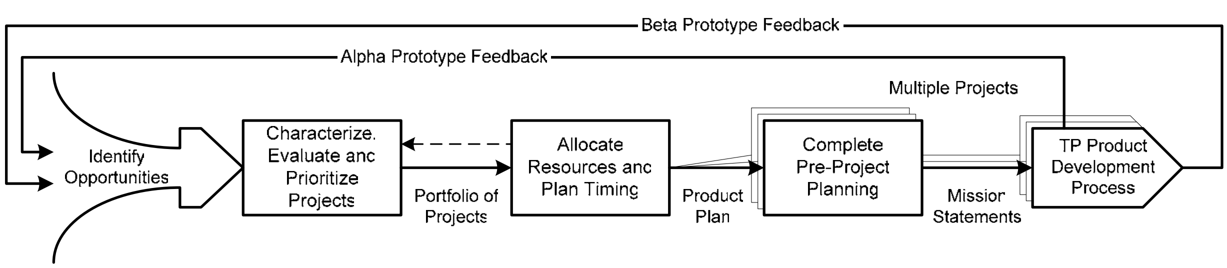

Figure 1.4 Planning Phase Of Bishop's Comprehensive TP Model

1.1 Obstacles In Creating a Detailed CG&E Process

There are several obstacles to creating a detailed CG&E process for TP. First there is currently no defined process for TP product development. Market-pull has long been established as the more reliable method of creating marketable products. It sets out with a definite goal in mind, and results in products that are successful more often than those developed using a TP strategy. The TP strategy is more open-ended, and, with no set process, runs a greater risk of creating less marketable products.

Creating a detailed model to characterize technologies carries several obstacles with it. The first problem is deciding on which metrics to base the characterization. Among the possible candidate classes for characterization are: functional, behavioral, descriptive, and strategic. Choosing too few metrics will result in an incomplete characterization. Choosing too many will create a process that is so cumbersome that it would not be worth the effort to go through it.

A second obstacle in this area is that there is no established method for performing technology characterization, and each of the proposed methods has inherent flaws. Creating a functional map of current technologies that allows developers to have their technologies pre-characterized is a large and nearly unmanageable task. It is also impossible to create a model that will characterize current as well as future technologies because technology evolves so rapidly. For example, a technology may be invented in the future that is in a class by itself, and cannot be currently characterized.

Creating a process in the Application Identification stage is difficult because it is an inherently open-ended phase that requires the developer to identify as many concepts in as many different industries as possible. This differs from market-pull development, where a number of concepts may be generated, yet all the concepts are focused on a pre-determined set of customer needs. In TP development the customer needs have not been defined in the Application Identification stage, which allows the scope of concepts being generated to vary more widely. This open-endedness makes it difficult to know when a sufficient number of applications have been discovered, allowing the process to move on to the next stage. Another difficulty in identifying applications is finding the balance between creating a set process that provides enough guidance to maximize the number of concepts generated while avoiding rigidity in the process that could limit the creativity needed to generate those potential applications. One of the main purposes of developing this stage is to help product developers understand a variety of potential uses for their technology. This requires identifying several potential applications, while aiding the developer in generating applications that will match well with the characteristics of the technology.

The primary obstacle in evaluating potential applications is selecting appropriate metrics to assess the applications. The applications must have both the proper fit with the technical characteristics of the technology being developed and alignment with the current strategy and capabilities of the firm that is doing the development [25]. The evaluation must also take into account the size of the potential market being explored in order to fully gauge the marketability of the concepts that were generated in first two stages.

1.2 Objective

The objective of this thesis is to provide a step-by-step process to direct design engineers through the CG&E stages of TP product development, namely, technology characterization, application identification and application evaluation. Specific guidelines will be provided so that the designers may effectively complete each of these stages.

This objective will be achieved by identifying the inputs and outputs of the three steps in the process, and by overcoming the obstacles listed in the previous section.

1.3 Contribution

Because of several difficulties, including those listed in section 1.2, most companies avoid a TP strategy. However, many of the difficulties encountered by those who have employed a push strategy could be alleviated with a set process that guided the developer through the steps necessary to increase the chance of success. The contributions of having a practicable CG&E process include:

- An increase in the probability of successfully developing a technology,
- A spreading of technology development investment over multiple product applications,
- More extensive utilization of an organization's core competencies, and
- The discovery of lucrative new market opportunities.

This process would be especially useful to smaller businesses and universities. These groups often develop impressive technologies without passing through the traditional product development model of assessing customer needs, etc. They may also lack the resources or infrastructure dedicated to product development that would be found in larger companies. Furthermore, these groups often have their competencies focused in a narrow area, and may not effectively pass through the stages of a market-pull development process.

Another industry that would benefit greatly from an efficient TP process would be the materials science industry. For example, the popular aramid fiber Kevlar was first used as an asbestos replacement in flame retardants and specialty paper applications. It was then utilized in gaskets, brake pads, drum brake linings, and clutch faces [1]. Several years after its initial development the fibers were used in their most well known application - bulletproof vests. Even after the body armor application, developers continued to push Kevlar into markets such as parachutes, canoes, and underwater cables. There are authors who argue that by listening only to your customers, a company will never develop breakthrough products, rather only making incremental improvements to existing products [3]. The TP process is far more likely to produce revolutionary products that may be considered “disruptive”, that is, they are not accepted by the current market, but have characteristics that are valued by a different market, and in time may overtake the current market.

In addition to the contribution of having a complete and detailed CG&E process, there are also beneficial contributions to be made by the specific steps of technology characterization, application identification and application evaluation. A detailed technology characterization model will help the product developer to describe the technology in simple, easily understandable terms. The model should also help open the developer’s eyes to new ways that the technology could be characterized. Once the developer has passed through this stage, he or she should have a complete understanding of the characteristics of the technology. This will allow the developer to more fully understand the technology while moving through the other stages of the process. After the technology is characterized, it should be ready to move on to the application identification stage.

The application identification stage holds immense potential contribution. Most companies who develop TP products skip all other steps and simply focus on identifying potential applications. The development of an efficient and comprehensive process would allow the developer to create multiple product applications with a single R&D effort. It would also allow a company to see how changes in a technology would allow it to develop other products. When creating multiple products with the same R&D effort, the company is able to stay close to their core competency while extending their product line. A process for application identification should give the developer a comprehensive list of the potential applications. It should guide the developer to find solutions within the constraints of the technological characterization without stifling the creative process.

The steps of technology characterization and application identification logically proceed into an evaluation of the identified applications. This step would allow firms to determine which of the applications would be the most appropriate for development. An accurate evaluation would help firms to select applications that would be profitable, that would build upon and enhance the existing capabilities of the firm, and have a close match with the technology at hand.

1.4 Conclusion

When developing products, most companies will choose a market pull approach. This is the logical conclusion, as it is a safer and more reliable approach to product development. However, there are several cases where companies have developed technologies, and are searching for a way to market their products. Completing a practicable process for generating and evaluating concepts in a TP environment will allow these companies to find the best product match for their technology, create multiple products from a single R&D effort, and create multiple products that strategically match with a company's core competency. The completion of this process presents several difficulties. In characterizing the technology, the model must use the best metrics in order to create a complete characterization, and be able to characterize the full range of mechanical technologies. In the application identification stage, the process must be focused enough to arrive at usable products, yet open enough to allow for the necessary creativity. The purpose of this thesis is to provide a process for CG&E in a TP environment that overcomes the stated obstacles and yields marketable products for further development.

Chapter 2 Literature Review

Larsen's and Bishop's theses are some of the first efforts to lay out a detailed process for TP product development. Only a handful of other efforts exist in the published literature. Each of these processes contains a general outline of the steps within TP product development, yet gave little detail on the intermediate steps necessary to accomplish the process. While there is a lack of knowledge regarding TP process as a whole, several terms relating to the subject have been well defined. TP product development and its related terms are defined in this chapter, followed by a description of how the current boundary of knowledge will be expanded.

2.1 Literature Review

Outlines for TP product development have been created by Ulrich and Eppinger [23], Souder [20], Rothwell [5], Spivey et al. [21], Paul [17], Larsen [11], and Bishop [2]. Each of these works has provided an overall summary of the steps needed to proceed through the TP process, yet lack sufficient detail to provide a complete and practicable process without having further detail provided. This section reviews the authors' methods, and their explanation of the technology characterization and application identification stages.

2.1.1 Ulrich and Eppinger

Ulrich and Eppinger are regarded as leaders in the field of product development. While the vast majority of their work focuses on market-pull, they mention TP as one of the alternatives to the traditional product development process. Ulrich and Eppinger define TP products as those where "the firm begins with a new proprietary technology and looks for an appropriate market in which to apply this technology" [23]. They then identify Gore-Tex as an example of successful TP product development. Gore-Tex has been used in medical applications, dental floss, fabrics for outerwear, insulation for electrical cables, and other applications.

Ulrich and Eppinger believe that TP product development can be converted into market-pull product development through one step. They call this the planning phase, which consists of matching the given technology with a specific market [23]. There is, however, no further instruction on how to best match technologies to markets, or how to pick the best market for a specific technology. According to the authors, the most important factor in the new technology's success is ensuring that the new technology offers a distinct competitive advantage over the existing products.

2.1.2 Souder

Souder's process was derived through interviews with several companies who had engaged in successful TP processes [20]. The products varied from materials projects such as nylon and synthetic diamonds to processes such as xerography and holography. From these studies Souder was able to flowchart an 8-step process with stages common to each project (See Figure 2.1).

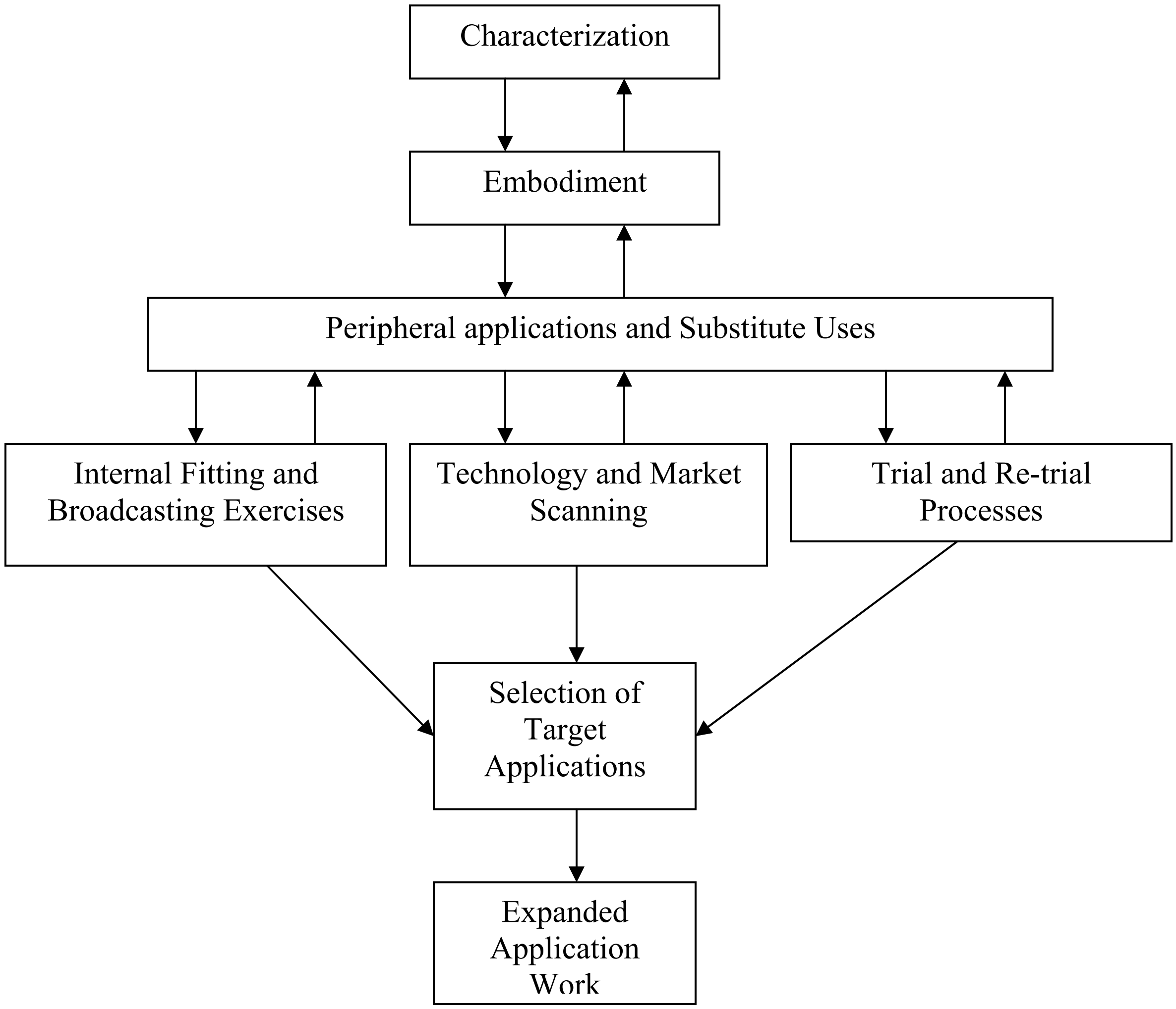

Figure 2.1 Souder Technology Push Model

The first step, characterization, looks to define the technology in terms of unique advantages over current technologies. This step is to be completed while looking forward to the next step of embodiment. Souder describes this step as "a way to facilitate a connection between what it is, what it can do, and some potential need". It is important to note that there is little additional detail given on how to complete the characterization. Once the various characterizations are completed, the author suggests that the "best" one be selected and taken to the next step. Again, there are no guidelines on how to select the best characterization. As can be see in the flowchart, Souder sees the characterization stage as an iterative process that may be revisited and refined as the process progresses.

The second stage details what the author terms “embodiment”, which is very similar to the application identification stage. In this step Souder recommends using the technology as a substitute for a current technology in a product or process. In order to arrive at this end Souder recommends an interdisciplinary brainstorming process involving R&D, marketing, and engineering departments. Once again, Souder recommends an iterative process in order to properly embodying the technology.

2.1.3 Rothwell

Rothwell provides a historical viewpoint of the technology push process, describing it as a linear process consisting of five steps, as seen in Figure 2.2.

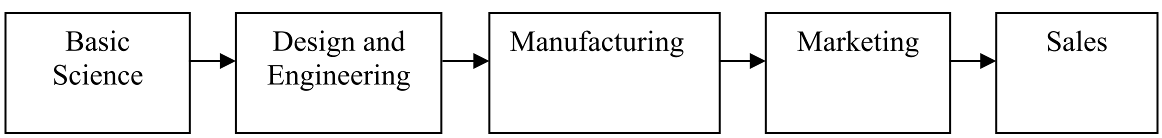

Figure 2.2 Rothwell Linear TP model

Rothwell saw TP as the precursor to market pull processes. While most companies practiced a form of TP product development in the 1950s-60s, the focus on improving product development led companies to adopt a market pull strategy. Rothwell prescribed a combination of market pull and TP to drive industrial innovation. Rothwell’s combined push-pull model is show in Figure 2.3.

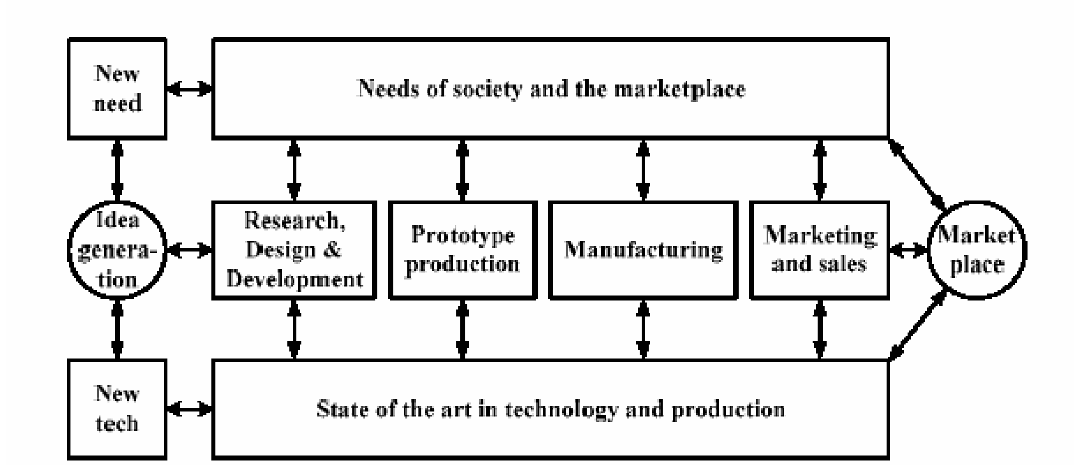

Figure 2.3 Rothwell's Combined Push-Pull Model

Rothwell's combined model incorporates a series of loopbacks and iterations to ensure that the customers' needs are being met with the latest technologies available.

2.1.4 Paul

Paul's work focused on the similarities between market-pull product development and TP product development. These similarities can be seen in Table 2.1, taken from his work.

Table 2.1 Paul's Comparison Of Pull And Push Processes

Market Pull Process	**TP Process**
1) Identify Customer values	1) Identify Technology
2) Creatively identify solutions and Approaches	2) Creatively identify possible customers/applications
3) Do Homework	3) Do Homework
4) Validate with market research	4) Validate with market research
5) Test	5) Test
6) Launch	6) Launch

As can be seen by the above table, Paul also recognizes the first two steps of TP product development to be technology characterization and application identification. Paul goes on to outline four steps necessary to have TP work:

1. Must meet unmet needs
2. Must be economically in reach of target market
3. Must be treated with customer sensitive care
4. Must be treated patiently – adoption likely to be slow

These criteria will be useful with the development of application identification and evaluation processes.

2.1.5 Spivey et al.

Spivey's process is specifically geared towards the technology transfer process, yet he provides a process that is directly applicable to TP product development. Spivey took a phemenonological approach, and focused his study on IT technologies within the Department of Defense [21]. Personal interviews and mail questionnaires were used to find the best practices within this setting. The stages and related activities are listed in Table 2.2.

Table 2.2 Spivey's TP Process

Stage in Technology Movement	Related Activity in New Product Development Process
Disclosing Technology	
Linking Technology with Needs	Initial Screening Preliminary Market Assessment
Assessing Technology	Preliminary Technical Assessment
Matching Technology with Functional Need	Detailed Market Study
Refining Technology for Specific Needs	Business /Financial Analysis Product Development In House Testing
Preparing to Launch into the User's World	Customer Tests Test Market Trial Production Precommercialization Business Analysis
Managing Technology Over its Life Cycle	Production Start Up Market Launch

Spivey's process, much like Souder's, begins with an initial assessment and a preliminary technical assessment. In this process these steps encompass the technical characterization and application identification steps. Spivey reports that in this setting the scientists and engineers completed the technology assessment, yet offers few details on how these tasks were completed [21].

2.1.6 Larsen

Larsen set out to provide a clear and practicable framework for TP product development. His goal was not to go in depth in every step of the process, but to outline a general process and leave the detailed work for further research. His outline is shown in Figure 2.4.

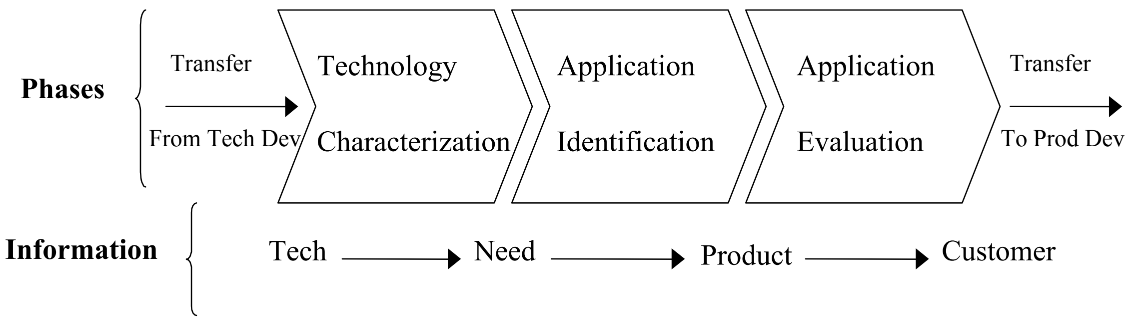

Figure 2.4 Larsen's Technology Application Selection (TAS) Process

The fact that all of these processes support the same general framework, yet none provide an in depth explanation of how to achieve the individual steps, lends credence to the work that will be accomplished in this thesis.

2.1.7 Bishop

Building on conclusions from the preliminary work by Larsen and the author, Bishop created a model for TP product development that expanded beyond the original scope of Larsen's TAS process and incorporated much of the existing literature on TP. Among Bishop's additions to the TAS process are:

- An increased focus on bringing in industry experts to assist in the product development
- Instructions on how to incorporate prototypes in the development process
- Directions on how to develop new markets created by the technology being pushed
- Increased clarity surrounding methods of gathering market data.

The flow showing the "Planning" phase view of Bishop's combined model is seen in Figure 2.5. A precursor to the Identify Opportunities step is a Technology Characterization stage.

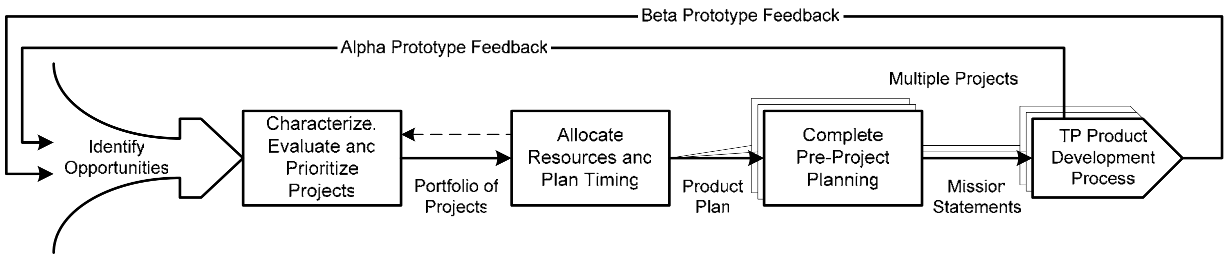

Figure 2.5 A High-Level View Of Bishop's Combined TP Model Planning Phase

Bishop's "Technology Characterization" closely mirrors its namesake in Larsen's framework, and incorporates steps and terminology created in early revisions of this work (See Figure 2.6).

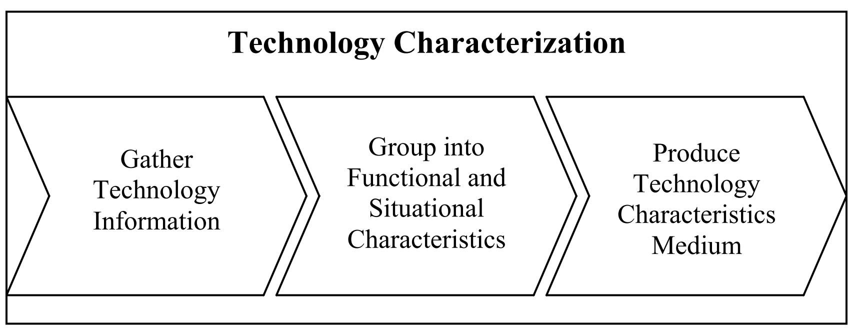

Figure 2.6 Detailed View Of Bishop's Technology Characterization Stage

Figure 2.7 shows Bishop's "Identify Opportunities" section. This lines up with Larsen's "Application Identification" step. Here Bishop specifically calls out the need to bring in industry specialists to assist in identifying applications. One of the primary functions of these specialists is to help the developers understand the markets for potential products.

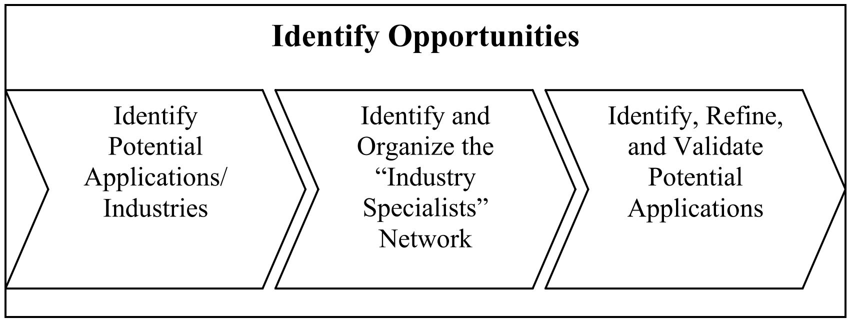

Figure 2.7 Detailed View Of Bishop's Identify Opportunities Stage

Finally, the "Characterize, Evaluate and Prioritize Projects" portion incorporates Larsen's "Application Evaluation" step into the expanded process (See Figure 2.8).

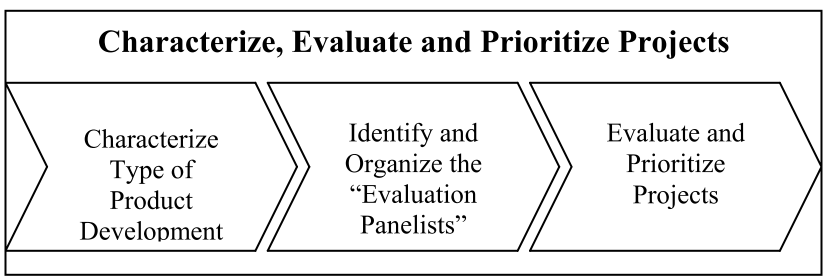

Figure 2.8 Detailed View Of Bishop's Characterize, Evaluate And Prioritize Projects Stage

Bishop further broadens the scope of the development process by detailing which steps follow the TAS process. In the preliminary work for this thesis, the product selected for development was to be transferred to a market pull environment using Ulrich and Eppinger's methodology, with an admission in the author's conclusion that this area was underdeveloped and would need further attention in subsequent research. Bishop addresses this area comprehensively, showing how prototypes, target specs and detailed design all round out the development process.

As the CG&E fits under the larger scope developed in Bishop's work, Chapters 5-7 will show how each step in the CG&E process fits into the Comprehensive TP Model developed by Bishop.

2.2 Definitions

There are six terms that will be used extensively throughout this thesis, and it is therefore necessary to gain a clear understanding of their definitions. Larsen defined some of these terms in his work. Necessary adjustments to his definitions have been made so that they are relevant to this work.

2.2.1 Product Development

The subject of product development has inspired hundreds of books and articles. While each piece of literature presents a slightly different definition, most authors reference or refer to Ulrich and Eppinger's [23] definition: "the set of activities beginning with the perception of a market opportunity and ending in the production, sale, and delivery of a product."

2.2.2 TP Product Development

As defined by Larsen, TP product development is "the realization of a product through embodying *a specific* technology in a manner meant to satisfy customer needs." The information in TP product development begins with technology and ends with the customer (Figure 1.3). However, it is important to remember that the customer must still be the focus of the product development. This is particularly pertinent in the application identification and application evaluation stages, when selecting the target market is essential to finding the most marketable product possible.

2.2.3 Technology Characterization

The first step in the technology application selection process is characterizing the technology. For the purpose of this thesis, technology characterization will be defined as "a comprehensive description of a technology's attributes that will provide unique competitive advantages". The purpose of this stage is threefold: to gain as deep an understanding as possible about the technology being developed, to describe the technology in as simple terms as possible to aid with the application identification, and to characterize the technology in relation to the company's strategy [11]. Souder explained that the characterization stage should answer the following questions: What will the technology do better than an existing product? How is it unique? What other products is it like? What needs does it fill? [20]. These questions assume that the the developer has sufficient familiarity with the technology that he/she has already thought of potential applications. The technology characterization step is completed while looking at how the technology will be able to create unique and marketable products. This will greatly ease the transition into application identification.

2.2.4 Application Identification

After a complete understanding of the characterization is completed, the process moves on to application identification. In this work the definition of application identification is "the discovery of potential products that will appropriately embody the selected technology". This is inherently the most difficult step in the process, due to its open-endedness. The majority of products identified in this stage will focus on ways that the technology can be substituted for existing products to improve technological performance or to reduce cost. Brainstorming is a key component in meeting the qualifications of application identification.

2.2.5 Brainstorming

Brainstorming involves several members of a group focusing on creating a breadth of solutions through the unrestrained offering of ideas in order to solve a given problem. Adhering to brainstorming criteria will greatly improve the chances for success. These criteria, listed below, will be further explored in Chapter 6.

1. Limit the group to 5-12 participants and a leader.
2. Focus on one problem per session.
3. Adhere to the 4 basic principles of brainstorming, (1) do not criticize 2) encourage unorthodox ideas 3)strive toward quantity of ideas; 4)build on other ideas)
4. Define the problem.
5. Select a meeting environment that minimizes anxiety and tension.
6. Record ideas.
7. Discuss follow-up calls or sessions.
8. Allow a decision-making committee, normally comprising 3-4 members of management, to evaluate ideas and suggestions.

2.2.6 Multifaceted Technologies

Multifaceted technologies are technologies that “present a variety of potential upstream processes and downstream applications or end products for commercialization” [9]. Though all technologies could possibly fit into this definition, there are some technologies that open the doors to more downstream applications than others. The technology characterization process will be designed to find all of the different facets that may be utilized to identify potential downstream applications.

2.2.7 Core Competency

A key definition in determining the strategic characterization is a firm's core competencies. Prahalad and Hamel define core competencies as "the collective learning in the firm, especially how to coordinate diverse production skills and integrate multiple streams of technologies" [18]. In other words, the core competencies of a firm are skills, experiences and behaviors that signal success for that firm. It is important to note that the core competencies are not the actual core products of a firm, but rather serve as the foundation that leads to the development of core products. The core competencies of a firm must constantly be reevaluated, as the network of knowledge and skills changes with turnover in a firm [4].

2.2.8 Functional Mapping

Functional mapping is a method of characterizing technologies. This involves breaking the technology down into its most basic function in order to better understand how the technology can apply to different settings. Some researchers have pursued this method in an attempt to more easily reverse engineer products by first looking at their characteristics, then examining how the basic functional characteristics of different products relate to one another [24].

2.3 Summary

There is no detailed process in place for generating and evaluating concepts when performing TP product development. Several authors have given a broad outline of the steps that may be completed, and most of their processes are similar in nature. This lack of information adds importance to the process proposed in this thesis. This work adds to the current boundary of knowledge by laying out a step-by-step process for concept generation and evaluation in this type of product development. This will allow product designers to follow a more formalized course that will yield a greater quantity of successful products from the technologies being developed.

Chapter 3 Research Methods

This chapter describes the methods to be used in order to accomplish the thesis objectives. It demonstrates how the research will further the boundary of knowledge, and give a gauge on the success of the processes proposed in this thesis. The methods for testing the findings of this thesis include a number of experiments, which will be briefly detailed in this chapter.

3.1 Desirable Process Characteristics (Chapter 4)

The first step in the research process will be to establish desirable process characteristics with accompanying metrics. This will be accomplished through a search of the existing literature for attributes of existing prodcut development processes. These characteristics will guide the development of process towards a well-defined goal while also assisting in the evaluation of the CG&E process at the conclusion of the thesis.

3.2 Technology Characterization Process (Chapter 5)

The next section of the thesis will deal with characterizing the technology. First the interface from technology transfer will be established and analyzed. Then the process for technology characterization will be laid out. Lastly, the process will be briefly compared to the desirable process characteristics.

3.3 Application Identification Process (Chapter 6)

The method for creating the application identification process will be similar to the one used in creating the technology characterization process. The interface between technology characterization and application identification will first be analyzed. Then, the proposed application identification process will be laid out. This chapter will end with a comparison of the proposal to the desired process characteristics given in chapter 4.

3.4 Application Evaluation Process (Chapter 7)

The application evaluation process will use principles already introduced in chapters 5 and 6 to select the best potential applications. This process will also follow the guidelines laid out in Chapter 4.

3.5 Experiment (Chapter 8)

In order to test the proposed processes, a set of experiments will be conducted. The experiments were carried out in both academic and professional settings. The participants in these experiments evaluated the process against the desired process characteristics outlined in Chapter 4.

3.5.1 Academic Experiments

The processes will first be tested in an academic setting. The Compliant Mechanisms class at Brigham Young University (ME EN 538) requires that students design a compliant mechanism product. As these students have a basic knowledge of the technology, they were asked to proceed through all three stages of TP product development, yielding a product that they feel would have the greatest chance of success using the compliant mechanism technology. The students were then asked to evaluate the process and offer suggestions for improvement. These suggestions were used to further refine the process.

The processes will also be tested in the Compliant Mechanisms Research group funded by the Utah Center of Excellence. This group of students has been studying compliant mechanisms technology for a longer period of time. In this experiment the students were asked to use the proposed process on subsets of compliant mechanisms. The results of these groups were then compared and evaluated to see if the TP product development process meets the Desirable Process Characteristics outlined in Chapter 4.

3.5.2 Professional Case Study

A second case study will take place in a professional setting. A Utah company uses carbon fiber technology to manufacture artificial feet, gun barrels, and other products. This company has successfully developed products in a TP setting, yet has done so without the benefit of a formalized process. The company agreed to experiment with the process developed in this thesis. The case study was used to help evaluate the practicability of the methods developed herein. This company was also asked to evaluate the process, and its response was compared to the Desirable Process Characteristics outlined in Chapter 4. The professional case study will be especially useful in evaluating the fit of the potential products with the core competencies of the company, as this cannot be readily evaluated in an academic setting.

Chapter 4 Desirable Process Characteristics

Before creating the CG&E process, it is first necessary to establish the characteristics by which the process will be measured. These characteristics provide a standard to which the process will be tailored, and provide a measure against which the process may be judged. The experiments reported on in chapter 8 tested the efficacy of the process by asking the participants to critique the process using the criteria set forth in this chapter. Due to the inherently subjective nature of product development processes, it will take time beyond the scope of this thesis to definitively show the efficacy of this process as a model for CG&E, but the judging done by the users of the process in this thesis will show whether or not the process meets the criteria of a successful process. This chapter will first define the metrics for success for products discovered in a TP product development process. It will then identify which characteristics are most important in creating a successful process.

4.1 Product Success Criteria

TP product development is an inherently open-ended process. Because of this fact, it is necessary for a successful product development process to generate a substantial quantity of ideas. While the number of ideas generated is one of the success criteria, the quality of concepts generated also must be met by the development process. A successful product development process should incorporate both ideals of quality and quantity. The quality of the ideas for this process are customer centric, and are based on four factors, derived from the works of Gregory [7] and McNaughton [14]:

1) How closely the proposed product matches with the characteristics of the technology

2) Market size of the proposed product

3) Likelihood that the product could be developed

4) The value added to an existing product by the technology

These factors will be explained in detail in the following section.

4.1.1 Technology Match

This metric is scored based on the closeness of fit between the function of the technology, which was outlined in the technology characterization stage, and the customer needs of the proposed product. For example, a product that could use a given technology with no noticeable loss in technical performance would receive a high score for this metric. Conversely, a product that could use a given technology, but only with significant neglect to the customer's needs would receive low scores for this metric.

4.1.2 Market Size

The ultimate goal of TP product development is to discover marketable and profitable products. Thus, if the success of this process were based solely on quantity of concepts generated, yet none of those ideas held any market potential, the process would not fulfill its full purpose. The products chosen through the application selection process will be chosen primarily because they have the potential to be marketed. This metric is scored on a competitive basis. The potential products' market size score is determined by comparing the market to that of the other competitive products. While factors determining market size are not explored in depth in this work, they are largely due to the following factors: size of customer base, profit margins in the industry, competition in the industry, and barriers to entry in the industry. Hauser [22], Mullins [16], and Dougherty [6] have written extensively on the subject of market size determination, and may be viewed for further information on the subject.

4.1.3 Likelihood of Development

While a potential product may be able to closely use the technology in question, and may have a huge potential market size, there are certain products that are easier to develop than others. Factors affecting this metric include: overhead costs, barriers to entry for a given market, strength of existing players in the current market and potential for acceptance of a new technology in a given market. For example, a new technology may be developed that could change the way nuclear warheads are manufactured. This technology would be expected to receive a low score on the likelihood of development metric for several reasons. First of all, the manufacture of nuclear weapons would undoubtedly have enormous overhead costs. Second, there are tremendously high barriers to entry that must be passed in order to produce such a product. The government would need to approve the manufacturing facility, a military contract would need to be secured, and there would need to be prolonged testing on the equipment, etc.

4.1.4 Value Added to the Product

The last metric to measure a successful product is how much value the technology adds to the new product. This metric makes the assumption that the technology will be replacing another technology in a product in order to achieve superior technological performance or to reduce price. The value added to the product by the new technology may be measured by either improved price or advanced technology.

4.2 Concerns Regarding Success Criteria

While there are concerns that the four factors in section 4.1 are based largely on objective measures, this is not unlike the product development process in market pull situations. Ulrich and Eppinger [23] base their concept selection criteria on a ranking system that is dependent on the developer opinions. In addition to this factor, the weights for their evaluation stages are reliant upon subjectively assigned values. Much of the concept selection stage for any product development process is inherently dependent upon the designer's background and knowledge. This is no different in the process proposed for TP product development.

4.3 Process Characteristics

The product development process itself must possess several characteristics so that its users may apply it in a way that will produce successful products. In order to develop these criteria, interviews were conducted with twelve students in a graduate level class on product design, each of whom had studied different theories on product design. The interviews focused on what are the characteristics of a successful product design process. Their responses were consolidated into four groups, which are explained below:

4.3.1 Specific

The process must be specific. The problem with the current technology-push development processes is that they only provide a general outline, while failing to provide any specific details on how to work the process. Being specific implies a step-by-step process with clear metrics to measure the results. Specificity makes the process to be clear and practicable. This will help the process to be "idiot-proof", or, in other words, the process may be easily executed regardless of who is carrying it out. It is also imperative that the instructions for the process be specific and clear.

4.3.2 Efficiently Comprehensive

One of the primary challenges of this style of product development is how open-ended it is, particularly in the application identification and technology characterization stages. It would be nearly impossible, or at least highly inefficient, to think of every possible product to be derived from a technology. It would also be very difficult to list every possible attribute of a technology. First of all, some attributes may provide any significant advantage, and second, a comprehensive list of attributes for a given technology has yet to be derived. Thus, the challenge for this characteristic is to balance efficiency with completeness. In order to accomplish this objective, the process may require multiple iterations. This would allow the users to discover a wide variety of ideas while avoiding excessively long process times and redundant steps.

4.3.3 Provide successful solutions

The purpose of creating a process for TP product development is to find which marketable applications will work best for a given technology and a given company. A process that creates successful solutions is customer-centric, and allows the developers to arrive at one "best" concept that can be pursued for development. Further details on this characteristic are provided in Section 4.1 – Product Success Criteria.

4.3.4 Dynamic

A good TP product development process should also be dynamic. A dynamic process may be used with various technologies and with developers of different backgrounds while still being effective. Because of the multidisciplinary approach recommended for successful product development, this attribute becomes especially important. A dynamic process would be able to adapt as new technologies are discovered, and work with the knowledge of the individual designer to come up with the best products possible.

4.4 Inputs and Outputs

In order to help reach the desirable process characteristics, clear inputs and outputs are defined for each step in the process. These inputs and outputs serve several purposes in the process. First, they lend clarity to the process, and make the process more user friendly. Second, the inputs and outputs serve as gates, ensuring that the product developer has completed each step before moving on to the next step. Last, well-defined inputs and outputs allow the product developer to see progress in the process, and move them towards their objectives. Individual inputs and outputs are described with their respective steps in Chapters 5-8.

4.5 Desirable Process Attributes Conclusion

The current process used in TP product development is a simple and informal brainstorming session. While this process may provide a certain quantity of ideas, there is no established method for judging the quality of ideas generated. Four metrics were selected to determine the quality of ideas produced in this setting:

1) How closely the proposed product matches with the characteristics of the technology

2) Market size of the proposed product

3) Likelihood that the product could be developed

4) The value added to an existing product by the technology.

Successful concepts are more likely to be generated when an effective process is used. The process created in this thesis is judged against the following four criteria:

1) Specific

2) Efficiently Comprehensive

3) Creates successful products

4) Dynamic

Following these process characteristics will allow the user to achieve the desirable inputs and outputs, which will be used as gates between the process steps. These gates are described with their corresponding chapters.

Chapter 5 Technology Characterization Process

The Concept Generation and Evaluation Process begins with a comprehensive characterization of the technology. This gives several advantages to the product developer. The characterization should expand and solidify the developer's understanding of the technology's characteristics. These characteristics relate both to the functions that the technology may perform and to the way that the technology fits into the company's current abilities. It should also provide a smooth transition to the application identification stage. The characterization will break the technology down into its most basic components and may then be used to identify products in subsequent process steps. Finally, the characterization process initiates the transition from a research driven process to a customer focused product development process.

5.1 Process Overview

A flowchart has been created so that the product developer may follow along with the process being laid out for TP CG&E, and indicate to the developer where he/she is in the process. The flowchart is shown in Figure 5.1.

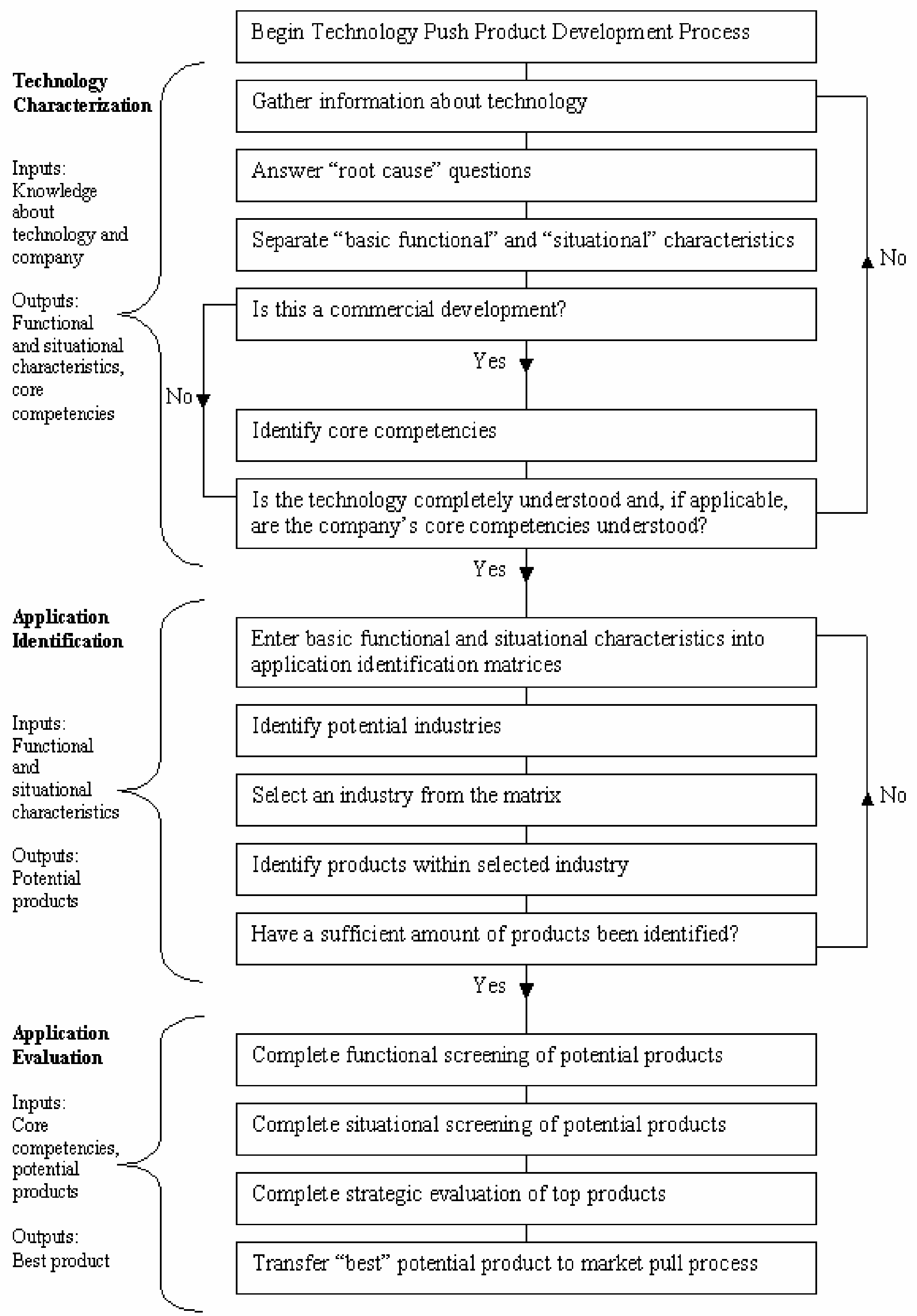

Figure 5.1 Flowchart Of The Concept Generation And Evaluation Process

In addition to the chart showing the entire process, a cutaway of each individual process step is contained in each chapter. Included in the chart are the inputs and outputs for each stage and gates that allow the developer to move on to the next stage. Figure 5.2 details the cutaway for the technology characterization stage. The other stages are included in their respective chapters.

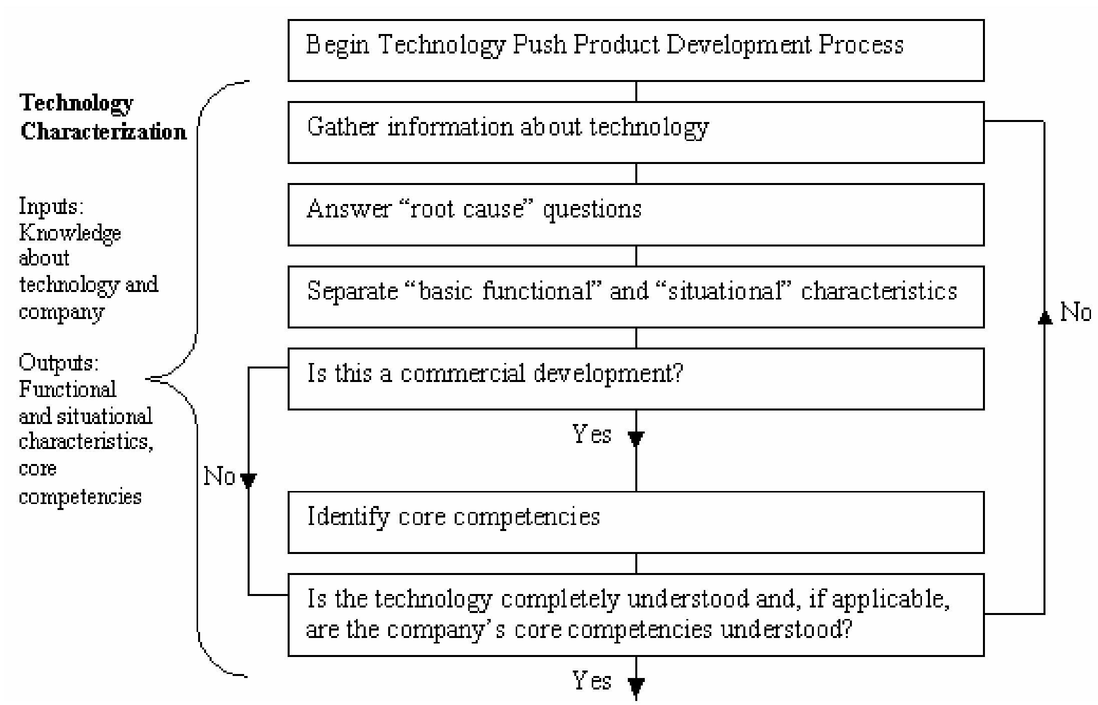

Figure 5.2 Flowchart Of Technology Characterization Stage

5.2 Desired Inputs and Outputs

As the TP product development process begins, it moves from a research stage, where the goal is to expand the current boundary of knowledge, to a product development stage, where the goal is to create marketable products. In order to understand when the developer is ready to progress to the next stage of the product development process, it is necessary to establish gates between the stages. Once the developer has completed the outputs of one stage, he has the necessary information to begin the next stage.

5.2.1 Inputs for Technology Characterization Stage

The inputs for this stage include a thorough understanding of the technology and the core competencies of the firm conducting the product development. This understanding may be derived from engineering notebooks, laboratory testing, literature reviews, or other studies. The core competencies of the firm should be outlined and readily available to those working in the firm. If not already established, it is important that the core competencies be determined. Guidelines on how to do this will be offered later in this chapter.

5.2.2 Outputs for Technology Characterization Stage

After the technology characterization stage is completed, there will be a number of outputs. Reaching these outputs will serve as a gate to proceed to the next stage. That is, if the developers are not satisfied that the outputs have been met, this stage should be reiterated. If necessary the inputs may need to be improved before moving on. The outputs for this stage are as follows:

1) Completed list of functional characteristics
2) Completed list of situational characteristics
3) Identification of the company's core competencies

5.3 Fit with Bishop's Comprehensive TP model

Bishop [2] also used technology characterization as the initiation of his overall TPPD model, and the steps found in this chapter align with the first steps in the technology characterization stage of his process. This relationship is shown in Figure

5.3. His work cites the tools and processes developed in this thesis for technology characterization, though they are grouped differently.

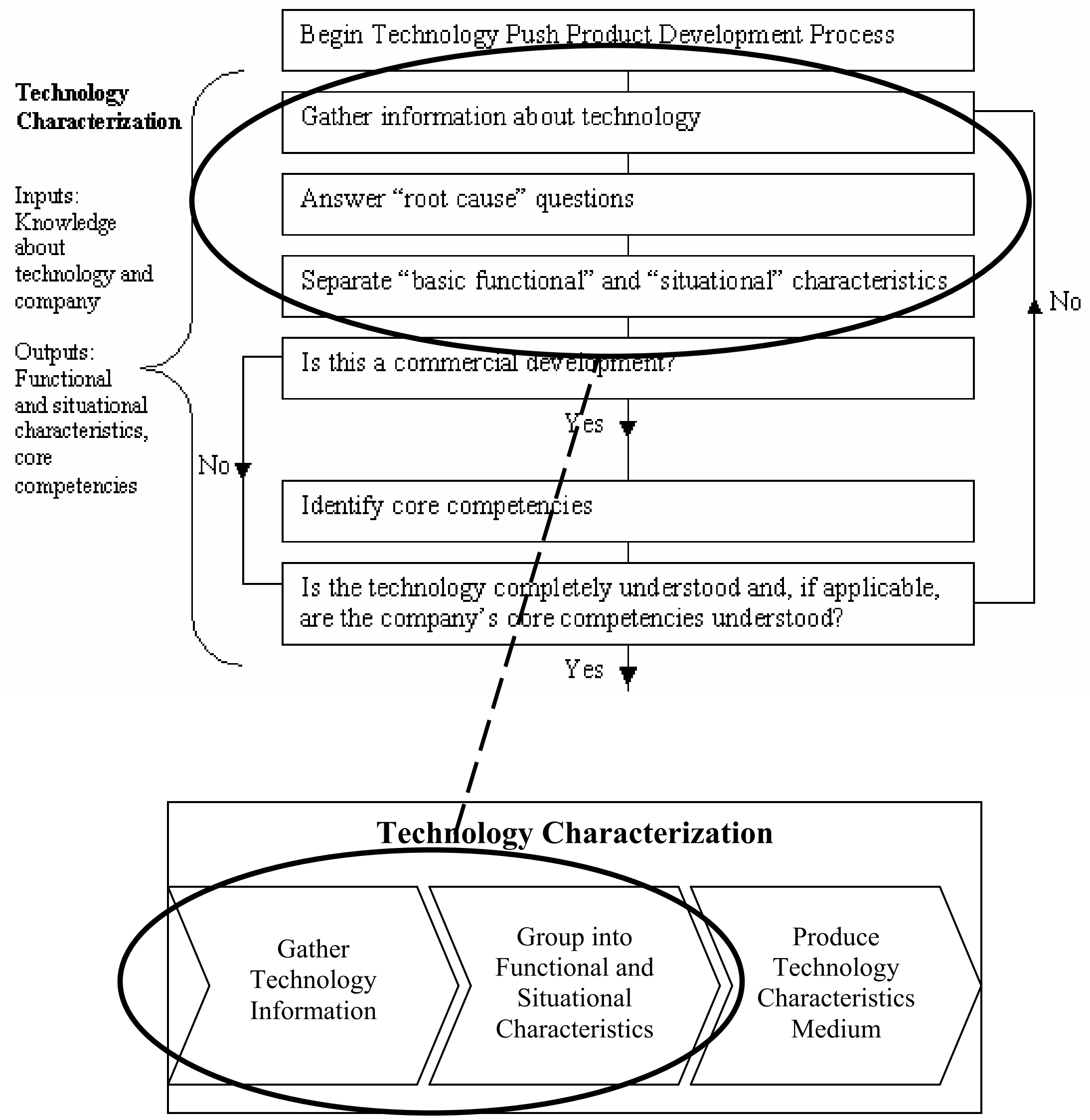

Figure 5.3 Relationship Between The Author's Work (Top) And Bishop's Work (Bottom)

5.4 Characterization Options

There are several potential styles of methodology that may be used to characterize the technology being studied. Among the possible candidates for characterization are: functional, behavioral, descriptive, and strategic. The methods selected for use in this thesis are functional and strategic. These methods were chosen due to their measurability and repeatability. The descriptive and behavioral methods of characterization are the most vague and subjective measures in the group. The functional and strategic methods may be evaluated against set criteria, allowing the process to be conducted in a repeatable fashion. Selecting the functional and strategic methods also offers a multidisciplinary approach to the process, examining the technology from technical and commercial points of view.

5.5 Functional Characterization

Functional Characterization allows the technology to be broken up into its most basic characteristics. This step in the process permits the product developer to view each of the traits of the technology, which will help to find unique competitive advantages in potential products. Functionally characterizing the technology entails both understanding the basic scientific principles upon which the technology is founded, and how those principles may be translated into situations where the technology may be substituted for existing products. Thus, the better the technology is understood, the greater the chance of discovering potentially marketable products.

5.5.1 Functional Characterization Options

There are two candidates for completing the functional characterization. The first method is called the functional mapping method. This method, laid out by Wood, involves obtaining or developing a comprehensive list of available technological characteristics, and comparing which traits of the technology being developed to the all-encompassing list [24]. This allows the technology to be broken down into its most basic functions in order to be built up for different uses.

As part of this work, a second option for functional characterization was developed. This technique will be termed the "root cause method". Unlike Wood's functional map, this method does not use a static list of technologies, and instead relies on the background knowledge and experience of those completing the product development. This method asks questions that are answered by the product developers that will determine the most basic functions of the product, as well as determining situations where the technology would be most effective.

5.5.2 Selection of Functional Characterization Methodology

The selection of the methodology used for functional characterization is based on the desirable process characteristics outlined in chapter 4. The comparison of the two methodologies is shown below in Table 5.1. The column on the far left contains the desirable characteristics, while the top row contains both methods, as well as a column in which method would be preferred for each process characteristic.

Table 5.1 Selection Of Functional Characterization Methodology

Specific	Very Specific	Very Specific	Either
Efficiently Comprehensive	Very Comprehensive, very inefficient	Equally Comprehensive, much more efficient	Root Cause
Successful Solutions	Likely to produce	Likely to produce	Either
Dynamic	Static	Dynamic	Root Cause

Overall, the root cause method was found be to be the most appropriate method according to the desirable process characteristics. Both methods were specific and equally likely to produce successful solutions. The functional mapping method, however, does not satisfy the other two characteristics. First of all, no comprehensive list of technological characteristics exists. Preliminary attempts have been made at such lists, and a completed work would include hundreds or possibly thousands of characteristics. Sifting through this list to find characteristics that matched the proposed technology would be highly inefficient, despite being comprehensive. The process set out in this work for the root cause method could achieve the same results with far less effort. Another problem with the functional mapping method is that it provides a static list that must be updated each time a new technological characteristic is discovered. The root cause method satisfies the process characteristic of being dynamic, as it does not rely on any static measures or characteristics. All of the characterization information is derived from the developers' knowledge, which is constantly changing and growing.

5.5.3 Selection of Questions for Root Cause Method

In order to reach the goals of technology characterization set out by Larsen [11], the questions used for functional characterization using the root cause method must accomplish three aims.

1) Identify all laws governing the technology in question.
2) Find the attributes that control the functions of the technology
3) Identify possible situations where the technology could be used

In order to achieve these aims, a number of possible questions for the product developers were developed. These candidates were then pared down to ensure that the three aims could be achieved while avoiding redundancy in the questioning. The questions selected for use in the technology characterization stage are:

1) What are the technology's attributes?
2) What laws govern its performance?
3) How would you describe the function of the technology?
4) What potential needs could this technology fill? Why?
5) As you have studied the technology, you have probably thought of some possible applications, or seen the technology in use. List four or five that you think would work (or would work) the best. What is it about this technology that makes it work in these situations?

These questions are all designed to extract the necessary information while looking forward toward the application identification stage. Questions four and five are clearly steering the characterization towards customer needs. This will aid in the transition between the technology characterization and application identification stages.

The questions asking for concepts that the developer has already considered are designed to create "seed thoughts", or ideas that may be built upon in the brainstorming process to spark other potential applications. They are also intended to draw out which technology attributes cause the preconceived concepts to be considered, so that those attributes may be leveraged to discover other concepts later in the process.

5.5.4 Grouping Into Functional and Situational Characteristics

After the selected questions have been answered, the product developer will have a list of technological characteristics to work from. A study of a number of past TP product developments shows that these characteristics may be divided into two categories: in this work they will be termed "functional" and "situational". The functional characteristics are those that may be defined by natural laws or equations. They will always be a defining function that is inherent to the technology, no matter how it is embodied. Examples of functional characteristics are: high tensile strength, low density, etc. The situational characteristics are those that describe potential situations where the technology may provide a competitive advantage. These characteristics are much more broad, and may or may not apply to the technology, depending on how the technology is embodied.. Some examples of situational characteristics are: disposable, sterile, low maintenance. Separating the functional characteristics into these two groups will facilitate the application identification stage.

5.6 Technology Characterization Examples

In order to further clarify the step-by-step TP CG&E process, two examples will be given. These examples will examine technologies as they pass through the various stages of product development outlined in this work. The first technology example in this thesis is Kevlar. This technology was selected because it is a well-known, multifaceted technology that allows the reader to see how the process works on a technology that is common in many industries. The second example centers on constant force compliant mechanisms. This example demonstrates how the process may be used with an emerging technology. These examples illustrate how the technology may be broken down into its characteristics, and then built back up as part of a product.

5.6.1 Kevlar Technology Characterization

Seen below in Figure 5.4 is an example of the questions used to complete the technology characterization of Kevlar. The characteristics identified in the five questions are grouped into situational and functional characteristics at the bottom of the characterization.

Technology functional characterization questions for Kevlar:
What are the technology's attributes?
High strength to weight, thermally stable, corrosion resistant, flame retardant, excellent in tension, chemical resistant

What laws govern its performance?
Polymer chain properties (parallel orientation), hydrogen bonding, high tensile strength,

How would you describe the function of the technology?
Energy absorption, heat and chemical resistance, structural applications

What potential needs could this technology fill? Why?
Reduced part count (composites can be molded to replace several parts), safety (chemical and heat resistance), Low maintenance (resistant to most corrosive materials)

As you have studied the technology, you have probably thought of some possible applications, or seen the technology in use. List four or five applications that you think work (or would work) the best. What is it about this technology that would make it work in these situations?
Gloves for a chemical environment: lightweight, heat and chemical resistant, may be woven into cloth
High performance tents: Lightweight, durable,
Motorcycle helmets: Lightweight, energy absorbent
Medical Rescue Stretchers: Potentially sterile, very light for airborne rescues
Parachutes and parachute lines: Good in tension, capability to be compressed

Now group the characteristics into the following areas:
Functional – Inherent to the technology (ex: force-deflection)
Polymer chain properties (parallel orientation), hydrogen bonding, high tensile strength, low coefficient thermal expansion, high strength to weight ratio

Situational – Dependent on how the technology is embodied (ex: disposable, low maintenance)
Chemical resistant, low maintenance, energy absorbent, reduced part count, heat resistant, sterile, and compactable, may be woven into cloth

Figure 5.4 Technology Characterization Of Kevlar

5.6.2 Constant Force Compliant Mechanism Technology Characterization

Constant Force Compliant Mechanisms (CFCMs) combine the effects of mechanical advantage and stored strain energy of flexible members to obtain a constant output force over a large range of displacements [19]. Figure 5.5 shows the questions used to complete the technology characterization, this time used for CFCMs technology.

Technology functional characterization questions for CFCMs:

What are the technology's attributes?
Constant output force regardless of input displacement. Ability to create constant force in compression. Adjustable, scalable, forgiving, no external power needed.

What laws govern its performance?
Mechanical advantage and stored strain energy of flexible members.

How would you describe the function of the technology?
Constant output force regardless of compression input displacement.

What potential needs could this technology fill? Why?
Reduced part count due to compliant mechanisms, ability to create constant force in compression, ability to grip fragile parts without damaging parts. wear reduction

As you have studied the technology, you have probably thought of some possible applications, or seen the technology in use. List four or five applications that you think work (or would work) the best. What is it about this technology that would make it work in these situations?
Electronic connectors that maintain a constant force regardless of part tolerances (constant force output)
Spring in a hospital bed that would allow the same force to be that would allow the same force to be reduce bed sores (scalable)
A gripping device to hold delicate parts of varying size (constant force output, adjustable))
Motor brush wear improvement (constant force output, wear reduction)
Biomedical implants (no external power needed)

Now group the characteristics into the following areas:
Functional – Inherent to the technology (ex: force-deflection)
Constant output force regardless of input displacement. Mechanical advantage and stored strain energy of flexible members.

Situational – Dependent on how the technology is embodied (ex: disposable, low maintenance)
Adjustable, scalable, forgiving, no external power needed, reduced part count, grip fragile parts

Figure 5.5 Technology Characterization Of CFCMs

5.7 Strategic Characterization

In addition to functional characterization, the company must lay the foundation for a strategic characterization. While the strategic characterization is not completely finished until the application evaluation stage, a significant portion of the work is accomplished in this stage.

In order to strategically characterize a technology, a company must first understand and list their core competencies. The potential products identified in this product development process are then evaluated by matching the characteristics of the products against the skills, behaviors and experiences listed in the core competencies of the organization. Since introducing a product in a technology push situation is already at a disadvantage to a product in a market pull situation, it becomes even more important to utilize the company's competencies to help the product succeed.

Several studies have shown the importance of matching new product development with existing core competencies [25] [12]. Each of these studies found that new products were more likely to be successful when building upon existing technological, marketing, and distribution strengths.

5.7.1 Core Competency Identification

A company's core competencies are defined by Prahalad and Hamel [18] as "the collective learning in the organization, especially how to coordinate diverse production skills and integrate multiple streams of technologies". As previously mentioned, core competencies are not the most important products that a company produces, but rather the knowledge and skills that produce the core competencies. In the example provided by Prahalad and Hamel, Canon's core competencies are fine optics, precision mechanics and microelectronics. These core competencies translate into their core products of printers, copiers and faxes. Thus, to identify potential core competencies, a company must examine their most important products, and then identify what knowledge and skills set that product apart in the marketplace.

Once the potential competencies are identified, there are three tests that may be applied to recognize the true core competences within a company.

1) A core competence should provide potential access to several different markets
2) A core competence should make a significant contribution to the benefits of the end product.
3) A core competence should be difficult for competitors to imitate.

Prahalad and Hamel state that most companies will have less than five true core competencies [18]. If a company finds more than five core competencies, then it is likely that some of the competencies they have identified do not satisfy the criteria listed above.

5.8 Development Example – Core Competency Identifications

In order to fully evaluate the products identified in this example it is necessary to create a hypothetical company for that is performing the product development for each of the example technologies. The imaginary company carrying out the product development for Kevlar in this example will have core competencies in: knowledge of extrusion process, adhesive and epoxy expertise, and sales and marketing relationships with the sports gear industry. Another hypothetical company is needed for the CFCM example. In this case the company performing the product development has core competencies in injection molding processes and designing for cost.

5.9 Conclusion

At the end of the technology characterization stage, the product developer should have a knowledge of three different categories: the "functional" characteristics of the technology, the "situational" characteristics of the technology, and the core competencies of the company funding the development. These three areas allow the developer to understand the technology, see where it may potentially be used, and understand how it fits into the company's overall strategy. When the developer is satisfied that the knowledge of these three areas is sufficient, the process may move on to the application identification stage.

Chapter 6 Application Identification Process

After gaining a complete understanding of the technology and the strategy of the company performing the development, the process progresses on to identifying potential concepts for the technology. This step matches up the inherent characteristics of the technology with the customer needs of specific industries, which may then be embodied in commercial products within those industries. The flowchart of this stage of the process may be seen in Figure 6.1.

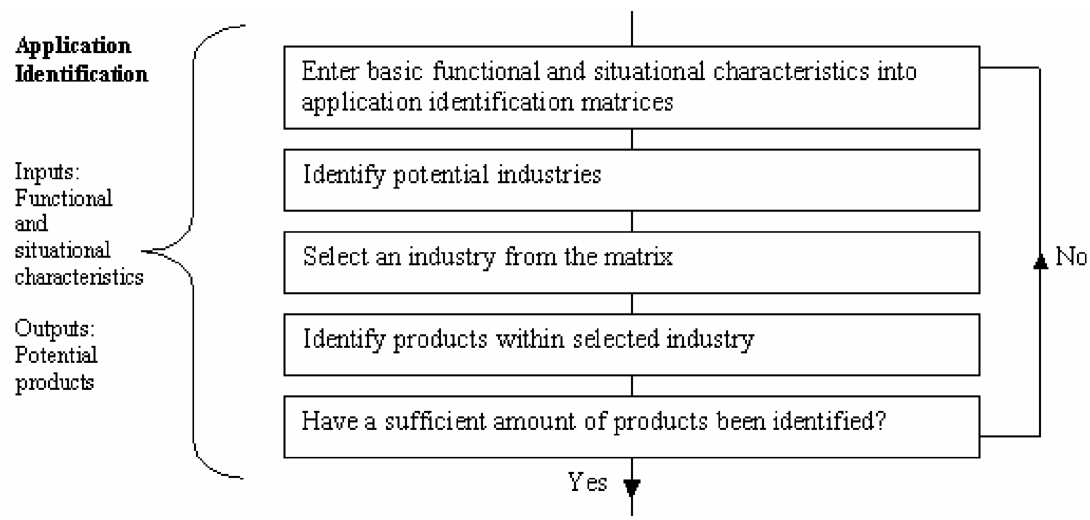

Figure 6.1 Flowchart Of Application Identification Stage

6.1 Desired Inputs and Outputs

Like the technology characterization stage, the application identification stage has predetermined inputs and outputs. The inputs consist of the functional and situational characteristics that have been identified in the previous step. These characteristics may be transferred directly to the application identification matrices provided in this stage. The output for this step is a list of potential applications that will be evaluated in the final stage.

6.2 Fit With Bishop's Comprehensive TP model

Figure 6.2 shows how the Application Identification portion of the CG&E process fits into Bishop's TP model.

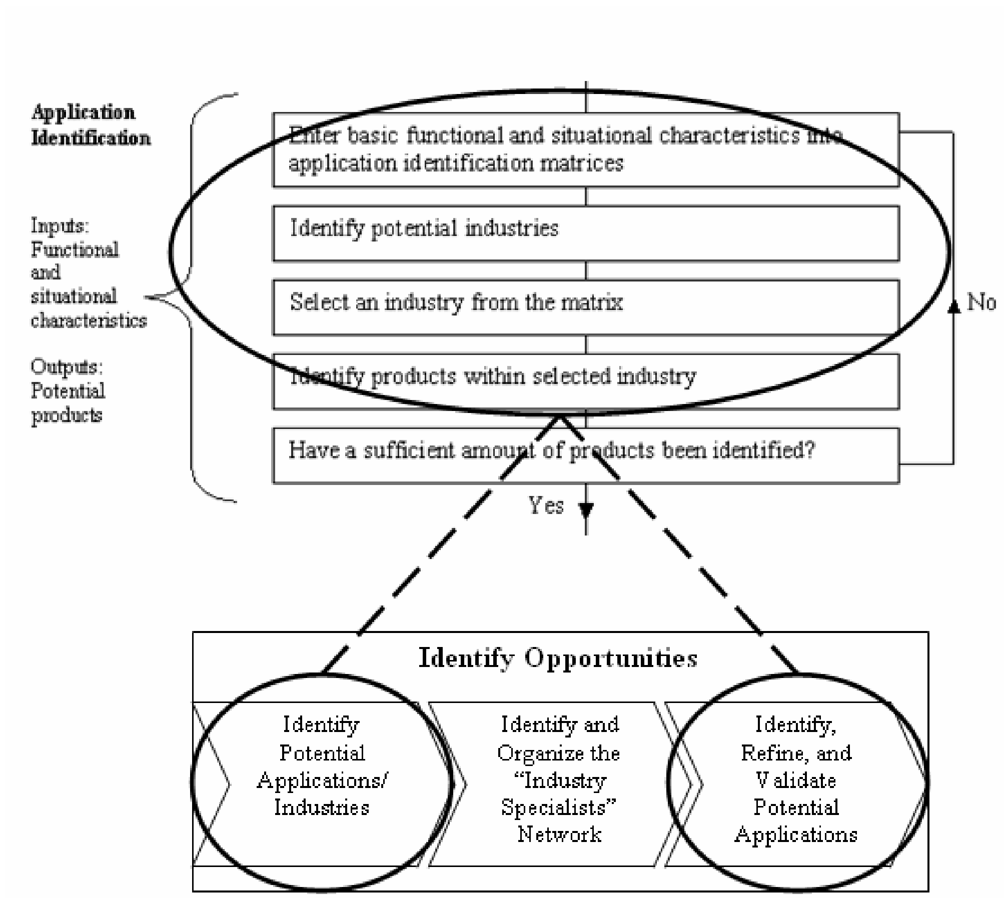

Figure 6.2 Relationship Between The Author's Application Identification (Top) And Bishop's Identify Opportunities (Bottom)

Bishop arranged the steps from the application identification process differently, and created an intermediate step to bring in outside experts to aid in the identification process. This step of bringing in outside experts was put into practice with positive results in one of the examples given later in this chapter. It was not, however, formalized as one of the steps in the process for this work.

6.3 Application Identification Techniques

As seen in the first chapter, one of the primary obstacles to overcome in TP product development is the open-endedness of the process. This open-endedness is especially present in the application identification stage. As a result, there is a special emphasis on being *efficiently* comprehensive in this stage. This is largely because there is no way of determining whether or not every possible application has been discovered through the techniques used. In order to make the process efficient, a method that in this work will be called "focused brainstorming" will be used. A funneling process will follow the focused brainstorming. This funneling process will move the identification process from an industry-level view to a product-level view.

6.3.1 Focused Brainstorming

Focused brainstorming is a term used in this work to describe the method of finding different potential applications. This method consists of brainstorming while guided by the various functional and situational characteristics listed in the Technology Characterization process step. This brainstorming process is completed with the aid of a "product identification matrix". This method provides two advantages to the product developer. First, it gives all of the pertinent characteristic information to the developer on one sheet of paper, so that the information is not lost between steps. Second, it focuses the developer's thoughts on the characteristics outlined in the previous step, and helps to control the brainstorming process. This focused brainstorming process, with the identification matrices will be demonstrated in the example in sections 6.6 and 6.8.

The situational characteristics are listed along the axes of the matrix in order to facilitate the brainstorming. The matrix allows the developers to evaluate pairs of characteristics when generating concepts. The concepts are placed in the square that relates to the situational characteristics the most closely apply to the concept in order to help generate other concepts with similar characteristics. However, developers should not spend an inordinate amount of time deciding which square the concept should be placed in, as all concepts will be moved on to the next stage, regardless of their placement within the matrix.

6.3.2 The Funneling Process

In order to include the greatest number of possible products, brainstorming is completed first on an industry-level view, then on a product-level view. This allows the developers to first understand on a higher level where their technology may be useful. Then, as many industries value certain characteristics for multiple products, the process will help to identify additional potential products. For example, a certain material may prove to be lightweight, easily manufactured, and highly corrosion resistant. Possible industries would include deep-sea oil recovery and chemical companies. However, inside those industries there are dozens of potential products, many with similar customer needs.   These products with similar customer needs may all be potential products for the technology being examined. The funneling process, as it moves from an industry-level search to a product family-level search to a specific product, is shown in Figure 6.3

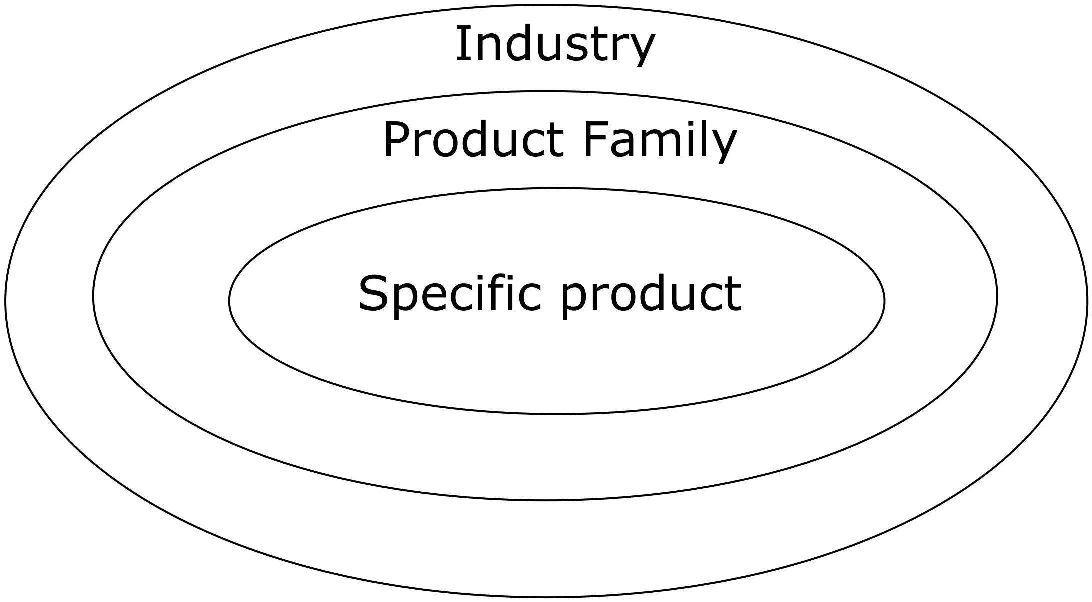

Figure 6.3: Application Identification Funneling Process

6.4 Focused Brainstorming Techniques

Aside from using the situational and basic functional characteristics as guides, focused brainstorming follows the same rules as traditional brainstorming. As many developers are unfamiliar with how to properly brainstorm, these techniques will be outlined in this section. Widely accepted rules that must be applied to a brainstorming session are as follows [10].

1. Limit the group to 5-12 participants and a leader.
2. Focus on one problem per session.
3. Adhere to the 4 basic principles of brainstorming, i.e., do not criticize; encourage unorthodox ideas; strive toward quantity of ideas; build on other ideas.
4. Define the problem

5. Select a meeting environment that minimizes anxiety and tension.
6. Record ideas

While there are guidelines to make the brainstorm more effective, they play a secondary role, with encouraging creativity, imagination, and quantity of ideas being the primary objective. Even in the focused brainstorm, where there are additional guidelines to help the developers generate concepts that will utilize the selected technology, there should never be criticism of what may seem like infeasible, or off the wall ideas. Judgment of the brainstormed ideas should be postponed until the appropriate time. Sometimes what may initially seem to be an impractible idea may serve as a springboard to generate other ideas in the brainstorming sessions[10].

6.5 Industry Selection

As previously mentioned, there are two stages to the application selection process. Both stages are similar, in that they identify potential used by using the situational characteristics listed in the technology characterization stage. The industry selection stage looks at potential applications at a broader level. When the product developers are brainstorming for possible solutions at this level, they may come up with products. These products may then be extrapolated up to the industry level. For example, during an industry-level brainstorming session, one of the members may come up with the idea of using the technology in surgical applications. This could be extrapolated to the medical industry level. If the product developer later chose to identify products within the medical industry, the surgical applications product would then be placed in the product application identification matrix.

6.6 Industry Identification Examples

Continuing with the product development examples that were initiated in the previous chapter, the Kevlar and Constant Force Compliant Mechanism (CFCM) technologies are now ready for the application identification stage. It should be noted that these examples are given as an instructive aide, and not intended to be a comprehensive listing of potential products for these technologies. As was previously noted, the applications identified will depend largely on the varying personal experiences and backgrounds developers. Iterations of these exercises by different developers would almost certainly produce a different set of concepts that could be carried forward for evaluation.

6.6.1 Kevlar Industry Identification Example

As seen below in the Kevlar example, the basic functional characteristics have been transferred to the top of the page, and the situational characteristics have been listed along the axes of the identification matrix (See Figure 6.4). This allows the product developer to have all the pertinent information at hand while completing the focused brainstorming. In several instances during the industry-level brainstorming a potential product was discovered. In these cases the concept was extrapolated out to the industry level, and the industry was listed on the matrix. This would then allow the developers to further investigate other products within the industry. For example, the technology could be used for tent poles, yet this falls under the larger category of sports gear, so the sports gear industry would be listed on industry application identification matrix.

Industry Application Identification

Basic Functional characteristics: Polymer chain properties (parallel orientation), hydrogen bonding, high tensile strength, low coefficient thermal expansion, high strength to weight ratio

Situational Characteristics:	Chemical Resistant	Low Maintenance	Energy Absorbent	Reduced Part Count	Heat Resistant	Sterile	May be woven into cloth
Chemical Resistant	Undersea Industry			Construction	Chemical Plant Safety	Surgical Replacements	
Low Maintenance			Sports Gear	Aerospace	Welding Safety Friction Products	Medical	Sports Gear
Energy Absorbent			Defense	Automotive Safety Sports Gear			
Reduced Part Count					Automotive		
Heat Resistant							
Sterile							Medical Rescue
May be woven into cloth							

Figure 6.4 Kevlar Industry Identification Example

6.6.2 CFCM Industry Identification Example

The industry identification process is very similar for CFCMs. Again, the basic functional characteristics are listed along the top of the matrix, and the situational characteristics are placed along the axes to guide the developers as they completed the focused brainstorming techniques. The industries are placed into the box whose attributes best describe which functions of the technology are most applicable to the industry listed. The complete industry identification matrix for CFCMs is seen in Figure 6.5

Industry Application Identification

Basic Functional characteristics: Constant output force regardless of input displacement. Mechanical advantage and stored strain energy of flexible members.

Situational Characteristics:	Adjustable	No external power needed	Scalable	Grip fragile parts	Low weight	Forgiving	Reduced Part Count
Adjustable			Mechanical Component Assembly	Robotic Grasping		Infant Safety	Haptic Devices
No external power needed			MEMs	Military Field Medicine	Aerospace	Healthcare	Sports/Recreational equipment
Scalable				Optics	Firearm manufacturing and safety	Automotive safety	
Grip fragile parts					Aerospace		
Low weight							
Scalable							
Reduced Part Count							

Figure 6.5 CFCM Industry Identification Example

6.7 Product Application Identification

Following the industry application identification stage, the process continues on to product application identification. The first step within this stage is to select which industries to focus on first. This selection should be made based on several factors. These include: industries that the developer is most familiar with, industries that hold the highest market potential, industries that are closest to the products that the company currently produces, and industries that have the greatest number of potential applications. The step from industry level application identification to product level application identification is an iterative one. It should be repeated until the developers feel that they have discovered enough potential applications to advance to the application evaluation stage. If there is an insufficient amount of potential applications, the product developers should return to the industry level, select another industry to examine, and complete another product level application identification. There is no predetermined quota on how many potential applications should be identified. For the purpose of this thesis a minimum of 15 potential products were generated before moving on to the next phase in order to adequately demonstrate the process. This quantity of applications will provide sufficient data for the relative measures used in the application evaluation stage.

6.8 Product Identification Examples

After identifying the potential industries for the technologies being developed, the industry identification matrix was examined to find which areas would be best to further explore. As can be seen in Figure 6.6, 6.7, 6.8 and 6.9, the product identification matrices look nearly identical to the industry identification matrices. All of the functional and situational characteristics are still in place, and the matrix has the same basic layout. The only difference being that the specific industry being examined is placed at the top of the page, and the brainstorming is further focused to that particular area. While this portion of the process should be focused on a particular industry, it is likely that the brainstorming may produce ideas outside of the focus area. In this case, these ideas may simply be included in the product application identification matrix and assessed with the other concepts in the application evaluation stage.

6.8.1 Kevlar Product Identification Example

In the case of Kevlar, the medical and sports gear industries were selected for their market potential, and the quantity of potential applications. These two industries produced a sufficient number of potential products to move on to the application evaluation stage. Had a smaller number of potential products been identified, the product application identification process could have been reiterated for another industry. Figure 6.6 shows the process example for the sports gear industry, and Figure 6.7 shows the same process for the medical industry.

Product Application Identification

Industry: Sports Gear

Basic Functional characteristics: Polymer chain properties (parallel orientation), hydrogen bonding, high tensile strength, low coefficient thermal expansion, high strength to weight ratio

Situational Characteristics:	Chemical Resistant	Low Maintenance	Energy Absorbent	Reduced Part Count	Heat Resistant	Sterile	May be woven into cloth
Chemical Resistant		Racing Sculls (boats), boat paddles		Waterskiing lines, waterskis			Fish nets
Low Maintenance			Tent Poles				Parachute lines, snowboard gloves, outerwear, rock climbing gear
Energy Absorbent			Snowboards, Motorcycle helmets, Hiking poles				
Reduced Part Count							
Heat Resistant							Extreme temperature clothing
Sterile							
May be woven into cloth							Higher performance tents, backpacks

Figure 6.6 Kevlar Application Identification Matrix Example For Sports Gear

Product Application Identification

Industry: Medical

Basic Functional characteristics: Polymer chain properties (parallel orientation), hydrogen bonding, high tensile strength, low coefficient thermal expansion, high strength to weight ratio

Situational Characteristics:	Chemical Resistant	Low Maintenance	Energy Absorbent	Reduced Part Count	Heat Resistant	Sterile	May be woven into cloth
Chemical Resistant						Stitches	
Low Maintenance			Artificial ligaments, tendons			Splints	
Energy Absorbent						Artificial limbs	
Reduced Part Count							
Heat Resistant							
Sterile							Medical Resue stretcher
May be woven into cloth							

Figure 6.7 Kevlar Application Identification Matrix Example For Medical Products

6.8.2 CFCM Product Identification Example

The product identification process is now repeated for CFCMs. The two industries selected for closer examination were Fragile/Robotic Grasping and Healthcare. Similar to the Kevlar examples, these industries were chosen for their large markets and broad range of applications. In order to identify a greater amount of potential products in the healthcare field a physical therapist and a family practice physician were consulted during the focused brainstorming session with excellent results. It is interesting to note that although neither of the health care professionals were previously familiar with the CFCM technology, they were able to quickly become familiar with its attributes by using the characteristics listed in the matrix seen in Figure 6.8, and produced many valuable results. The product identification matrix for the Fragile/Robotic Grasping industry is also included below in Figure 6.9.

Product Application Identification

Industry: Healthcare

Basic Functional characteristics: Constant output force regardless of input displacement. Mechanical advantage and stored strain energy of flexible members.

Situational Characteristics:	Adjustable	No external power needed	Scalable	Grip fragile parts	Low weight	Forgiving	Reduced Part Count
Adjustable		Clamps	Stents, Colon cancer sample extractor	Vascular Surgical Tools	Dolorimeter	Corneal shaving, Automated Intravenous Initiator	
No external power needed					Compression sleeve		Pressure applicator for elderly physical thrapy patients
Scalable					Splints/Casts (reduce pressure on nerves)		
Grip fragile parts						Stabilization for object extraction from eyes	Tissue manipulation by battlefield surgical robots
Low weight							
Scalable							
Reduced Part Count							

Figure 6.8 CFCM Application Identification Matrix Example For Healthcare

Product Application Identification

Industry: Fragile/Robotic Grasping

Basic Functional characteristics: Constant output force regardless of input displacement. Mechanical advantage and stored strain energy of flexible members.

Situational Characteristics:	Adjustable	No external power needed	Scalable	Grip fragile parts	Low weight	Forgiving	Reduced Part Count
Adjustable	Injection Molding Plunger	Archeological recovery		Porcelain houseware manufacturing	Aeropspace Mylar grasping	Ceramic dinnerware manufacturing	
No external power needed				Glass warehousing		Fruit processing	
Scalable				Hard disk plate manufacturing			
Grip fragile parts						Superconductor manufacturing, Microchip Wafer handling	
Low weight							
Scalable							
Reduced Part Count							

Figure 6.9 CFCM Application Identification Matrix Example For Fragile/Robotic Grasping

6.9 Conclusion

The application identification stage begins with a list of the technology's attributes and ends with a list of potential products ready to be evaluated. In order to arrive at this point the attributes are first associated with industries that have customer needs that may be met by the technology's characteristics. After identifying the industries where the technology may be used, the process funnels down to products within those industries. The CFCM case study showed that bringing in industry experts to aid in the product identification stage was extremely productive. While these experts only had a rudimentary knowledge of the technology being studied, they were able to understand its capabilities simply by using the application identification matrices. The process of identifying products within industries should be repeated until there is a sufficient quantity of ideas to be evaluated.

Chapter 7 Application Evaluation

The final step in the CG&E process is determining which of the potential applications should be pursued for further development. Finding the most appropriate application requires looking at the products from multiple viewpoints. This chapter will show how the potential products discovered in Chapter 6 may be evaluated from functional and strategic perspectives. As with the other chapters, a flowchart of this stage is included in Figure 7.1.

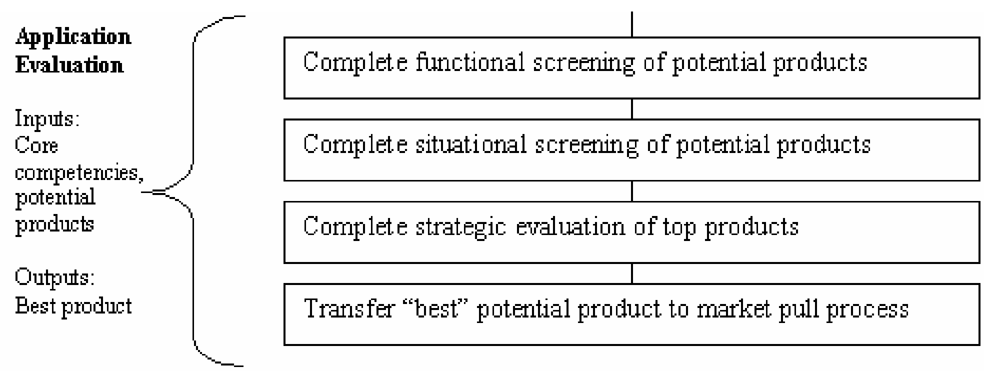

Figure 7.1 Flowchart Of The Application Evaluation Stage

7.1 Inputs and Outputs

As with the other two process steps, the application evaluation stage has specific inputs and outputs. Its inputs are the list of potential products derived from Chapter 6, as well as the core competencies of the company performing the development, derived from Chapter 5. After this stage is completed, the process should output the best candidate for further development. The process then transitions into a traditional market-pull product development process. The steps of identifying customer needs, product specifications, concept generation, and concept selection have been completed, and the market pull process may then proceed with concept testing, DFM, prototyping, etc.

7.2 Fit With Bishop's Comprehensive TP model

Figure 7.2 shows how the Application Evaluation portion of the CG&E process fits into Bishop's model.

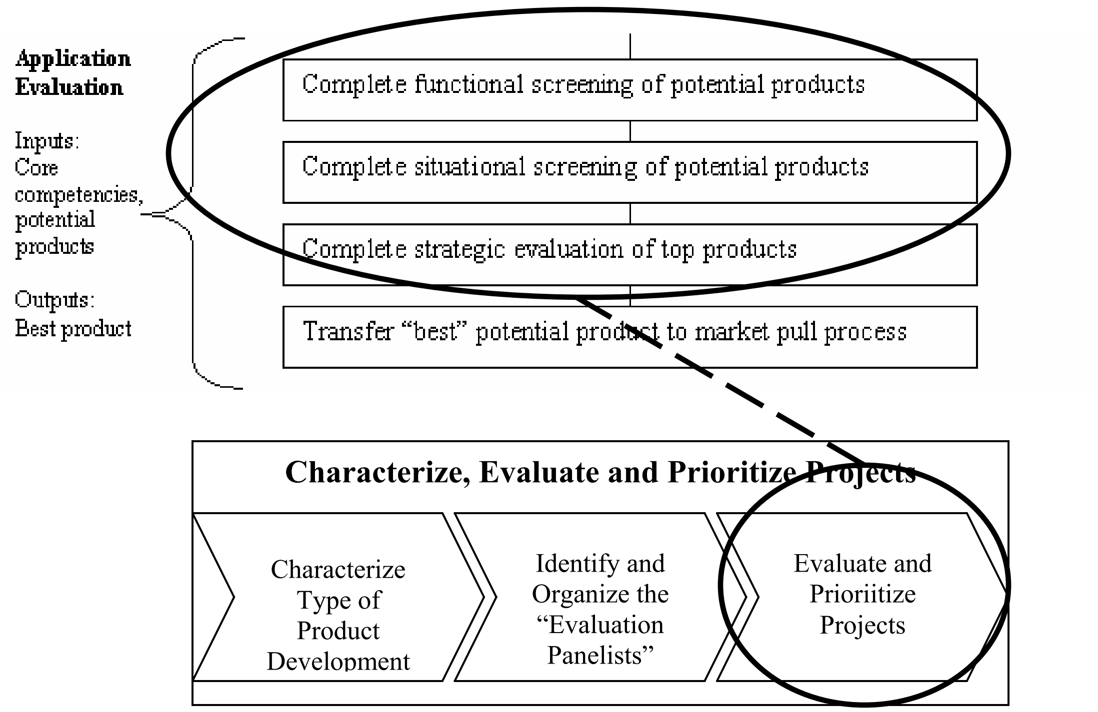

Figure 7.2 Relationship Between The Author's Application Evaluation (Top) And Bishop's Characterize, Evaluate And Prioritize Projects (Bottom)

At this stage Bishop's process and the author's process diverge. The first two chevrons in Bishops process are not included in this work. The final step for the Application Evaluation Stage – Transfer "best" potential product to market pull process –

is discussed in far greater detail in Bishop's work as part of his expanded scope. However, the Evaluate and Prioritize Projects chevron of Bishops lines up with the rest of the steps for the process shown in the remainder of this chapter.

7.3 Hierarchy of Characteristics

The case studies in this work unveiled a hierarchy of characteristics that are used for evaluating the concepts generated in chapters 5 and 6. The products are each evaluated against characteristics regarding their functional, situational, and strategic attributes. As products are evaluated, they must satisfy one level of characteristics before they move onto the next level. The hierarchy moves from Functional Characteristics to Situational Characteristics to Strategic Characteristics. This hierarchy satisfies intuition, as a product must have certain functional characteristics to satisfy a given set of situational characteristics. If the product cannot satisfy the set of situational characteristics, it is irrelevant whether or not it fits into a company's strategy.

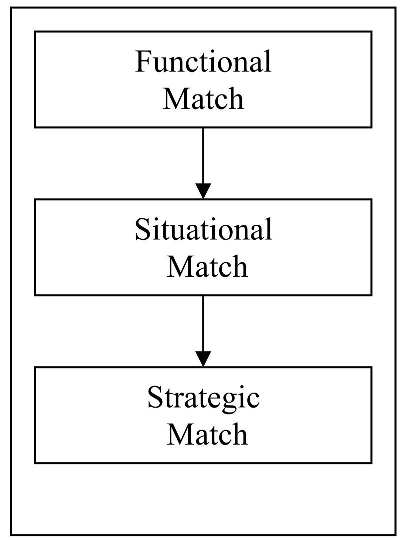

Figure 7.3 Hierarchy Of Characteristics

7.4 Functional Screening

The products are first examined from a functional perspective. As described above, the reason for this is simple. If the potential product does not work with the technology, or cannot be a commercial success, it will not matter if the product fits into the company's strategy. For each of these criteria, it is assumed that the technology being developed will be replacing an existing technology. The criteria for successful products from a functional perspective have been established previously in Chapter 4, and will be reviewed here. These metrics also serve to evaluate the situational characteristics of the technology. As the evaluation is made at the product level, and each product contains the basic functional and situational characteristics, making it difficult to completely separate the evaluation of the two characteristics. As these metrics were more applicable to the functional characterization, they are included in this section.

7.4.1 Metric 1: Technology Match

This metric measures how well the technology's functions are able to meet the customer's needs for the proposed product. This is the most important metric in the functional evaluation. Clearly, if the technology is a poor fit for the proposed product, it will be a commercial failure regardless of market size or how easy it would be to develop.

7.4.2 Metric 2: Value Added to the Product

This metric measures what difference the technology makes in the product it is replacing. This difference may be either in technical performance or in reduced cost. The range of value that may be added can vary greatly, depending on how widely the technology is used in a product, and the magnitude of difference that is made by replacing the current technology with the new technology.

7.4.3 Relative Scoring

For subjective criteria such as these, it is difficult to establish an absolute scale to measure the different proposed products. Thus the products are judged against each other on a relative scale. If Product A has a much closer technology match than Product B, then Product Awould receive a higher score in this metric. This relative scoring is used for all four of the functional and situational metrics.

7.4.4 Screening Process

The functional screening process serves to eliminate potential products that either have customer needs that cannot be met by the technology, or products where the use of the technology would have a minimal impact on the product. In order to screen out these products, the developer should first sum the score of the two metrics, and then eliminate those products that fall in the bottom half of the scores. The products that score in the upper half of the evaluation will move on to the situational screening.

7.5 Functional Screening Examples

The potential products discovered in the identification matrices in Chapter 6 were taken and inserted into the "Potential Applications" column of the Functional Screening Matrices (Tables 7.1 and 7.2). Each product was then evaluated as to how well they met metrics #1 and #2. The products that scored in the lower half were then eliminated and are not evaluated at the situational level.

7.5.1 Kevlar Functional Screening

Table 7.1 Kevlar Functional Screening

Potential Application	#1 (Functional Match)	#2 (Value added to product)	Functional Screening Sum
Artificial tendons	9	8	17
~~Artificial limbs~~	~~6~~	~~8~~	~~14~~
Stretcher	8	9	17
~~Splints~~	~~6~~	~~6~~	~~12~~
~~Stitches~~	~~9~~	4	~~13~~
~~Boat Paddles~~	~~6~~	~~6~~	~~12~~
Waterski lines	9	8	17
~~Waterskis~~	~~8~~	~~7~~	~~15~~
High- End Tents	8	8	16
Fish nets	8	8	16
~~Extreme temp clothing~~	~~7~~	~~6~~	~~13~~
Snowboard gloves	9	8	17
Snowboards	8	8	16
Hiking poles	9	8	17
~~Motorcycle helmets~~	~~6~~	~~9~~	~~15~~

7.5.2 CFCM Functional Screening

Table 7.2 CFCM Functional Screening

Potential Application	#1 (Functional Match)	#2 (Value added to product)	Functional Screening Sum
Stents	4	~~5~~	~~9~~
~~Polyp Extractor~~	~~3~~	~~7~~	~~10~~
Vascular Surgical Tools	7	8	15
Dolorimeter	9	9	18
Compression Sleeve	5	7	12
Splints/Casts	6	6	12
Corneal Shaving	8	7	15
~~Automated Intravenous Initiator~~	~~5~~	~~6~~	~~11~~

Table 7.2 Continued CFCM Functional Screening

Potential Application	#1 (Functional Match)	#2 (Value added to product)	Functional Screening Sum
Battlefield Surgical Robots	9	7	16
~~Injection Molding Plunger~~	~~6~~	~~3~~	~~9~~
Archeological Recovery	8	6	14
~~Porcelain Housewares Mfg~~	~~6~~	~~3~~	~~9~~
~~Glass Warehousing~~	~~6~~	~~5~~	~~11~~
Disk Drive Plate Grasping	7	7	14
Aerospace Mylar Grasping	6	8	14
~~Ceramic Dinnerware Mfg~~	~~8~~	~~3~~	~~11~~
~~Fruit Processing~~	~~6~~	~~5~~	~~11~~
~~Superconductor Handling~~	4	4	~~8~~
Microchip Wafer Handling	7	7	14

7.6 Situational Screening

After the functional characterization screening step, the evaluation moves on to how well the products utilize the situational characteristics of the technology. These metrics examine the proposed technology from a commercial point of view. This evaluates how well the technology is able to turn its ability to meet customer needs into a product that meets the most customers' needs.

7.6.1 Metric 3: Market Size

As stated earlier, the ultimate goal of TP product development it to discover marketable and profitable products. Products that offer technological superiority over the existing alternatives will generate more revenue when entering into larger markets. The science of determining market size is not discussed in depth here, but may be referenced in works by the following authors: Hauser [22], Pringle [16], and Dougherty [6].

7.6.2 Metric 4: Likelihood of Development

The final metric examines factors that may hinder development of the product or entry into a given market. As mentioned in Chapter 4, these factors include, but are not limited to: overhead costs, barriers to entry for a given market, strength of existing players in the current market and potential for acceptance of a new technology in a given market.

7.6.3 Situational Screening

Much like functional screening, situational screening is devised to further pare down the potential products in an effort to find the "best" idea out of the group. The scores of all four of the metrics are summed, and the top half of the products moves on to the strategic screening process, while the lower half are left out. If none of the products in the upper half satisfy the requirements in the strategic evaluation, then the lower half may be evaluated at the strategic level.

7.7 Situational Screening Examples

The products that advance through the functional screening continue on to the situational screening. These products receive additional relative scores for metrics #3 and #4. The scores of the four metrics are then summed, to determine which products should first be evaluated on a strategic level.

7.7.1 Situational Screening for Kevlar

The top products have been bolded and underlined in the "Sum of Scores" column in Table 7.3. As this example yielded three products with equal scores from the four metrics, they will each be evaluated at the strategic level.

Table 7.3 Kevlar Situational Screening

Potential Application	#1 (Functional Match)	#2 (Value added to product)	#3 (Market Size)	#4 (Feasibility of Development)	Sum of Scores
Artificial tendons	9	8	4	4	25
~~Artificial limbs~~	~~6~~	~~8~~			
Stretcher	8	9	6	8	31
~~Splints~~	~~6~~	~~6~~			
~~Stitches~~	~~9~~	~~4~~			
~~Boat Paddles~~	~~6~~	~~6~~			
Waterski lines	9	8	6	9	**32**
~~Waterskis~~	~~8~~	~~7~~			
High- End Tents	8	8	5	6	27
Fish nets	8	8	5	6	27
~~Extreme temp clothing~~	~~7~~	~~6~~			
Snowboard gloves	9	8	6	8	31
Snowboards	8	8	8	8	**32**
Hiking poles	9	8	6	9	**32**
~~Motorcycle helmets~~	~~6~~	~~9~~			

7.7.2 Situational Screening for CFCMs

Table 7.4 CFCM Situational Screening

Potential Application	#1 (Functional Match)	#2 (Value added to product)	#3 (Market Size)	#4 (Feasibility of Development)	Sum of Scores
Stents	4	~~5~~			
Polyp Extractor	~~3~~	~~7~~			
Vascular Surgical Tools	7	8	6	6	**27**
Dolorimeter	9	9	8	10	**36**
Compression Sleeve	5	7	7	5	24
Splints/Casts	6	6	7	5	24
Corneal Shaving	8	7	5	4	24
Automated Intravenous Initiator	~~5~~	~~6~~			
Object Extractor	~~6~~	4			
Pressure for Elderly Patients	~~7~~	4			

Table 7.4 Continued CFCM Situational Screening

Potential Application	#1 (Functional Match)	#2 (Value added to product)	#3 (Market Size)	#4 (Feasibility of Development)	Sum of Scores
Archeological Recovery	8	6	6	6	26
Porcelain Housewares Mfg	~~6~~	~~3~~			
Glass Warehousing	~~6~~	~~5~~			
Disk Drive Plate Grasping	7	7	6	7	**27**
Aerospace Mylar Grasping	6	8	3	6	23
Ceramic Dinnerware Mfg	~~8~~	~~3~~			
Fruit Processing	~~6~~	~~5~~			
Superconductor Handling	4	4			
Microchip Wafer Handling	7	7	6	7	**27**

Unlike the previous example, the CFCM Situational Screening yielded a clear top score, the dolorimeter. This device is used to gauge the amount of pressure needed to elicit pain in patients, helping to diagnose various ailments. The medical professionals felt that none of the current products on the market would work as well as the CFCM dolorimeter, and medical professionals are currently told to use the “white fingernail” test, pressing on a patient’s tender point until the doctor’s fingernail turns white. This allows for wide variability in the amount of force being applied to the patient’s tender points. As insurance companies rely on this kind of data to evaluate claims, a more standardized approach for diagnosing pain would be welcome. There were three runners up in the situational screening: Microchip Wafer Handling, Hard Disk Handling, and Vascular Surgical Tools. These three applications all rely on CFCMs’ ability to forgiving in unstable situations.

7.8 Strategic Evaluation

After the products have been screened on a functional and situational level, they are ready to be evaluated according to the strategy of the company performing the product development. The first step in this process is to retrieve the list of core competencies developed in Chapter 4. The products will be evaluated against these competencies. Once the potential products have been evaluated against the functional characteristics of the technology and the core competencies of the company, they may be placed in a decision matrix such as the one below:

Strategic Characterization:

Functional Characterization:	Poor fit with core competencies	Close fit with core competencies
Close fit with technology	<u>License:</u> This potential application can be made from the company's technology, yet does not fit with your company's strategy. If potential market is large enough, the company may consider a spin-off.	<u>Proceed with development:</u> In order to choose between different products that fit into this category, evaluate potential market size, and begin with product with largest potential market
Poor fit with technology	<u>Ignore:</u> The potential product has little to no value given the current circumstances.	<u>Shelf or continue search:</u> The potential product fits with the strategy, but not with the technological characteristics. Inventory the idea and search for a better technology fit before developing.

Figure 7.4 Strategic Characterization 2x2 Decision Matrix.

In order to illustrate the use of the matrix, I will refer back to Canon's core competencies of fine optics, precision mechanics and microelectronics. If Canon developed a technology that could electronically improve optical capabilities, and they decided this could be used in a new line of scanners to deliver higher resolution, this would fall within the "proceed with development" quadrant, as the product makes good use of the technology and builds upon existing core competencies. If the same technology were developed, yet it was decided that it would work well in a scopes for rifles, this may fall in the "license" category, since a rifle scope would not make use of Canon's competencies in microelectronics or precision mechanics. Moreover, the rifle scope would not fit in with Canon's marketing and distribution strategy, and would receive no synergies from existing products. If Canon wanted to embody the technology in eyeglasses, this would fit into the "ignore" category. The technology is a poor fit for this product, being somewhat overkill. It also creates no synergy with Canon's existing core competencies. Finally, if Canon wanted to use the optical development in a manner that would somehow increase the precision of their printers, it would most likely fall into the "shelf" quadrant. The idea works with Canon's competencies, but this technology is inappropriate for accomplishing the task.

This decision matrix, if properly followed, gives companies a guideline for which path to follow after identifying potential applications, and leads to a greater probability of success in TP product development.

7.8.1 Iteration Process

The strategic evaluation matrix should first be used on the product with the highest composite score from the situational and functional screening process. If this product fits in well with the company's core competencies, then this product should be developed. If the product fails to fit within the company's core competencies, then the second highest score from the functional and situational screening processes should be evaluated, and so on. If there is a tie score from the screening stages between two or more potential products, then those products should be evaluated on a relative scale as to which has the best fit with the company's core competencies.

7.9 Strategic Evaluation – Kevlar Example

The three products that were selected to advance to this stage were hiking poles, snowboards, and waterski lines. In order to evaluate the products on a strategic level the core competencies must first be reviewed. From Chapter 5, the competencies that were identified for the hypothetical company were: extrusion process expertise, knowledge of epoxies and adhesives, and sales and marketing relationships with large sports equipment dealers. Since all three of the products are in the sports industry, they would each benefit from the existing sales and marketing relationships. The snowboards and hiking poles would each profit more from the knowledge of epoxies and adhesives, as they would both be cured, while the water-skiing line would not gain from this knowledge. The hiking poles would be able to benefit the most from the company's extrusion process knowledge. They would be made with a pultrusion process, very similar to the extrusion process. On the other hand, snowboards would be made with a hand layup process that would not build on the existing competencies. Thus the product that best utilizes the existing core competencies would be the hiking poles concept. This idea would then be transferred to a market-pull process, as described in section 7.10.

7.10 Strategic Evaluation – CFCM Example

The four ideas to arrive at this stage were the dolorimeter, the microchip wafer and hard disk handlers, and the vascular surgical tools. The core competencies for the second hypothetical company were injection molding processes and designing for cost.

While all four of the products would benefit from the company's expertise in injection molding, the design for cost competency most favors the dolorimeter concept. The other three ideas would fit into the "License" quadrant of the decision matrix presented in 7.7. They would all be excellent uses for the new technology, but would be best suited being further developed by a company already ingrained with high-tech manufacturing, or a company that is familiar with the procedures necessary to have a new product approved for use in surgical situations.

7.11 Conclusion

The potential products from the application identification may be evaluated on three different levels. First, the products are examined to see how well they use the functional characteristics of the technology. This is determined by how close of a functional match there is between the technology's attributes and the functional needs of the product, and the level of value added by using the technology in place of an existing technology. Next the potential products are viewed on a situational level in order to see how many customers the product will be able to satisfy. This is measured through the market size of the product and the feasibility of development. The top products from these two screening processes are then evaluated on a company-wide level through a strategic evaluation. This compares the technology needed for each product to the existing core competencies in a company. The product that passes through the two screening processes and matches up with the company's core competencies should be pursued for further development.

Chapter 8 Experiments and Results

In order to gain a better sense of the viability of the process laid out in this thesis, the process was tested with three different groups. This chapter will examine the differences between the experiments in the groups, as well as the results of the different experiments. The method for TP product development was used with three different groups: a graduate level engineering class at Brigham Young University, a research group at Brigham Young University focusing on the TP product development of compliant mechanisms, and Advanced Composite Technologies, a small business that specializes in the manufacture of high end composites.

8.1 Experiments Process Evaluation Criteria

Each of the experiments gave the developers the opportunity to rate different facets of the product development process. Chapter Four laid out a set of criteria designed to evaluate the efficacy of the product development process in this thesis. These criteria are listed below:

1) Specific

2) Efficiently Comprehensive

3) Create successful products

4) Dynamic

The developers involved in the experiments described in this chapter were asked to fill out surveys in order to rate the effectiveness of the process' ability to produce potential products. The questions asked of the developers are seen in Figure 8.1:

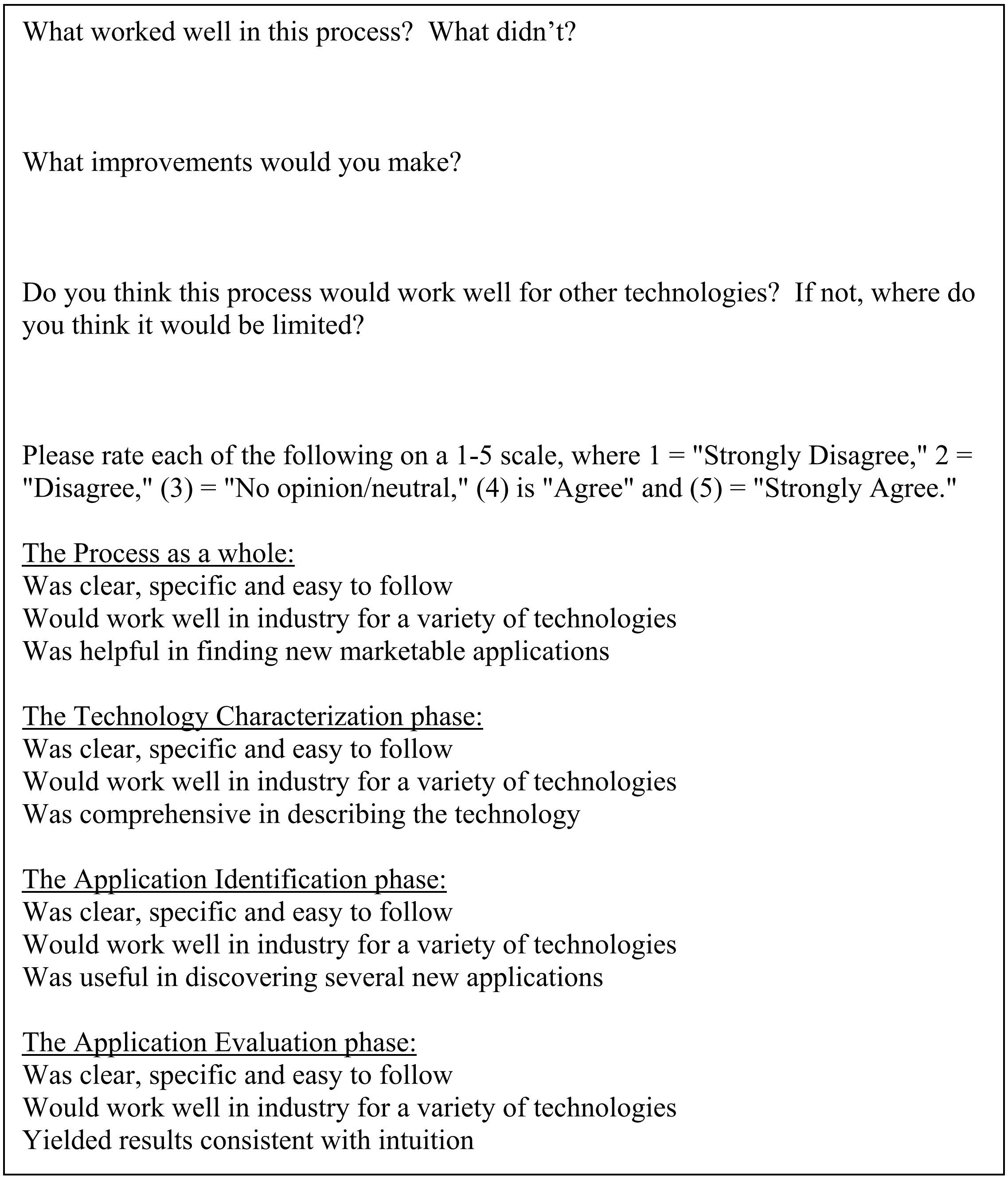

Figure 8.1 Post Product Development Survey

Each of the process criteria is addressed in this set of questions. The developer is asked to gauge the specificity of the process for each step in the process. The technology characterization section of the survey specifically addresses the issue of the process being comprehensive. The process as a whole is scored on how well it creates successful products, and each step contains a question asking if the the process is dynamic.
The feedback received through these surveys was used to tweak the process as well as to modify the manner in which the process was presented to the product developers participating in the experiments. The results of the surveys are included in the writeups for each experiment.

8.2 ME EN 538 Compliant Mechanisms Course

The process was first used in a ME EN 538, graduate level Mechanical Engineering Course devoted to the study of Compliant Mechanisms. Compliant Mechanisms are mechanisms that gain some or all of their motion from the deflection of flexible members rather than moveable joints only [8]. The study of compliant mechanisms is still relatively new, and has been primarily focused on understanding the functional characteristics of the technology. While some products have been created using compliant mechanisms technology the area as a whole is still relatively untapped. The TP product development process was explained to the 32 students in the graduate level class, along with a handout that showed the steps and the Kevlar example as shown in this work. As the process for TP CG&E was still being developed, this experiment served two purposes. First, it provided an opportunity to receive feedback on how to improve the CG&E process and the instructions given on how the process was to be carried out. Second, this experiment showed if the process in its current state could provide a sufficient amount of useful products from the compliant mechanism technology that could be further developed for commercial use.

8.2.1 Results of ME EN 538 Experiment

The results of the experiment in the ME EN 538 class were encouraging. The students were broken up into groups of 3-4 people. The groups were able to identify 14 different industries that the technology could be used in. As each group was asked to perform the product identification within two industries, the class as a whole identified 118 different products. After completing the application evaluation process, the groups selected 18 products to be investigated further. Only two of the 18 products were selected by more than one group. The applications selected by the students are seen in Table 8.1. For a more complete summary of the results of this experiment, please see Appendix B.

Table 8.1 Selected Applications From ME EN 538 Class Experiment

Ironing Board	Hair Clip	Meal Containers (2)	Switches
Folding Chairs	Buttons	Surgical Tools	Prosthetics
Windshield Wipers (2)	Constant Force Gripper	Metrology Equipment	Phone Keypad
Toys	Water Bottle Lid	Coke bottle cap	Hygiene Products

Overall, the feedback scores for the process were low for areas ranking the clarity of the process, and higher for raking the effectiveness of the process (See Table 8.2).

Table 8.2 Survey Results Of ME EN 538 Class Experiment

	Process as a whole			Technology Characterization Phase			Application Identification Phase			Application Evaluation Phase		
	team members	Work well in Industry	Helpful in finding applications	Clear	Work well in Industry	Comprehensive	Clear	Work well in Industry	Useful in Discovery	Clear	Work well in Industry	Consistent with intuition
Group 1	2	3	4	2	4	3	2	4	4	4	4	4
Group 2	2	3	2	1	2	2	3	2	2	1	3	2
Group 3	1	3	4	1	3	2	1	3	4	1	3	3
Group 4	4	4	4	3	3	3.5	4	3	3	4	4	4
Group 5	2	4	3	2	4	4	2	3	4	4	4	4
Group 6	2	4	3	2	4	2	2	4	3	4	5	3
Group 7	1	3	3	2	4	3	3	4	3	4	2	2
Group 8	3	4	4	2	3	3	2	3	4	5	5	4
Group 9	3	5	5	2.5	3	4	5	5	5	5	5	4
Average	2.22	3.67	3.56	1.94	3.33	2.94	2.67	3.44	3.56	3.56	3.89	3.33

This was to be expected, as this experiment was meant to fine-tune the process. The presentation used to explain the motivation behind the process, and the methods used to explain the different steps in the process were greatly improved by using the feedback provided from this iteration of the experiment. The changes made in these areas are reflected in higher feedback scores from the second two experiments seen in this chapter.

8.2.2 Conclusions From ME EN 538 Class

As can be seen from table 8.2, the lowest feedback scores were given for the explanation of the technology characterization process. This process was revamped after the first experiment, to eliminate some of the redundant questions in the technology characterization worksheet, causing higher survey scores in subsequent experiments. Another common theme in the feedback was that the scope was too broad. Compliant mechanisms is a large subject with several subtopics. Several of the students offered feedback stating that it would have been helpful to be assigned to a subtopic within compliant mechanisms. This would help the participants to fully characterize the technology and narrow their focus when identifying applications. This feedback was also taken into account, and led to a smaller scope for the other two experiments detailed in this chapter.

Of the 18 potential applications identified in this process, only two were repeated by different groups. This lack of standardization across different groups is due to several factors. First, as mentioned above, the technology being studied was very broad, and could be pursued in dozens of different directions. Second, the applications will always vary from group to group due to the different backgrounds and experiences of the participants involved. Finally, in this case, the final products may have varied due to the perceived lack of clarity in the instructions.

8.3 Compliant Mechanisms Research Group Experiment

The second experiment was performed with a research group, also at Brigham Young University. The Compliant Mechanisms Research (CMR) group also works with compliant mechanisms, seeking to create commercial applications that may then be licensed. In 2002 the group consisted of 13 students and 3 faculty members. Most members had been associated with the group for about a year, and have a deeper understanding of compliant mechanisms than the students in the ME EN 538 class. After receiving the feedback from the first experiment, the compliant mechanisms technology was broken up into three subtopics: compliant mechanisms using energy storage, compliant orthoplanar metamorphic mechanisms (COPMMs), and compliant mechanisms in compression. This experiment was held at a yearly retreat for the research group which limited the time available for the experiment to an hour. In order to complete the experiment in the allotted time, I met with a member of the research group that specialized in each of the three areas before the retreat to complete the technological characterization. The industry and application identifications, found in Appendix C, were then performed with the entire group at the retreat during the allotted hour. The final stage, application evaluation, was then completed after retreat with the same member of the research group that assisted with the technology characterization.

Each of the three groups successfully completed the industry identification and application identification segments of the process in 40 minutes. After a fifteen-minute explanation using the revised PowerPoint presentation used in the ME EN 538 experiment, each of the groups was asked to spend the first 20 minutes completing the industry identification matrix, and then 10 minutes each on the product identification matrix for two selected industries.

8.3.1 Results of Compliant Mechanisms in Compression

The benefits of compliant mechanisms have been well documented, and range from ease of manufacturing to long life cycles. One of the perceived weaknesses, however, is their inability to handle loads in compression. The CMR group developed configurations to allow compliant mechanisms to deal with compression loads, and was now looking for commercial applications for these configurations. Prior to this experiment, the only commercial application being considered was prosthetics. The team working on the group was able to determine nine different industries that could use the technology. From the nine industries identified, the team chose to perform the product identification matrix in the staging equipment and aerospace industries. From these two industries the team was able to identify 13 different products. The application evaluation matrix can be seen in Table 8.3.

Table 8.3: Application Evaluation Matrix For Compliant Mechanisms In Compression

Potential Application	#1 (Functional Match)	#2 (Market Size)	#3 (Feasibility of Development)	#4 (Value added to product)	Sum of Scores
Folding Tables	8	9	8	10	**35**
Projector Stands	8	9	7	5	29
Portable Stages	8	9	7	7	31
Camping Tables	8	9	8	8	**33**
4-bar rocking chairs	~~7~~	~~5~~			
Strollers	~~5~~	~~8~~			
Pop up trailers	~~6~~	~~9~~			
Deployment hinges	9	6	8	6	**32**
Landing Gear	~~5~~	~~7~~			
NASA rovers	~~5~~	~~3~~			

This group was the least successful of the CMR experiments in terms of generating a large quantity of potential products. As seen in Table 8.3, the products selected for further development were folding tables, camping tables, and deployment hinges in an aerospace application.

8.3.2 Results of COPMMs Experiment

Compliant Orthoplanar Metamorphic Mechanisms (COPPMs) are mechanisms that are able to be arranged in different configurations that allow the mechanism to vary its degrees of freedom. This allows a single mechanism, (created from a single manufacturing effort), to perform the functions of multiple mechanisms depending on how it is configured. As with the compliant mechanisms in compression, the technology characterization was completed outside of class. The technologies identified for the COPMMs were very similar to those identified for compliant mechanisms in compression. As with the other compliant mechanism subtopics, the groups performed the industry identification matrix, then selected two industries to investigate further. The two selected industries were the packaging and camping industries. The products found in this activity are shown in the application evaluation table below:

Table 8.4: Application Evaluation Matrix For COPMMS

Potential Application	#1 (Functional Match)	#2 (Market Size)	#3 (Feasibility of Development)	#4 (Value added to product)	Sum of Scores
Box Handles	8	8	8	10	34
Packing Materials	~~7~~	~~3~~			
Food Containers	7	5	5	6	23
Crates	4	4			
Food Lids	~~5~~	~~5~~			
Storage Bins	~~5~~	~~5~~			
Camping Chairs	8	9	9	9	**35**
Camping Tables	8	9	9	9	**35**
Stoves	~~5~~	4			
Grills	~~5~~	4			
Tents	6	6	6	5	23
Pots	4	4			
Toilet Seats for Camping	8	10	9	8	**35**
Shovels	~~5~~	4			
Backpack Frames	6	7	6	7	26
Cots	7	5	7	6	25
Fishing poles	4	~~3~~			

As can be seen from Table 8.4, the selected applications were camping tables, camping chairs, and camping toilet seats. This group was more successful in identifying both industries and products than the compression group, as they identified 18 industries, and 19 products in the two selected industries. Previous to this exercise the researchers on this product had ideas for three potential products.

8.3.3 Results of Energy Storage Mechanisms

The final experiment run with the CMR focused on identifying potential applications for the energy storage capacity of compliant mechanisms. The current research focused on developing the appropriate coefficients of restitution for golf club manufacturing. It has become clear that the ability of compliant mechanisms to store energy and release it at the appropriate time has a large commercial potential. After completing the same steps as the other two groups, the group decided to investigate the sports and construction equipment industries as seen in table 8.5.

Table 8.5: Application Evaluation Matrix For Energy Storage

Potential Application	#1 (Functional Match)	#2 (Market Size)	#3 (Feasibility of Development)	#4 (Value added to product)	Sum of Scores
Diving Board	9	5	7	6	27
Gymnastics Springboard	9	8	8	6	**31**
Golf Clubs	10	10	9	10	**39**
Shoes	~~5~~	~~8~~			
Pogo Sticks	8	7	8	8	**31**
Flooring	~~5~~	~~7~~			
Breakaway rims	~~6~~	~~6~~			
Puck - Ball	~~3~~	~~8~~			
Compactors	9	8	5	7	29
Forging/Stamping	9	7	5	7	28
Mechanical Jacks	~~5~~	~~5~~			
Demolition	~~9~~	4			
Nail Gun	~~8~~	~~5~~			
Pile Driver	8	7	6	7	28
Hammer	~~8~~	~~5~~			

Not surprisingly, the golf club application continued to score highly. Also scoring highly in the application evaluation were springboards and pogo sticks. The applications in the construction industry scored low due to a low feasibility of development.

8.3.4 CMR Survey Results

The survey results for all three groups at the CMR retreat are seen in Table 8.6. The average scores improved across the board, particularly for the questions regarding the clarity of the process.

Table 8.6: Survey Results for the CMR Retreat Experiment

	Process as a whole			Technology Characterization Phase			Application Identification Phase			Application Evaluation Phase		
	team members	Work well in Industry	Helpful in finding applications	Clear	Work well in Industry	Comprehensive	Clear	Work well in Industry	Useful in Discovery	Clear	Work well in Industry	Consistent with intuition
Compression	6	4	3	3	4	3	4	4	4	4	4	4
Energy Return	5	4	4	3	3	3	4	4	4	4	5	3
COPMMs	5	4	5	4	3	3	3	5	5	4	5	4
Average	5.33	4.00	4.00	3.33	3.33	3.00	3.67	4.33	4.33	4.00	4.67	3.67

This improvement in scores is most likely due to the changes in the way the TP CG&E process was presented. Also, because of the limited time at the retreat, the application identification was completed beforehand on a one-on-one basis with the research lead for each area. This may have allowed the research lead to feel more comfortable asking questions, which would lead to a higher score for the clarity portion of the technology characterization phase. The higher application identification scores may also be partially explained by the fact that the scope was narrowed from the first experiment to allow the developer to use a more focused set of characteristics when identifying industries and products to be developed.

8.4 Advanced Composite Technology (ACT) Experiment

The final experiment was held at ACT, a company headquartered in Fayette, Utah. ACT specializes in manufacturing prosthetics and custom-made projects that use carbon fiber technology, and currently has 8 different products on the market. The goal of the experiment at ACT was to see if other commercially viable products could be developed from their extensive knowledge of carbon fiber's characteristics. The participants in the experiment included the founder of the company, the VP of product development, and two manufacturing shift supervisors. Each step of the TP product development process was performed sequentially in a 90 minute time period.

8.4.1 Results of the ACT Experiment

The group at the ACT had a very in-depth knowledge of their technology, and was able to quickly and comprehensively pass through the technology characterization stage. This allowed for more time to be spent on the Industry Identification stage. The group was able to identify 23 different industries where carbon fiber could be used. The two industries selected for further exploration were the automotive and medical industries. Table 8.7 shows the application evaluation matrix for the products discovered in these two industries. The full results of the ACT experiment are found in Appendix D.

Table 8.7: Application Evaluation Matrix For ACT

Potential Application	#1 (Functional Match)	#2 (Market Size)	#3 (Feasibility of Development)	#4 (Value added to product)	Sum of Scores
Jaws of Life	8	10	9	5	32
Portable X-Ray	8	10	6	7	32
Cutting Devices	~~7~~	~~6~~			
MRI Tables	~~7~~	~~5~~			
Operating Tables	10	9	6	8	33
Knee Braces	10	9	6	8	33
X-Ray Tables	10	10	7	8	35
Splints	~~7~~	~~6~~			
Fixation Devices	8	9	9	5	31
Orthotics	~~8~~	~~7~~			
Bone Replacement	~~7~~	~~7~~			
Stretcher/Gurney	8	9	8	9	34
Wheel chair	8	10	8	9	35
Tooth replacement	4	~~6~~			

Table 8.7 Continued Application Evaluation Matrix For ACT

Potential Application	#1 (Functional Match)	#2 (Market Size)	#3 (Feasibility of Development)	#4 (Value added to product)	Sum of Scores
Back braces	~~8~~	~~6~~			
EMS Cases	~~7~~	~~6~~			
Stethoscopes	8	10	10	9	**37**
Driveshaft	~~8~~	~~7~~			
Brake pads	~~5~~	~~6~~			
Push Rods	~~5~~	~~6~~			
Undercarriage	~~5~~	~~7~~			
Bumpers	~~6~~	~~8~~			
Skid plates	~~9~~	~~6~~			
Radiator	~~2~~	~~6~~			
Dash components	~~5~~	~~5~~			
Rims	8	8	9	10	35
Fuel tanks	~~8~~	~~6~~			
Accumulator	10	10	10	9	**39**
Light housing	~~6~~	~~6~~			
Seat springs	4	~~5~~			

The two best applications, as determined by this matrix, are the accumulator tanks and stethoscopes. These applications would take advantage of the strengths of the technology as well as the company's competencies. This experiment showed that the process can be successfully applied with an existing company, and may prove especially useful in smaller companies, where there is no dedicated full-time product development staff. An interesting result from the application identification portion of this experiment was that the majority of the new ideas came from the manufacturing shift supervisors. This may be due to the fact that the owner and the VP of product development had fallen into a pattern of thinking how the technology should be used, while the manufacturing employees, also familiar with the technology, had not previously been asked for suggestions on how it could be used in different products. This was consistent with the findings in Chapter 6, where the medical professionals, although unfamiliar with the technology being developed, discovered the greatest number of potential products.

8.4.2 Survey Results of the ACT Experiment

The same survey was again administered to the experiment participants at ACT, and the results are seen in Table 8.8.

Table 8.8: Survey Results Of ACT Experiment

	team members	Work well in Industry	Helpful in finding applications	Clear	Work well in Industry	Comprehensive	Clear	Work well in Industry	Useful in Discovery	Clear	Work well in Industry	Consistent with intuition
Developer #1	1	4	4	3	4	3	4	4	4	4	4	4
Developer #2	1	4	4	3	3	3.5	4	4	4	4	5	3
Developer #3	1	3	3	4	4	4	4	4	5	5	5	4
Developer #4	1	4	5	4	3	3	3	5	5	4	5	4
Average	1.00	3.75	4.00	3.50	3.50	3.38	3.75	4.25	4.50	4.25	4.75	3.75

Most of the measures of the CG&E process in the ACT experiment saw a slight improvement over the CMR Experiment scores. The small size of the group (4) may have again played a part in the higher scores, as the participants were able to receive more individualized attention when questions arose. The participants' pre-existing familiarity with carbon fiber may have also played a part in the higher scores, as they did not have to worry about truly understanding the technology at hand, and were able to focus their efforts on understanding the CG&E process.

8.5 Experiments Conclusion

The process proved successful in the three experiments described in this chapter. In each case, the steps taken opened up new possibilities to the developers, and provided a structured method for evaluating where future development energies could best be used. In the case of the ME EN 538 class, the large amount of students involved in the experiment translated into a wide variety of selected concepts. This showed how the backgrounds and experiences of the product developers influences the type of ideas generated in the application identification. The Compliant Mechanisms Research experiments opened up a wide variety of potential applications for technologies that had been previously focused on developing a single product. In the ACT example, the steps taken opened up new potential products. It is interesting to note that the application evaluation also provided ACT with a product that was later further investigated and put into production. Each experiment also proved useful in refining the CG&E process and the method by which the process was explained, as shown by the consistent improvement in the survey scores.

Chapter 9 Conclusions and Recommendations

The concept of technology push product development is a concept has long been seen as a potentially valuable tool, yet has always lacked a step-by step process necessary for it to be adopted on a large scale. Research has shown [15] that even in companies known for being technologically innovative, there is no established step by step process for technology push product development.

9.1 Research Review

This thesis provides a process to direct design engineers through the technology characterization, application identification and application evaluation stages of technology push product development. Specific guidelines are offered so that the designers can effectively accomplish these three stages. The flowchart provided throughout the thesis also identifies the inputs and outputs of the three steps in the process, allowing designers to overcome the obstacles to effective product development. In order to illustrate how these three phases may be executed, two examples were provided throughout the thesis, one of a well-known technology, and another of a lesser-known technology. Three sets of experiments are also provided at the end of the thesis to show how well the process worked in a live environment. Finally, user surveys were reviewed to show how well the process met its original objectives.

9.2 Areas for Further Research

This thesis concludes leaving several areas open for further research. The most obvious is the need for further case studies by product developers in order to find other changes and improvements to the process. Case studies also need to be performed using the CG&E process as part of Bishop's comprehensive TP model. Further research could also be dedicated to a computational matching program that would allow attributes of new technologies to be plugged into an existing database of products and attributes, allowing developers to instantaneously see products that match the characteristics of the new technology. The transition between the application evaluation stage and the standard market pull process is an area that can be more fully developed. Each quadrant of the 2x2 strategic matrix explained as part of the strategic evaluation in section 7.7 could also be developed further. More research should also be devoted to finding the optimal number of developers involved in product development sessions, as well as what mix of backgrounds should be involved. As was discussed earlier in the thesis, the process was generally more productive when completed by those not normally involved in product development. Finding an optimal level of involvement for these non-product developers could greatly enhance the results of the process. Finally, an effort focused on modifying and applying the process to develop disruptive technologies could potentially reap rewards, as this area remains largely unexplored.

9.3 Conclusion

This research has resulted in a defined, step-by-step process for completing the technology characterization, application identification and application evaluation stages of technology push product development. It has also taken into account the core competencies and strategies of the company performing the development. These steps will enhance the abilities of product developers, allowing them to use available and newly discovered technologies to create marketable products that fit within the existing strategies of their organizations.

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Appendix

Appendix A: Results of Class Survey on Desirable Product Development Process Characteristics

Each response is listed along with the grouping it was placed into.

Clear (Specific)
Not redundant in questioning (Specific)
Detailed (Specific)
Practicable (Specific)
Clear gates before moving on to the next step (Specific)
Clear Metrics (Specific)

Provide wide variety of ideas (Comprehensive)
Iterative (Comprehensive)
Comprehensive (Comprehensive)
Quantity and quality (Comprehensive)

Provide ideas with greater probability of being marketed (Successful Solutions)
Yield results with highest potential market (Successful Solutions)
Yield products where technology would supply a competitive advantage (Successful Solutions)
Customer centric (Successful Solutions)
Come up with optimal concept (Successful Solutions)
Yield results consistent with intuition (Successful Solutions)

Multidisciplinary (Dynamic)
Facilitate creativity; rein in best ideas (Dynamic)
Works with knowledge of designers (Dynamic)
Easily adaptable to individual situations (Dynamic)
Non-static (Dynamic)
Accommodating (Dynamic)

Not placed into a category:
Moves the team towards their objectives
Fast
Clear Metrics
Set Process
Eliminate objective reasoning as far as possible
Repeatable
Achieve uniform results

Appendix B: Summary of Process Results from ME EN 538 Experiment

The table below shows the situational characteristics identified by the 9 student groups performing the CG&E experiment on Compliant Mechanisms.

Situational Characteristic	Times selected by a group
Corrosion Resistant	4
Disposable	5
Ease of Assembly	2
Ease of Mfg	2
Ease of Use	1
Energy Storage	3
Harsh Environment	1
Heat Resistant	1
Inexpensive	1
Lightweight	1
Looks Good	1
Low Friction	1
Low Maintenance	8
Low Part Count	7
Low Wear	1
Low Weight	1
Miniturization	1
Planar Design	1
Precision	4
Reliable	1
Simplicity	1
Sterile	4
Variable Material	1

The concepts generated by each of the groups are summarized below. The concepts that scored the highest in each group are bolded:

Group 1	**Group 2**	**Group 3**
Assembly Line Equipment	Bistable Forceps	Compliant End Defector
High Speed Operations	Needle Recepticle Cap	Microsurgery
Tight Tolerance Operations	**Coke Bottle Cap**	**Meal Containers**
Measurement	Radiator Cap	Camping Gear Boxes

Operations		
Surgical Equipment	Climbing Clip	Food Dispensers
Heart Valves	**Water Bottle Lid**	Board Games
Prosthetics	Backpack Clip	Positioners
	Army Knife	**Constant Force Gripper**

<u>Group 4</u>	**<u>Group 5</u>**	**<u>Group 6</u>**
Clothes Pin	**Toys**	**Metrology Equipment**
		Disposable meal containers
Compliant Knee	Automotive	
Pantograph	Camping Equipment	Robot Joints
Ski Boot Adjustment	Medical Equipment	Heart Valves
Ratcheting Mechanism	**Hygiene**	Artificial Joints
Pliers	Kites	Diagnostic Instruments
Oil Filter Wrench	Spark Plugs	
Windshield Wipers	Oil Filters	
Fuse Puller	Cup Holder	
Toothpaste Lid	Gas Tank Lid	
Blinker Mechanism	Jack Stand	
Gas Tank Parts	Wagons	
Phone Keypad	Gliders	
Hair Clip		
Clock Parts		
Window Mechanism		
Heart Valve		
Replacement Ankle.		

<u>Group 7</u>	**<u>Group 8</u>**	**<u>Group 9</u>**
Folding Doors	**Switches**	Transmission
Car Hood	**Buttons**	**Windshield Wipers**
Ironing Board	Glasses Hinge	Door Hinges
Folding Chairs	Garlic Crusher	Suspension
Windshield Wipers	Workbox Clasp	Bumpers
	Clipboard Clasp	Side Panels
	1 Degree of Freedom Actuator	Battery Terminals
	Micro Switches	Connectors
	Tools	Medical Furniture
		Implants
		Artificial Joints
		Medical Instruments
		Surgical Tools

Appendix C: Application Identification Matrices from Compliant Mechanisms Research Group Experiment

Industry Application Identification - Energy Storage

Basic Functional characteristics: High fatigue life, large deflections, energy storage potential, tensile strength, creep, force deflection relationships							
Situational Characteristics:	Low Friction	High Precision- easily controllable	Wide range of stiffness available	Tight tolerances under impact loading	Gee whiz factor	Low maintenance	Harsh environment resistant
Low Friction			Medical				
High Precision- easily controllable				Robotics, Automated Handling			
Wide range of stiffness available				Manufacturing			
Tight tolerances under impact loading							Construction
Gee whiz factor						Sports	Toys
Low maintenance							
Harsh environment resistant							

Product Application Identification - Energy Storage

Industry: Sports

Basic Functional characteristics: Constant output force regardless of input displacement. Mechanical advantage and stored strain energy of flexible members.

Situational Characteristics:	Low Friction	High Precision- easily controllable	Wide range of stiffness available	Tight tolerances under impact loading	Gee whiz factor	Low maintenance	Harsh environment resistant
Low Friction							
High Precision- easily controllable			Pogo Sticks, golf clubs			Springboard, breakaway rims,	Diving board
Wide range of stiffness available					Shoes, puck, balll,		
Tight tolerances under impact loading				Flooring			
Gee whiz factor							
Low maintenance							
Harsh environment resistant							

Product Application Identification - Energy Storage

Industry: Fragile/Robotic Grasping

Basic Functional characteristics: Constant output force regardless of input displacement. Mechanical advantage and stored strain energy of flexible members.

Situational Characteristics:	Low Friction	High Precision- easily controllable	Wide range of stiffness available	Tight tolerances under impact loading	Gee whiz factor	Low maintenance	Harsh environment resistant
Low Friction							
High Precision- easily controllable				Mechanical Jacks			
Wide range of stiffness available				Nail gun, pile driver, hammer			
Tight tolerances under impact loading				Flooring, forging, stamping			compactors
Gee whiz factor							
Low maintenance							
Harsh environment resistant							Demolition

Industry Application Identification - COPMMs

Basic Functional characteristics: High fatigue life, large deflections, energy storage potential, tensile strength, creep, force deflection relationships							
Situational Characteristics:	**Planar MFG**	**Reduced Part Count**	**Scalable**	**Low maintenance**	**Harsh environment resistant**	**Sterile**	**Reduced Wear**
Planar MFG		Container		Camping	Miltary		NASA
Reduced Part Count					Chemical Etch		
Scalable				MEMS			
Low maintenance					Prosthetics	Medical	
Harsh environment resistant						Food Industry	
Sterile							
Reduced Wear							

Product Application Identification - COPMMs

Industry: Transportation and Packaging

Basic Functional characteristics: Constant output force regardless of input displacement. Mechanical advantage and stored strain energy of flexible members.							
Situational Characteristics:	**Planar MFG**	**Reduced Part Count**	**Scalable**	**Low maintenance**	**Harsh environment resistant**	**Sterile**	**Reduced Wear**
Planar MFG		Box handles			Storage bins,	Packaging Materials, food lids,	NASA
Reduced Part Count							
Scalable							
Low maintenance						Ambulance stretchers	
Harsh environment resistant						Food Container	
Sterile							
Reduced Wear							

Product Application Identification - COPMMs

Industry: Outdoor Activities

Basic Functional characteristics: Constant output force regardless of input displacement. Mechanical advantage and stored strain energy of flexible members.

Situational Characteristics:	Planar MFG	Reduced Part Count	Scalable	Low maintenance	Harsh environment resistant	Sterile	Reduced Wear
Planar MFG		Foldable bike, cots	Backpack frames	RV Tables, popup cameras,	Acquatic transportation,		Chairs from floor
Reduced Part Count				Camping chairs, tables, stoves, grills, pots			Fishing pole & gear
Scalable							
Low maintenance					Tents, portable toilet seat		Shoe wheels
Harsh environment resistant							
Sterile							
Reduced Wear							

Industry Application Identification - CMs in Compression

Basic Functional characteristics: High fatigue life, large deflections, energy storage potential, tensile strength, creep, force deflection relationships

Situational Characteristics:	Low maintenance	Low Cost MFG	Low Friction	Harsh environment resistant	Reduced Part Count	Sterile	Scalable
Low maintenance		Container		Camping	Miltary		NASA
Low Cost MFG					Chemical Etch		
Low Friction				MEMS			
Harsh environment resistant					Prosthetics	Medical	
Reduced Part Count						Food Industry	
Sterile							
Scalable							

Product Application Identification - CMs in Compression

Industry: Baby products

Basic Functional characteristics: Constant output force regardless of input displacement. Mechanical advantage and stored strain energy of flexible members.

Situational Characteristics:	Low maintenance	Low Cost MFG	Low Friction	Harsh environment resistant	Reduced Part Count	Sterile	Scalable
Low maintenance		Strollers					
Low Cost MFG							
Low Friction					4-bar rocking chair		
Harsh environment resistant							
Reduced Part Count							
Sterile							
Scalable							

Product Application Identification - CMs in Compression

Industry: Presentation

Basic Functional characteristics: Constant output force regardless of input displacement. Mechanical advantage and stored strain energy of flexible members.

Situational Characteristics:	Low maintenance	Low Cost MFG	Low Friction	Harsh environment resistant	Reduced Part Count	Sterile	Scalable
Low maintenance			Pop-up trailers		Folding Tables,		
Low Cost MFG					Projector Stands		
Low Friction							
Harsh environment resistant				Etcing process equipment	Camping Tables		
Reduced Part Count							Deployment hinges
Sterile							
Scalable							

Appendix D: Technology Characterization and Application Identification Matrices from ACT Experiment

ACT Technology functional characterization questions (carbon fiber)

<u>What are the technology's attributes?</u>
High strength to weight, high stiffness to weight, net shape, energy storage, negative coefficient of thermal expansion (CTE), material needs to be oriented in certain directions, can be inconsistent, conducts heat

<u>What laws govern its performance?</u>
Manufacturing based, needs curing, follows general engineering laws, layup dependent, translucent

<u>How would you describe the function of the technology?</u>

<u>What potential needs could this technology fill? Why?</u>
Sporting Goods – Strength to weight ratio
Medical – Translucent
Optics –
Aerspace – lightweight, absorbs radar

As you have studied the technology, you have probably thought of some possible applications, or seen the technology in use. List four or five that you think would work (or would work) the best. What is it about this technology that makes it work in these situations?

Prosthetics – Corrosion resistant, lightweight, sterile, energy storage, strong
Halos - lightweight, sterile, translucent
Gun Barrels – Control whip, low cte, strong, dampening
Aircraft apps – lightweight, low maintenance
Rigs – No feedback, moldable

Now group the characteristics into the following areas:

<u>Basic Functional – Inherent to the technology (ex: force-deflection)</u>
Strength to weight, translucent, absorbs radar, conducts heat, negative CTE

Situational – Dependent on how the technology is embodied (ex: disposable, low maintenance)

Dampening, energy storage, net shape, corrosion resistant, low maintenance, lightweight

Industry Application Identification - ACT

Basic Functional characteristics: Constant output force regardless of input displacement. Mechanical advantage and stored strain energy of flexible members.

Situational Characteristics:	Dampening	Energy Storage	Net Shape MFG	Corrosion Resistant	Low Maintenance	Lightweight	
Dampening	high precision mfg						
Energy Storage							
Net Shape MFG			machine tools, fasteners,	street signals, boating,			
Corrosion Resistant				storage tanks, chemical etching,	surveillance	Medical, military, automotive	
Low Maintenance					optics	sporting goods	
Lightweight						structural, aerospace, entertainment	

Product Application Identification - ACT

Industry: Medical

Functional characteristics: Strength to weight, translucent, absorbs radar, conducts heat, negative CTE

Situational Characteristics:	Dampening	Energy Storage	Net Shape MFG	Corrosion Resistant	Low Maintenance	Lightweight	
Dampening		Jaws of life			stethescope	back braces	
Energy Storage				halo rods, bone replacement, tooth replacement, prosthetics,		knee braces, splints,	
Net Shape MFG			fixation devices,			orthotics,	
Corrosion Resistant				oxygen tanks,		cutting devices	
Low Maintenance						portable x-ray, headrests, wheelchair,	
Lightweight						MRI tables, operating tables, stretcher, EMT cases,	

Product Application Identification - ACT

Industry: Automotive

Functional characteristics: Strength to weight, translucent, absorbs radar, conducts heat, negative CTE

Situational Characteristics:	Dampening	Energy Storage	Net Shape MFG	Corrosion Resistant	Low Maintenance	Lightweight	
Dampening		Seat Springs		chassis, rims,			
Energy Storage							
Net Shape MFG			dash components, consoles, undercarriage,	torsion bars, brake pads, drums, roters, discs	bumpers,	Steering linkage, driveshaft, valve covers,	
Corrosion Resistant				fuel tanks, accumulator tanks, radiators,	oil pans, wheel wells, skid plates,	hoods, fenders, light housings, grilles,	
Low Maintenance							
Lightweight						Steering Column	