ROADMAP TO A SUCCESSFUL PRODUCT DEVELOPMENT: FROM CONCEPT TO LAUNCH

James A. Marquis

Under the Supervision of: Dr. Ruba Deeb & Dr. Gad J. Selig

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Approvals

Committee Members

Name	Signature	Date
Supervising Professor Dr. Ruba Deeb	[signature]	4/25/2019
Supervising Professor Dr. Gad J. Selig	[signature]	4/25/2019
Member 1: Dr. Christian Bach	[signature]	4/25/2019
Member 2: Dr. Elif Kongar	[signature]	4/25/2019
External Examiner: Dr. Charles Reinholtz	[signature]	5/2/2019

Ph.D. in Technology Management Program Director

Dr. Elif Kongar [signature] 5/9/19

Dean, School of Engineering

Dr. Tarek Sobh T. Sobh 5/9/19

ROADMAP TO A SUCCESSFUL PRODUCT DEVELOPMENT: FROM CONCEPT TO LAUNCH

Dedicated to my deceased wife Linda Ann Marquis

ABSTRACT

Technological companies are frequently developing new products. The marketing success rate is very often very poor for these new products. Many of the product failures can be traced to the lack of a disciplined process to follow from the concept of the product to the market research required to determine the attributes and price points that the market desires. The purpose of this research is to develop and test a disciplined step by step process with feedback paths to accomplish a successful product launch.

A New Product Development (NPD) process typically involves a number of stages required to design a product and bring it to market. These stages start at the planning or scoping stage, followed by the market planning stage, the *product concept stage,* the *product design stage*, and finally the testing and the launch stages. This manuscript describes and evaluates three of the six stages from the NPD process that include, *product concept* (Stage 3), *product design* (Stage 4) and *testing* (Stage 5). The *product concept stage* generates the bulk of the ground work in preparation for the design of the near final product which takes place during the *product design stage*. While all NPD process stages are necessary, the *product concept stage* involves numerous complex and intricate steps that are critical to the design of a successful product. The primary purpose of the research described herein is to design two adjoining methods that consist of systematic and rational multi-phase platforms with feedback mechanisms that allow for adjustments. The first method is termed the *product concept process* (Stage 3) which informs on project viability during the early steps of the *product development process and* before the initiation of the final product design. The second method is termed the *product design process* (Stage 4)

with logical steps that ensure a balance between market needs and product performance and reliability.

The *product concept process* (Stage 3) consists of different phases with detailed interconnected steps that carry a product concept through a conceptual stage (Phase I), into the generation of a "proof-of-concept" or an alpha prototype that allows for the initiation of Phase II steps. Steps within each phase describe estimates for development cost, market risk analysis, performance evaluation, and product manufacturing cost estimation. The final steps of the *product concept process* describe the pre-product design stage (Phase III), which is an expansion of the broader development cost estimates generated in Phase II and thus provides additional rigorous estimates for product development costs. Notably, modification or re-design of the product concept at any step within the three Phases resulting in their conversion into successful prospects that garner market acceptance and potential profitability is another tangible objective of this *product development process.*

The second method described in this research is the *product design process* (Stage 4). This process starts after the successful evaluation of all steps from the previous *product concept process*. The *product design process* includes the Initial Design: Path 1. This Phase involves the execution of product industrial design, market evaluation, mechanical and customer interface design, electronic and software design as well as cost analysis. Upon successful completion of the Initial Design Path, the Final Design (Path 2) is initiated. Path 2 serves to integrate various components interconnections. Path 2 also accommodates customer options which is capstoned by a thorough manufacturing cost analysis. Path 1 and Path 2 of the *product design process* employ feedback loops so that the process retains a balance between market needs, costs and eventually product performance and reliability.

These two methods terminate in Stage 5, the fabrication and testing stage. This is the Stage that demonstrates the effectiveness or lack thereof of the two methods. It is intended that these methods be followed in sequence but as will be described in some of the cases, if the essence of each step of each Phase or Path is accomplished, even if out of sequence, the NPD can be successful.

The two processes described in this study are used to evaluate a number of small/medium electronic products. Currently, For the purpose of this study, "small" implies a development project that would cost less than $250,000 to complete. A "medium" project development is that which can cost between $250,000 and $750,000 to complete. With respect to product design, it is also noteworthy that there are no current formal size-rating systems for defining small versus medium product designs. For the purpose of this study, a small electronic product is one that sells to the end user for $5,000 or less. A medium electronic product is one that sells to the end user for $25,000 or less. Electronic products that sell for more than $25,000 will require additional examination steps that are not described in the *product development process*. This study examines the successes and failures of several small/medium *product development processes* with respect to their submission and compliance to the disciplines of the *product development process* tool and the *product design process* tool.

1.1 INDEX TERMS—Alpha/beta prototype, continuous development, market risk analysis, market evaluation, market profitability, performance expectation, product concept, product development cost, product production cost, product development process, research and development, return-on-investment (ROI), ROI analysis.

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"We accept mistakes, but they must be original. We need well-intentioned failure"

Lewis Lehr, 3M President and CEO

CHAPTER 1: INTRODUCTION

Product development has occurred for centuries by various individuals and enterprises with varying degrees of success. Continuous development that includes new product development or significant improvements to existing products is necessary for organizational existence. New products can result from new inventions, improvements, or an innovative replacement technology. While successful new products achieve a good market-fit and become a leading sales brand, others fail for a variety of reasons that can range from poor performance to a low profit margin. Successful products are accepted, purchased and used by the general market and in many cases imitated and/or improved in performance or reduced in cost. Failed products are not widely accepted by the market, and in some cases, rejected entirely. The inability of a product to meet market profitability can have a negative impact on an enterprise's success as a whole. On the other hand, understanding and averting product failure expands the prospects for success.

To aid in the New Product Development (NPD) process a number of serial processes have been proffered by a number of authors. A well accepted process is the Stage-Gate system developed by Robert G. Cooper [1] which consists of a number of stages with gates between each stage at which the development team evaluates the value and effectiveness of each stage before proceeding to the next. A schematic of a typical stage-gate system is shown in Figure 1. This Stage-gate system has been modified to emphasize Gate 3 through Gate 6 of the NPD process that are the focal point of the work described in this dissertation. Stage 3, the product concept stage, is a critical stage in the NPD process. It is the foundation upon which the subsequent stages are based. If Stage 3 is not properly executed, the following Stages will require feedback to Stage 3 or Stage 2 to correct errors or omissions. Stage 3 is prefaced by Gate 3 which is where the business case (the proposed product) is evaluated based on specific criteria. Evaluation criteria address whether the product idea is viable and well received in the marketplace. Evaluation criteria also questions product purpose, functionality, size, style, cost, options, user interface or life cycle. They also assess input from a diverse group of users, potential users, trades people, trade associations, safety organizations, or government agencies. Therefore, this review gate is important because it places the foundation for Stage 3, the *product concept process*, which is detailed in Chapter 3.2. Stage 3 stops short of the actual product design which is initiated only after a rigorous evaluation of all steps taken during the *product concept process* at Gate 4. But a significant amount of testing will be performed on the "proof of concept" unit or the Alpha unit whichever unit was developed in Stage 3, Phase II. Stage 4 consists of the actual engineering and software design of the product. This Stage is very important and should be executed by experienced individuals while constantly conforming to the marketing, engineering and costs considerations detailed in Stage 3. Stage 5 is the important "proof of the pudding" stage-where the product demonstrates its attributes. Many of these tests will be a repeat of the tests performed in Stage 3, Phase II. It is important that the product be tested in as many scenarios and environmental conditions and by a variety of users. The smallest deviation from perfection in performance or appearance must be evaluated and corrected. Once an imperfection is corrected, all the testing should be repeated to confirm the correction was successful and did not cause other problems.

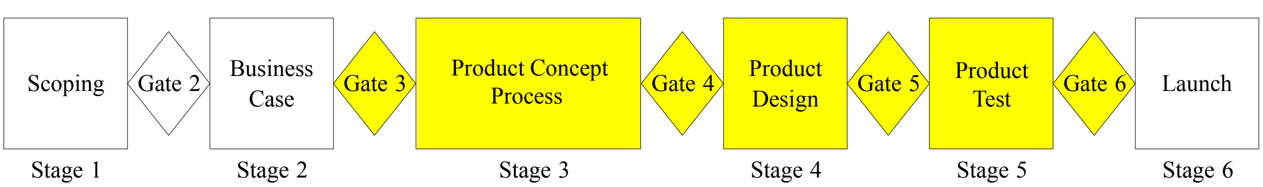

Figure 1: Modified Cooper's Stage-Gate System

1.1 RESEARCH PROBLEM AND SCOPE

This study proposes the development of a systematic and incremental method for defining and predicting which product concepts can develop into successful products and those that should not move forward in order to prevent the creation of an ill-fated product and marketing launch that can result in substantial financial loss. The design and development of a new product or the improvement of an existing product is complex and involves numerous features that require compliance with defined procedures. In earlier times, companies developed their ideas mostly based on internal employees and sales input. Formalized market research was the exception. One of the primary reasons for low market success for new products was the lack of a formalized process on which to base the NPD [2]. When it comes to new product development, many organizations bypass the use of a formalized or disciplined procedure [2] that help determine what the market desires or what the market perceives as a good value, and what performance attributes are necessary or desired. In fact, many products are developed based on opinions of design teams or sales personnel. Albeit experts in their own fields, they do not often seek the formalized input of the market that a product is intended to serve. Without good market analysis, design teams risk working without a well-defined and researched goal. This is the reason for such a low percentage of successful product developments. It is the purpose of this research to enumerate and formalize the steps necessary to ascertain market input which will direct a development team through a path which results in a product that meets the wants and desires of the market and not just the vision of a design team. Along with the other important steps in the NPD such as the design and testing steps, the use of a defined and disciplined procedure will result in a significantly higher market success rate.

1.2 MOTIVATION BEHIND THE RESEARCH

A defined *product development process* serves as a guide tool to the complex task of developing a product that has never been produced before or as a guide to a product redesign or upgrade. It provides a checklist of steps necessary for the development of a successful product [3, 4]. Following a disciplined process reduces the risks of a failed project [2, 5] or a product that is almost successful. With the availability of social media and the internet, market research has become significantly easier and more encompassing. The proper use of this modern tool should make researching market needs much easier and accurate, thus it has the potential of more clearly defining desirable product features and price points. However, this media can also serve as the death sentence of a product that does not fulfill its stated or assumed benefits and performance. Once negative reviews are published, it is very difficult refute or correct them. Thorough market research is an essential foundation for any product development and it is critical that the product performance meets the product claims.

1.3 POTENTIAL CONTRIBUTIONS OF THE PROPOSED RESEARCH

The proposed research will result in a formal framework for the design of all new small/medium product development projects. The *product development process* tool will serve as a roadmap throughout the *product development process* by providing a disciplined reiterative program of development resulting in a significant reduction in the risk of failure and a large increase in the probability of market success. The completed process results in a documented record of the various paths that lead to the final product design. It also documents considerations that were not employed and the reasons for their elimination.

CHAPTER 2: LITERATURE SURVEY

New products fail at an alarming rate. Approximately one in ten product concepts succeeds commercially and one in four development projects achieves commercial success [2]. Failure rates for new product introductions vary by industry but range from 30 percent to 90 percent [6].

To understand the reasons for the high rate of product failure, it is important to consider all the factors that impact New Product Development (NPD) success. Among managers and academics alike it is widely accepted that three main factors impact NPD success: time, quality, and expense [7-10]. Speed to market, also referred to as development cycle time, is the time span between idea generation and new product launch [11]. Product quality refers to customer perceptions of product superiority relative to competing alternatives [12]. Development expense is the extent of resources required for a project to advance from concept creation to commercial product [8].

In 2009, Robert G. Cooper, a pioneer in New Product Development research in the consumer goods sector, developed the Stage-Gate [1] model as a tool for managing new products development. Shortly after, the 2010 American Productivity & Quality Center (APQC) benchmarking study reported that 88% of U.S. businesses employ a Stage-Gate system to manage the flow of new product development of new products from idea to launch. Furthermore, companies that adopted this Stage-Gate system are reported to gain benefits that include improved teamwork, improved success rates, earlier detection of failure, a successful launch and shorter cycle times – reduced by about 30% [13].

Innovative organizations are not just those with new products but also those that can modify their formal development process to accelerate change. Apparently, companies use the

Stage-Gate processes to optimize their development process of product improvements in addition to the introduction of radical new technology products per se. Companies that employ the Stage-Gate system for new product development no longer have to argue that a trade-off between quality, cost, and delivery is the norm. In fact, for the first time, the vaunted and venerable 50% reduction in development time with no sacrifice in quality is now achievable and is not just words in presentations or a dream that general managers thought would never actually be obtained. The 50% barrier has finally been broken—not just by a few firms but by many [14]. During a *product development process*, it is essential to consider every feature of a proposed product throughout its design and development. The procedure described in this study starts at the conceptual stage where market acceptance, market risk and technological risk are evaluated jointly and ends with product testing following actual product design. It is significantly more cost-effective to introduce modifications at an early stage rather than later in the development process.

The most pivotal activities, those that significantly differentiate between successes and failures, are the early activities in a new product process [20]. The relationships between a firm's financial capabilities, managerial capabilities, and strategic focus on R&D, respectively have a more adverse effect on products that fail in late development stages than for products that fail in early development stages [21]. The ability to exploit information technology for inexpensive and rapid assessment of product feasibility at early development stages, appears to be an important feature to reduce uncertainties and costly iterations during advanced stages of product development [22].

The focus of the *product design process* is to take into consideration the interdependence of all of the steps in the process. Related literature addresses singular steps of the design process without much consideration to their interdependence. With respect to studies dealing with product development cost, the literature offers a wide variety of valuable topics. However, the majority focus on individual components of product development elements and costs rather than providing a holistic approach for cost analysis that weighs in additional factors such as customer need, time to market, and technology. Many studies have rigorously addressed topics that include: details of manufacturing costs of specific product features [23]; cost management [24] ; product properties in relation to the consumer [25]; market size to determine required product quality [26] ; product quality in relation to cycle time [27]; and collaboration to enhance product design, quality design and cycle time [28]. Furthermore, the application of concurrent engineering to improve quality, lower costs and reduce time to develop has been looked into [29] in addition to the performance of systematic cost analysis studies at an early stage in development [30]. This is also the case with measurements of the number of oligopolies in comparison to Research and Development (R&D) expenditure [31], and the expected rate of return versus product investment [32].Company reputation has also been considered as a factor of product success [33]. Many of these studies focus on one or a few steps of the *product development process*, although information on an algorithm for a complete evaluation of every step in the entire process is not currently available.

Although many firms realize the importance of generating market knowledge, there is a tendency among managers to overemphasize one process while ignoring others [34]. By concentrating on only one or two aspects of the *product development process*, important issues and attributes that are not considered can have negative consequences on the resultant product.

Projects, when managed through inter-firm contracts, are more likely to involve strategic change when risk is shared than when either the buyer or seller assumes full design, technical, and/or financial risk. Published results further suggest that projects containing shared buyer and seller risk enhance the prospects of joint gain through the generation of opportunities for learning [35].

The debate among practitioners about competence development often treats a market knowledge competence and a technology competence as two exclusive capabilities. For example, Chidamber and Kon found that decision makers often post competence selection as an either/or question [36]. Furthermore, Li and Calantone demonstrated that both market knowledge competence and R&D strength contribute to new product advantage [37]. Following a methodology similar to the one used in Cooper's New Product Development studies, the study conducted by Polk, Plank and Reid reveals the importance of the addition of technical risk assessment in predicting the potential success or failure of new high technology industrial products [38]. A New Product Development system matters in delivering product profitability because it positively impacts profits directly as well as indirectly through speed to market and product quality [39].

Prior research clearly argues that decision makers assign greater salience to certain competitors. Managers form their own opinions of their competition, resulting in the perception that some competitors are closer rivals than others [40-42]. As the prominence of certain types of competitors increase, they draw more attention while leaving less consideration available for other competitors. Thus, a key question in establishing how attention is allocated is understanding which types of firms managers are most likely to see as rivals [43]. Regulation is often mentioned as a barrier to technology innovation in various industries. Delayed market entry, stifled creativity, added activities and resource requirements are some frequently mentioned barriers. Formal statutory requirements only partly explain why regulation is perceived as a technology innovation barrier. Several discrepancies exist between stated and formal regulatory barriers and suggest that the majority of the stated barriers emerge within the organization during operationalization and the technology innovation process [5]. The possession of a regulatory strategy expedites the rate of commercialization; so too does the generation of clear product definitions and marketing claims in the earliest developmental phases. Moreover, results suggest that if the regulated industry strengthens its culture for regulation by prioritizing regulation over speed to market, by encouraging cross-functional team collaborations, and by taking a more proactive approach in post-marketing surveillance activities, it has the potential to improve customer satisfaction and enhance product innovation [44].

Estimating costs is an important task at every stage of product development. The planning phase allows for the evaluation of process cost-effectiveness and funding opportunities. The design stage allows for adjustment of future product parameters and the selection of resources for the manufacturing stage. Development costs are primary factors in decision-making and therefore their estimation plays an important role in management [45]. A successful new product development and launch is a key factor to continued business survival and growth. The activities ensuring the successful launch of a product begins already during early phases of the NPD process and include such things as the identification of client requirements and idea generation of a new product. A limited R&D budget requires selecting the most promising NPD projects, wherein cost estimation is helpful. If the new product is a modification of a previous product, cost estimation may be based on the data of the past NDP projects that is stored in an enterprise information system [46].

Industrial design is a major contributor to the success of products and the building of brands [47]. The extent to which firms integrate industrial design in new product development projects has a significant and positive influence on company performance, in particular when the strategy of investing in industrial design is relatively new for the industry involved [48].When implemented together, industrial design and cost engineering enhance both the effectiveness and efficiency of new product development in early-stage firms, to greater effect than each does individually. Intensive individual adoption of practices has a negative impact on development efficiency measures such as development cost and duration [49].

A user-oriented design (UOD) emphasis can contribute to the NPD effort as well as serve as a focal driver of that effort. Such a focus offers the potential to contribute to design performance in several important ways. User-oriented design can provide better appreciation of the potential challenges and a heightened sense of the range of possibilities for a product in development by ensuring that both the realities of the application (e.g., customer product use/needs) and the realities of the market are addressed. In addition to resulting in a product more in tune with the customers toward which it is targeted, incorporating UOD as a focal driver can produce a more comprehensive approach toward NPD and a resultant cost savings due to scenarios such as reductions in redesign work and heightened design for manufacturability, as well as shortening the length of the NPD process. UOD can also keep a development project on track and grounded, in constant touch with the ultimate objective of any development project-to provide real value in the form of a well thought-out and designed product that provides maximal utility to the user [50]. Developing an understanding of the ways that consumers process and react to product appearance can be a competitive advantage [51]. User ideas provide the starting point for industry development under the uncertain conditions of industry life cycles based on different cost/benefit structures [52].

In general, manufacturing costs are difficult to estimate and depend on a number of factors [53]. Manufacturing cost estimation procedures have concentrated more on the costs related to materials and processing. The manufacturing lead time also affects the product cost and modeling this cost is highly relevant toward analyzing product profitability [54].

CHAPTER 3: THE COMPLETE PRODUCT DEVELOPMENT PROCESS

The complete *product development process* as shown in the yellow highlighted areas in Figure 1 encompasses the process from Gate 3 through Gate 6 including stages within. The complete *product development process* detailed below addresses all of the significant considerations highlighted in the literature review and allows for a rigorous evaluation of each consideration for a balance of importance and priority in the development process.

3.1 GATE 3:

Gate 3 is where a business case (proposed product) is evaluated based on specific evaluation criteria that address whether the product idea is viable and well received in the marketplace. Evaluation criteria also question product purpose, functionality, size, style, cost, options, user interface or life cycle. They also assess input from a diverse group of users, potential users, trades people, trade associations, safety organizations, or government agencies. This input can be obtained by one on one interviews, focus groups, or questionnaires. Therefore, this review gate is important because it places the foundation for Stage 3, the *product concept process*, which is detailed in Chapter 3.2.

At this Gate a preliminary review of the Intellectual Property (IP) should be examined to determine if the product concept violates any existing products or patents. If there are areas of concern, a professional opinion should be sought before proceeding further. This step might guide the project down a different path if there are areas of concern. This IP review will be recommended at Gate 4 and Gate 5 to assure that the project is not violating other's rights.

3.2 STAGE 3 "THE PRODUCT CONCEPT PROCESS":

Stage 3, shown schematically in Figure 2 consists of three phases, the conceptual stage (Phase I), the developmental Stage (Phase II), and the pre-product design stage (Phase III).

3.2.1 PHASE I "CONCEPTUAL STAGE":

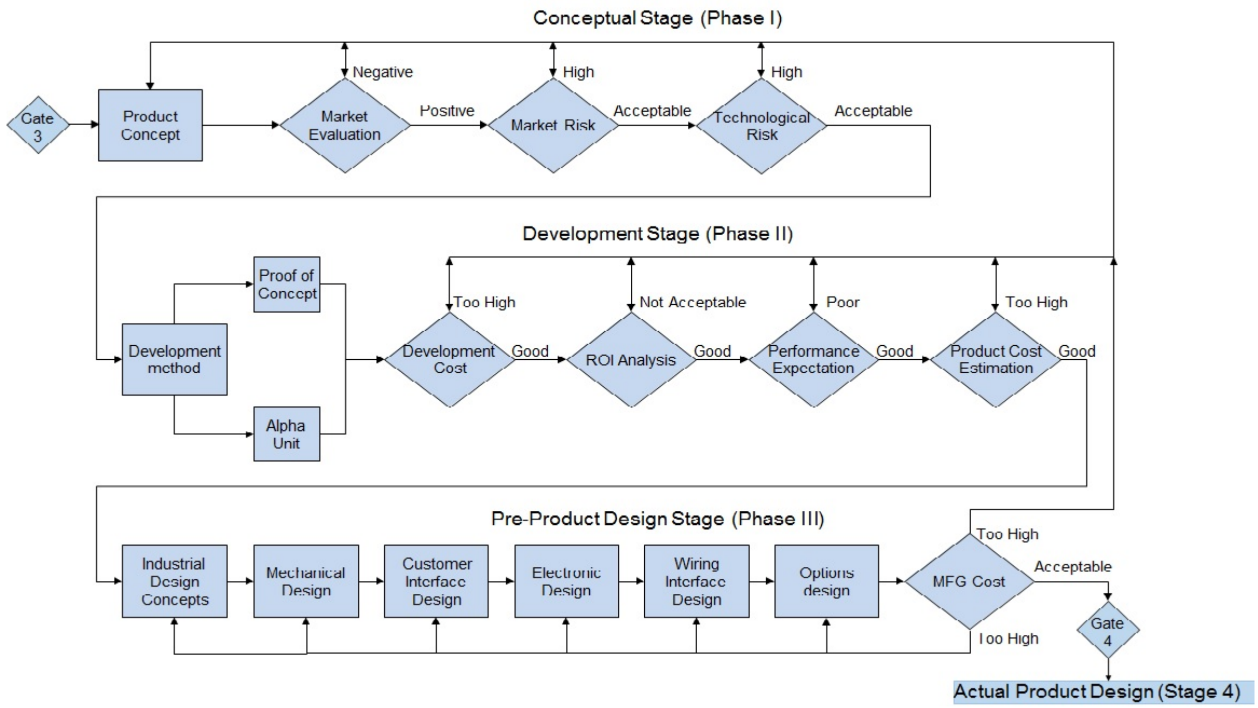

Figure 2: Schematic diagram of Stage 3, the *product concept process*

The *product development process* starts by generating a product concept which is the initial idea for a new product that can originate from a large variety of sources including sales, marketing, engineering, manufacturing, customers, trade shows, a serendipity experience, or any combination of these. Much of this information can derive from the efforts during stage one and stage two of the stage-gate process. It is important to discuss a new product idea with a diverse group of specialists from different disciplines. This discussion results in the creation of a wish list that captures many attributes and functions without the exclusion of any suggestions. Thus, during Phase I, a product concept is rigorously evaluated by engineering and sales/marketing experts in a number of free-thinking product concept meetings so that a viable product emerges. Additionally, in order to evaluate market acceptance, this viable product concept is then presented to potential customers with varying interests for their feedback. The same rigor employed in the market evaluation is also employed in the market risk and technological risk evaluation. Evaluations of the Conceptual Stage typically employ survey analyses of users of similar products or processes when applicable or future users of the potentially viable technological product in question and/or

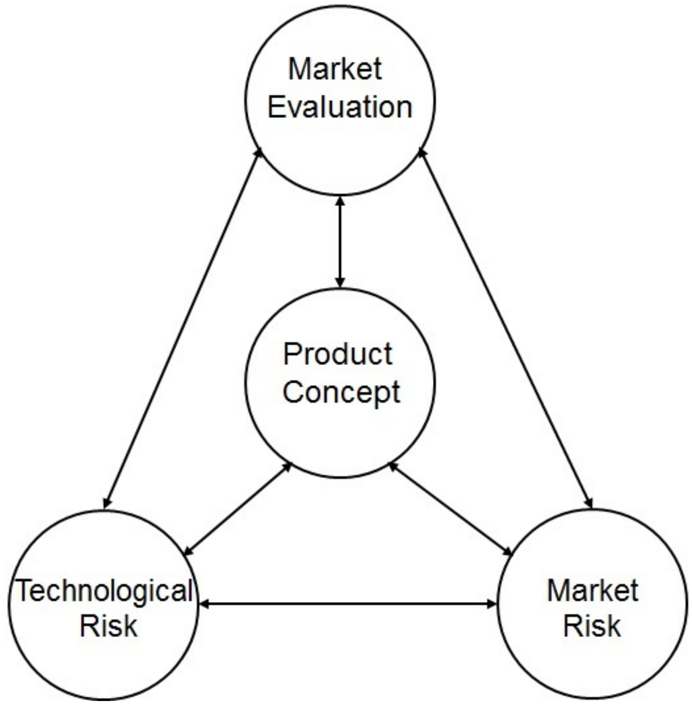

Figure 3: A schematic diagram of the conceptual stage (Phase I) steps in the *product development process*[4].

focus groups and group discussions. A simple questionnaire can be designed following careful consideration of the product concept and used for evaluations in Phase I of the product development effort. Survey results may reveal problematic features as well as potential technological risks for consideration by engineering and marketing experts in order to fine-tune the features of the product. Technical complexities and technological risks are weighed in order to generate a product that meets marketing goals in performance and cost. Following the evaluation steps from Phase I, it is useful to establish a price point range that the product in question should meet.

Once the market evaluation study is completed, the development team can proceed with the analysis of market risk which explores enthusiasm about the product idea, capability to introduce all requested features, profitability, competition with existing similar products, viability, and effects of regulatory and compliance issues via an additional survey. Technological risk assessment steps follow market analysis and explore product operation and performance.

Typical questions in a technological risk assessment survey (Table 1) explore the type of control circuitry, e.g. analog, digital, etc., state-of-the-art technology employed, design components that could become obsolete, type of customer interface, e.g. touch screen input, keyboard input, etc., memory required, power and stand-by power required, and board size for the control printed circuit board. The conceptual stage (Phase I) steps are summarized in a schematic diagram (Figure 3) that captures the interaction between Phase I steps and their interdependence on one another.

As the development team becomes more experienced and is exposed to different products and markets, there will likely be additional questions and attributes to be considered.

Table 1: A list of questions that require answers both from the design team and the market place.

Product concept questions
What is the primary purpose of the product?
Are size and weight important factors?
Is a power source important? Does the product need to be portable (refer to question 2)? Does the product need to be rechargeable? Is recharge time important?
Does the product operate in a timely manner?
Are shape and color important factors?
Does this product accomplish its task in an acceptable manner?
Is this product susceptible to obsolescence in the near future?
Does the operation require special education and/or talent?
Are there consumables involved? Are the consumables available on the open market?
What is the target market? Is it a growth market, fixed market, age defined, special need?
Is the market cyclical, seasonal, geographically dependent, time of day dependent?
Is there a selling price limitation?
Is it single use? Is it throwaway or can it be refurbished? What is the life cycle?
Is memory size important?
Market evaluation questions
Did the user understand the operation? Could the operation be made simpler?
What is the estimated size of the market? Is it growing or stagnant? Is there competition? If so, is there room for another entrant?

Do we sell the product directly from the company offices?
Do we sell the product through big box stores such as Best Buy, Target etc.?
Do we sell the product through a store that specializes in that particular market such as pools, leisure stores, sports stores, etc.?
Do we sell the product via television such as infomercial, direct T.V. adds, etc.?
Do we sell through magazine advertising?
Do we sell via social media such as Facebook?
Do we sell the product through Amazon or establish a store on Amazon?

Market evaluation questions (continued)
Does the product employ fast moving technology?
Is obsolescence a factor?
Is it dangerous technology such as nuclear?
Is it legal? Will it remain legal?
Is it new technology? Is it patentable?
If it uses replenish able material, is the material readily available at an acceptable cost?
Technological risk questions
What type of control system is to be employed? - Custom control logic circuitry - Microprocessor - Personal computer - Laptop - Smart phone - Other, describe
What type of display will be employed? - LED display - Commercial off the shelf (COS) - A custom designed display - Touch Screen - External display via USB or Ethernet - Individual LEDs on custom printed panel
What chip family will be used? Advance RISC (reduced instruction set computer) Machine (ARM) – The choice of the chip family could result in premature obsolescence. ARM chips are well imbedded and appear to have a long forward-looking product life cycle.
What is the power source? - Battery? Rechargeable? - A.C. Power? - Domestic or foreign?
What kind of memory will be required? - Random Access Memory (RAM) - SIMM (single inline memory module) card - Is space going to be limiting? - Are multi-layer PCBs required? - What are the environmental requirements? Temperature, Shock, Vibration, waterproof, altitude, product orientation.

3.2.2 PHASE II "DEVELOPMENT STAGE":

Steps in Phase II include the evaluation of engineering prototype designs for the product in question as well as a preliminary exploratory financial analysis that includes cost analysis for product design, manufacturing costs and market analysis of product performance. To date, a standard paradigm for performing stepwise analysis that influences manufacturing costs does not exist. The degree of difficulty in determining the development cost, performing a return on investment (ROI) analysis, performing a product performance expectation or a product cost estimation will depend on decisions made during the initial steps of Phase II in choosing a "proof-of-concept" design or an "alpha unit" design. A "proof-of-concept" design can be more cost-effective than an "alpha unit design" although it does not provide sufficient information for determining development cost, ROI analysis, performance expectation or product cost estimation. Because the alpha unit design is near complete and somewhat tooled and very similar to the final or "beta" unit design, it is easier to perform cost estimation on the four items described above. The proof-of-concept method should be employed only if one can render a reasonable version of the product that can provide the necessary data to perform the four steps of Phase II (Figure 2). Notably, financial risks can increase if the beta design is chosen and any one of the steps proves to be unacceptable.

After it is determined whether to employ a "proof-of-concept" or an alpha type prototype, the development cost of the prototype should be estimated. This estimation can be very informal but should not be underestimated since this may cause a "lack of faith" in the estimates during later steps. The next step is to perform an analysis of what kind of profitability will be required to recover the development cost. Since this step is still in the early stages of development, only estimations are expected. The begging questions are: "Is this a feasible project?" and "Is it possible to recover the cost of this project?" If the project looks feasible after analysis, a performance requirement list is then generated. This performance expectation document feeds back all the way to the four steps of Phase I and lists every expectation of the product including all of its functions, speed of operation, flexibility, mean time between failure (MTBF), life expectancy, reparability, environmental requirements, noise levels, portability, power requirements, cost of expendables, maintenance requirements, and optional performance requirements. Figure 4 is a schematic representation of the four steps in Phase II.

As an example of the "proof-of-concept" approach, consider a device that used a probe that contained an absorbent material coated with a proprietary mixture that changed color from white

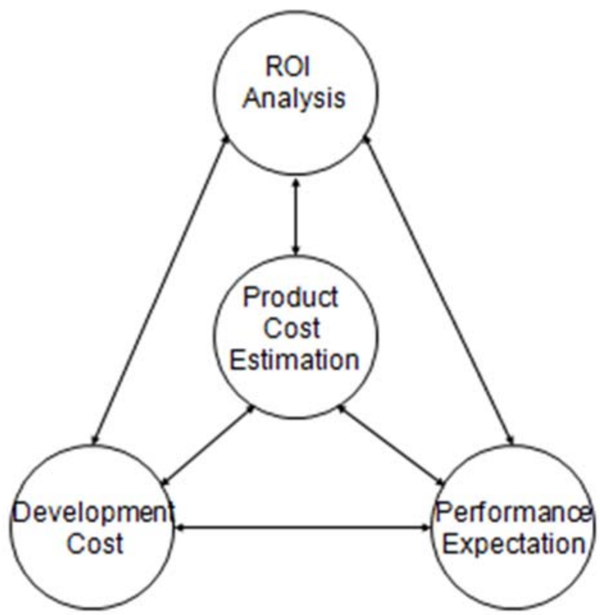

Figure 4: A schematic diagram of development stage (Phase II) steps in Stage 3.

to progressively darker blue as a function of time and following exposure to a contaminant material. It was empirically determined that consistent results were attained if the color intensity was read at 45 seconds after exposure to the liquid being tested. The color intensity at that particular moment in time indicates the parts per million (ppm) presence of the contaminant in question. The absorbent material was a woven material, similar in texture to a cotton swab that can have multiple reflective coefficients resulting from the heterogeneity of surface shapes, viz., more domed or less domed, frayed or less frayed, resulting in different absorbance readings for the same color intensity. This critical variation was not apparent at this stage of development and designing an alpha unit to determine the viability of test results was considered financially prohibitive. Thus, a “proof-of-concept” front-end device was developed for the measurement of reflectivity of numerous different probes to determine if output readings accurately measured the concentration in ppm of the substance under investigation. Results from the front-end device were transferred into a custom designed input converter that generated results representative of the level of contamination. These results were subsequently transferred into a personal computer (PC). After testing a number of light frequencies to determine the best color frequency to be used, it was determined that a bright visible range red light source yielded the highest output signal. However, the results were determined to be unreliable due to the varying reflectivity of the absorbent material. A method had to be developed that would standardize the readings based on the color intensity and not on the reflectivity of the absorbent material. It was determined that long wave infrared was blind to the color but could measure the reflectivity of the absorbent material. By measuring the reflectivity of many samples of the probe, and then exposing them to a known amount of the contaminant, a look-up table was generated that normalized the reflectivity of the absorbent material, resulting in accurate readings of the contaminant. A reference table of reflectivity readings from a large pool of probes provided a normalized chart for predicting the color intensity of a contaminating substance with great accuracy and reproducibility. Following these fine-tuning experiments with the front-end device, the “proof-of-concept” system was tested further to determine desirable attributes in the final instrument design, e.g. the original design estimated that 3 or 4 panel buttons would be necessary to obtain all of the data sought but the final design determined that 12 input buttons were required to accomplish this easily. The design of a new and permanent input device for each new modification would have been costly. Furthermore, the use of a flexible PC with updatable software significantly aided in reducing the cost and time needed to introduce modifications during Phase II development stage.

Achieving a balance among the four steps of Phase II (Figure 4) is dependent on the experience of a design team's ability to estimate development cost within 10% to 100% of the actual cost. For ROI analysis, accuracy will depend on sales and marketing knowledge of the market as well as extent of research performed in the user's market. The same accuracy criteria also apply for the performance expectation step. During the development of the color intensity instrument, many potential users were able to test the proof-of-concept unit. This enabled continuous optimization of the unit's performance and the elimination of needless additional options.

3.2.3 PHASE III "PRE-PRODUCT DESIGN STAGE":

Phase III steps include a rigorous financial analysis of each step before the creation of the final product design (Phase IV). During Phase III (Figure 2), project spending accelerates because designers put forth multiple industrial design concepts. For the most part, small and medium sized companies employ their own industrial designers instead of relying on independent industrial design firms. It is essential that engineering and marketing experts evaluate the merits of each design approach versus costs needed to produce the recommended industrial design concept. It is also important to weigh aesthetics against the tooling and manufacturing costs and to consider the cost of assembly, test and repair. Once a design concept emerges, it is possible to solidify mechanical design cost, and this includes the cost for the customer interface. Additional costs include those for software development, the design of the graphic user interface (GUI) and electrical engineering. At this step in Phase III of the product concept process, manufacturing costs are estimated. This is often a challenging task given that the product is well conceptualized but not physically created. Notably, at this stage of development, an actual Bill of Material (BOM) that calculates in advance the total manufacturing cost is not yet available. The sniper detection unit example (chapter 4) is used to demonstrate first steps in Phase III that determine the best and least costly configuration of the final product. Following discussion with the customer about potential final designs for the sniper detection unit, the design team determined that the detection unit needed a significant reduction in size and cost. The alpha unit (Phase II) consisted of fragmented units that included a power and processor box in one unit and a separate control and enunciator unit. Thus, the final conceptual design merged the control and enunciator units into one and introduced a variety of modifications that were proposed by various users of the alpha unit. Since the majority of software for this alpha unit was created during Phase II, cost estimates were only needed for the slight modifications that were introduced when redesigning the electronic components.

During Phase III steps, if estimated manufacturing costs approach the marketing-defined maximum product costs, it will be important to consider adjustments. These may include reducing product design features that can necessitate a re-evaluation of the product concept during Phase I or Phase II of the *product concept process*, re-evaluation of product design as envisioned during the initial steps of Phase III, or scrapping the project or re-evaluating allowable manufacturing cost. Therefore, Phase III steps serve to minimize the risk of cost/performance surprises before significant costs of actual product development are undertaken.

3.3 GATE 4:

Before initiating the Product Design Stage (Stage 4), it is imperative that evaluation of phases and steps of the *product concept process* (Stage 3) is performed through Gate 4.

The Conceptual Stage (Phase I):

1. Is the product right for the market?
2. Did the market readily accept the product idea?
3. Is the projected selling price acceptable to the market?
4. What are the market risks and have we considered the consequences of those risks? Are there ways of mitigating those risks?
5. What are the technological risks and have we considered the consequences of those risks? Are there ways of mitigating those risks?

The Development Stage (Phase II):

1. Is the projected development cost within the projected range and what is the possibility of significant cost overrun?
2. Is the Return-on-Investment (ROI) for the development within the range of acceptability?
3. Did the Proof of Concept/Alpha unit perform up to expectations?
4. Are there areas of performance that need improvement? At what risk, cost, and other consequences?

5) How viable is the product cost estimation? Is a cost increase tolerable and acceptable by the market?
6) Will a potential cost increase result in an unacceptable ROI?

The Pre-Product Design Stage (Phase III):

1. Would the Industrial Design Concepts generated in Phase III by inside talent require review and finalization by external industrial design expertise?
2. Will the designated budget accommodate an external designer?
3. Does the design concept meet market requirements as established in Phase I for the product?
4. Does the final mechanical design fulfill the image of the industrial design concept?
5. Is the mechanical design producible at a reasonable cost?
6. Is the customer interface user friendly and intuitive?
7. Is the electronic design efficient and composed of components that are unlikely to become obsolete in the next 5-10 years?
8. Are the interconnections accomplished with a minimum amount of hand wiring?
9. Do the options encompass all or most of the options identified in the market evaluation without overburdening the basic product cost?

   After examination of the areas outlined above, a decision must be made as to whether

   a) the project can proceed to Stage 4 or

   b) require a design modification at Stage 3 or

   c) termination of product development or

   d) postpone for reevaluation

10. Before proceeding it is necessary to once again review the IP to assure that the project is not encroaching on other’s rights.

3.4 STAGE 4 “THE PRODUCT DESIGN STAGE”:

After successful examination of the *Product Concept Process at Gate 4,* it is feasible to proceed towards the execution of the actual product design (Stage 4) which is shown schematically in Figure 5.

3.4.1 THE INITIAL DESIGN, STAGE 4, PATH 1:

The first step requires the-selection of an industrial design concept as shown in Path 1 of Figure 5. The execution of the design should conform to the identified and desirable features from the market evaluation performed in Stage 3. This may or may not require significant industrial design input or simple sheet-metal enclosure known in the industry as a "black box" design. In

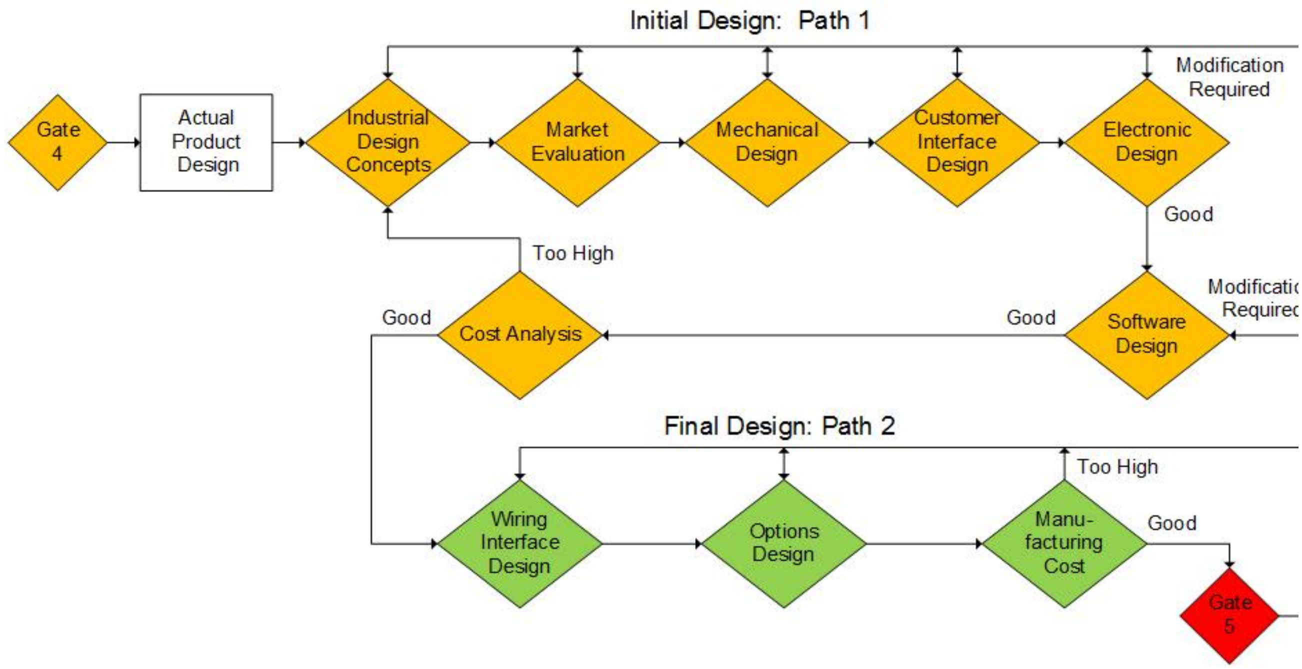

Figure 5: Schematic diagram of Stage 4

either case, the mechanical and electronic design teams must agree on the producibility of the design concept.

The market evaluation step in Stage 4 (Path 1), is derived from the market evaluation of Stage 3 (Phase 1) and forms an important bridge between the industrial design and the mechanical execution of that design. This task is performed by mechanical designers while taking into consideration customer interface requirements, electronic packaging needs, and ease of assembly considerations. This is a complex and iterative process because it involves coordinating the industrial design concept with the customer interface, mechanical and electronic requirements as well as organizing the mechanical requirements of the electronic design including the implementation of the wiring interface and options design of Path 2. Following the near completion of the mechanical design, customer interface design and the electronic design, a comprehensive manufacturing cost analysis should be performed. If this cost analysis is acceptable, the initial design (Path 1) can be finalized and the final design (Path 2) can be executed. If the costs are too high, Path 1 will have to be repeated.

3.4.2 THE FINAL DESIGN, STAGE 4, PATH 2:

The final design (Path 2), aims to minimize the use of individual wires and to integrate interconnections. Path 2 also includes the design of aftermarket options, all of which were part of the mechanical and electronic design considerations in Path 1. Allowing for options adds significant synergy for the product and allows for future improvements and features. However, this option ability should not add significantly to the basic product cost. The final step in Path 2 is the determination of the manufacturing cost. This may seem redundant since a cost analysis is also performed at the conclusion of Path 1, but it serves as a final and important check point before proceeding to Gate 5.

3.5 GATE 5:

Gate 5 reviews steps executed in Stage 4, Path 1 and 2. A major examination point is the manufacturing cost evaluated in Stage 4 (Path 2) and whether it aligns with manufacturing costs established in Stage 3 (Phase III). If manufacturing costs from Stage 3 and Stage 4 are not in accord, then a return to initial steps of Stage 4 (Path I) are highly recommended. In addition to evaluation of manufacturing cost, Gate 5 serves to thoroughly review every step of Path 1 and 2 as described below.

Again, at this Gate the IP should be evaluated to ascertain that the project is still not violating other's IP rights.

3.5.1 PATH 1 REVIEW:

Path 1 review examines the industrial design concept as well as market evaluation expectations that were put forth during Stage 3 (Phase I) of the product development process. Simply put, this review re-evaluates market requirements to ensure that the new product will meet the targeted consumer demand.

3.5.2 PATH 2 REVIEW:

Path 2 review ensures that the mechanical design allows the implementation of customer interface design, electrical design and facilitates assembly. Additionally, Path 2 review examines whether the electronic design is state-of-the-art as well as the aesthetics of the Customer Interface Design (CDI) and whether it is user-friendly. Furthermore, the minimal use of printed circuit boards and whether they are easily testable and repairable is looked into. The Bill of Material (BOM) is also reviewed to ensure the minimization of expensive parts as well as end of life or near end of life parts

A critical step in the Gate 5 review is the evaluation of the software, its ease of use, and if it is far enough along in its development that the testing of Stage 5 can begin. It is possible that additional software development may negate Stage 5 test results causing costs overruns. Alternatively, the initiation of testing can be beneficial by getting the product to market sooner thus making potential re-testing an acceptable cost.

3.6 STAGE 5 "FABRICATION AND TESTING":

Stage 5 in the product development process signals design completion and readiness for production (Figure 6). For this to take place, a decision must be made to determine the number of units to be produced in the first production run for the test program. For the initial test program, it

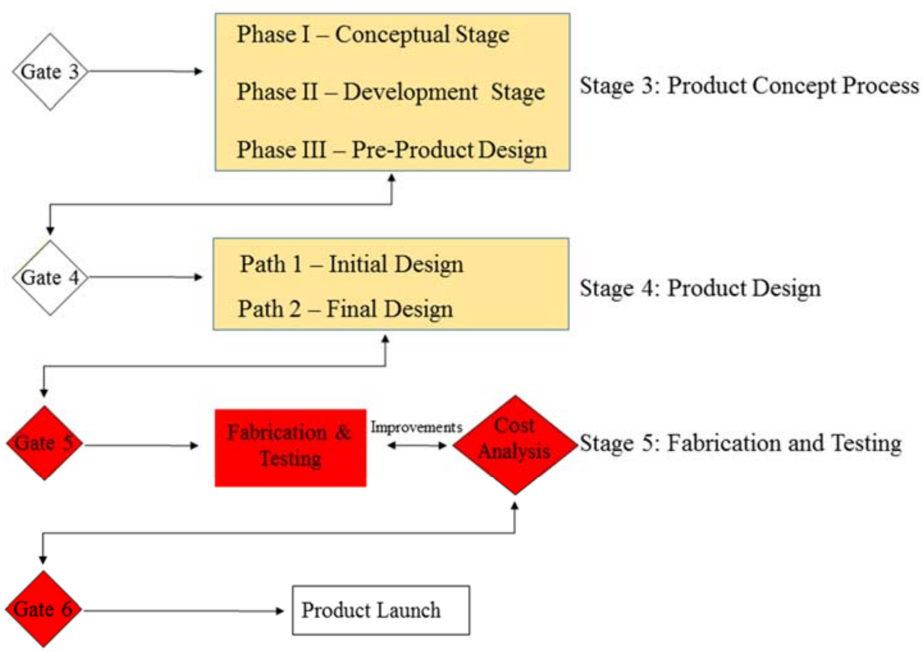

Figure 6: Graphic representation of Stages 3, 4 and 5

is possible to fabricate additional units for customers (Beta site) to test. Often times, it is desirable to produce a second release of the product that possesses additional production improvements.

During Stage 5, all modifications to near-final product should be tracked and proper revision control should be exercised. During product assembly, encountered problems and recommended changes should be documented and addressed. When the product is assembled it is ready to be subjected to the test program, a crucial step in ascertaining that the product performs as it was intended. A formal test procedure must be generated and test data recorded for each unit produced before the product can be released from the production line. At this point in the *product development process* the product is ready to undergo product qualification testing.

One of the most important steps in a *product development process* is the product qualification test plan. Unfortunately, many developers opt to shorten the development process by bypassing this critical test plan in order to accelerate the time to market. The test plan, if properly implemented, provides an abundance of critical information and useful answers to important questions that address product performance such as: Does the product perform reliably and as required? Is the product user friendly or does it require additional modifications? Are there other attributes or functions that should be added to the product? Conversely, are there product attributes or functions that are not necessary that add to the complexity of its use? Is the product compact enough and durable?

During the final testing program (Stage 5), many of the tests duplicates those performed in Stage 3 (Phase II) or tests performed during Stage 4 (Path 1 and 2) on various versions of the product. The only difference is that final tests and additional tests are performed on the final version of the product.

The final testing program can be conducted both within the company and by selected customers. Customer testing, typically known as “Beta Site” testing, should be conducted following the completion or near completion of internal company testing. The testing program is a critical step in the product design process and can lead to numerous improvements to its design and operation. The product should be tested under all intended environmental conditions that include temperature, shock, vibration, high/low power source conditions including noisy line conditions, battery conditions, humidity, salt spray and altitude. Detailed records should be kept and anomalies of operation noted and addressed.

If "Beta Site" testing is also performed by the customer, which is desirable, a test log sheet should be provided so the customer records the type of testing performed and the results experienced. The testing should not be limited by product launch deadlines, trade shows or management impatience. Proper testing and refinement can provide results that accomplish product improvements and attributes that were unintentionally missed during Stage 3 Phases or the Paths of Stage 4 that lead to the final product design.

After the completion and evaluation of the qualification test plan, cost analysis is reviewed once more to confirm that additional costs were not acquired. At its satisfactory conclusion the product development process can proceed to Gate 6.

3.7 GATE 6:

The review of any purchasing, manufacturing process, production testing and cost analysis issues is the first step in Gate 6 which is very beneficial to the ongoing manufacturing process. Another important step in Gate 6 review is the examination of the results of the product test plan. This examination reviews if the test plan was comprehensive and sufficient and whether product anomalies were discovered that require product modifications? It is important that the customer, developer, and Gate 6 review panel are fully satisfied (100%) with the results of the test plan and that the Gate 6 review group performs a final comprehensive surveillance of all of the preceding

Gates, from Gate 2 through Gate 5, of the *product development process* to ensure that all of the raised issues have been properly addressed.

CHAPTER 4: RESEARCH PLAN

In order to evaluate the *product development process,* five case studies of medium sized electronic products in development and one case of a product improvement are presented. The first case study is on a sniper detection system. The second case study is on a target scoring system. The third case study is about an on-site medical waste disposal system. The fourth case study is of man wearable 1, a failed product that violated a significant number of critical steps in the first three stages of the product development process. The fifth case study, man wearable 2, is of a product that replaced the failed product illustrated in the fourth case study and the sixth case study, the sniper detection system option, is of a product improvement that was saved from failure. None of these products were produced by following the exact proposed *product development process* in its entirety. Therefore, the positive and the negative outcomes of each program in choosing to adhere or not adhere to the *product development process* are analyzed.

4.1 SNIPER DETECTION SYSTEM (CASE STUDY 1):

During the war in Iraq, there was considerable enemy sniper activity both in inner cities and the open desert which was a significant impediment. Rifle shots in inner-cities are difficult to ascertain from whence they came due to echoes caused by surrounding buildings and the ever-present city noises. As a result, military troops could not eliminate or properly respond to sniper shooting. The development company for the sniper-detection system had expertise in sound analysis and processing. The sniper detection system is an acoustic system with seven especially designed microphones mounted around a spherical hub shown in Figure 7. When a shot is fired towards the hub, an acoustic shock wave precedes the bullet projectile and passes the microphone array. The time of passage at each microphone is captured and the information is sent to a remote console for analysis. The varying times are analyzed and a parabolic ellipsoid is calculated that

Figure 7: Sniper Detection System Mast

determines the direction of a projectile flight path of the projectile. The time span between the arrival of the shock wave and the arrival of the actual shot sound wave is measured and allows for the calculation of the distance from the microphone array to the shot source. The science team at the development company assumed a muzzle velocity of 2950 ft./sec and a sound velocity of 1127 ft./sec for the purposes of these calculations. Results of a shot are shown on a Light Emitting Diode (LED) display on the control console and are annunciated from a speaker and an optional ear bud. If a shot sound wave is detected in the absence of a shock wave, the data is ignored, thus minimizing false shot calls.

Therefore, a proof-of-concept system was developed (Figure 8) that was tested in the open field using live pistol and rifle shots. Inner city testing was delayed due to the lack of a safe environment for testing the proof-of-concept system. The operation of the test system was compared to a number of competing systems and it significantly outperformed all others.

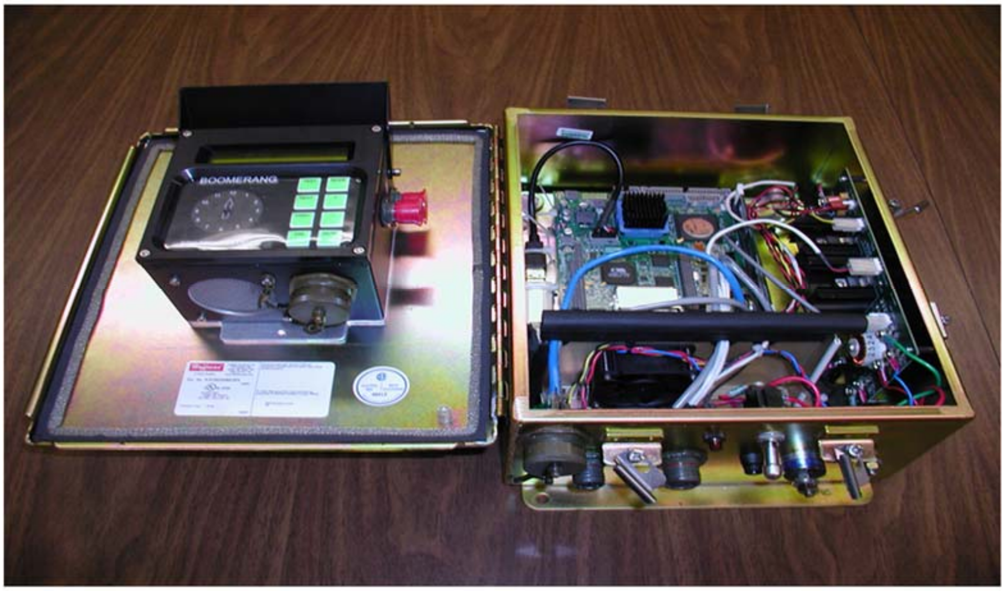

Figure 8: Sniper Detection System, Proof-of-Concept

Improvements included a reduction in false shot calls, and the elimination of failed shot calls and celebratory shots (shots in the air) relative to competing systems. At the completion of testing, the development company-queried the customer (military) on how the product should be packaged and utilized in the field. The above efforts served as a combination of the conceptual stage (Phase I) and part of the development stage (Phase II) as shown in Figure 2.

Following testing of the proof-of-concept sniper detection system, the development company proceeded to develop an alpha unit by hiring an external development company to package the system. However, the customer demand was that the parent development company needed to generate 50 alpha units in a very short time (45 days) which eliminated the time required for performing cost analysis. Time-to-market was the priority and the development company accomplished their goal and deployed 50 systems into the war zone. The feedback was very positive mixed with a few requested upgrades. As a result, the development company sold hundreds of the alpha units as it proceeded to develop a final product with system costs, size and appearance as design criteria. These efforts were a combination of the development stage (Phase II) and the pre-product design stage (Phase III) leading directly into the product design stage (Stage 4) as shown in Figure 6.

The sniper detection system product was very successful and more than 10,000 units were produced in the first year even though the product development company ~~A~~ did not follow the exact steps of the *product development process.* Notably, the company took a very high risk by not performing a cost analysis before generating the alpha unit. In fact, their tooling expenditure was significant before building a short run of the final product to prove and test the final product. The risks were calculated and were substantial. However, the decision was to proceed in spite of the risks because the need to get the product into the war zone outweighed the monetary risks if design or tooling changes were required. Fortunately, the problems and expenses were minor. The development company in this case study performed the essence of the *product development process* while evaluating the risks of bypassing or delaying some of the steps.

4.2 TARGET SCORING SYSTEM (CASE STUDY 2):

The target scoring system consists of four components that are used to implement up to 100 variable target shooting courses (scenarios).

These components are:

Component 1. An android smart phone or tablet running a custom application that controls and monitors the entire system via a Bluetooth radio link.

Component 2. Wristbands worn by individual shooters that detect shots using a combination of measured recoil and acoustic energy via an accelerometer and a microphone. The wristband also identifies the shooter, as there can be multiple shooters.

Component 3. Target controllers that raise and lower the targets and detect bullet impacts.

Component 4. A Field Network Controller (FNC) that manages a radio network that includes itself as well as all of the individual wristbands and target controllers.

There can be up to twenty pop-up targets placed along a designated course, and up to fifteen individual shooters. As each target and wristband is powered up and appears online, it is assigned a sequential target number or wristband number by the FNC that is retained throughout the session. Following the assignment of a number to a peripheral device, the FNC assigns a number to the device via the radio link followed by sending a month-day-year-hour-minute-second message to the device. All wristbands and target controllers contain real time clocks which allow for synchronization to the FNC's clock for purposes of shot and impact timing. The FNC can store up to 100 different shooting scenarios, with each scenario having between one and twenty individual steps. Scenarios will cause a given pop-up target to be raised at a designated time which can stay up for either a predetermined amount of time or for a predetermined number of bullet hits, selectable by the user. These parameters are stored within the scenario step. For example, assuming that a scenario step is programmed for 15 sec and 7 hits, if a step is set to the Drop-On Time option, then the target will stay up for the full 15 sec even if the desired 7 hits are recorded sooner than that. Alternatively, if the step is set for the Drop-On Hits option, then the target will be lowered as soon as 7 hits are recorded, regardless of the elapsed time. If 7 hits not be recorded within 15 sec, the target will be lowered at the end of the time interval.

A video system mounted on each target controller detects the presence of bullet holes in the target. The processing algorithm can manage approximately three video frames per second. By itself, the software detects every hole in the target and cannot distinguish between existing and new holes for each frame. To mask out existing holes in a given target, when the target is first powered up, the video system detects all existing holes and stores their locations in memory. As each subsequent video frame is processed, the software compares each hole found in the frame to its list of stored holes locations allowing for the detection and recording of new hole locations to the FNC for future processing.

When a shooter fires a shot, the wristband first detects the recoil (using an accelerometer) and then detects the subsequent acoustic energy (using a microphone) generated by the bullet when leaving the barrel. This two-pronged detection scheme is implemented so that a sudden wrist movement without an accompanying gunshot sound is not recorded as a shot. Conversely, since there could be several shooters standing in close proximity firing at the same target (and causing their own gunshot sounds), a gunshot sound without the associated recoil detections is also not recorded as a shot.

Once a wristband has detected a legitimate shot taken by its shooter, it relays the wristband number to the FNC, along with the time in hours, minute, and second of the detected shot. Upon receiving this information, the FNC waits for a prescribed time interval for a new hole-location to be reported from the target. Should the time interval elapse with no new hole reported by the target, the shot is scored as a miss. If the target reports a new hole, the FNC retrieves the time-of-impact information from the target, as well as the XY coordinates of the impact for scoring purposes. The system is designed to be accurate to ±¼ inch.

The target scoring system is presently in development at Phase II of Stage 3 and an alpha unit is developed (Figure 9). The customer originally placed a Request for Proposal (RFP) out to two development companies for the design and development of a target system that would employ a pop-up man-sized target that scores the hits and misses of shots fired. The requirement was for the development of a prototype (one unit) of the final product. The first company responded with

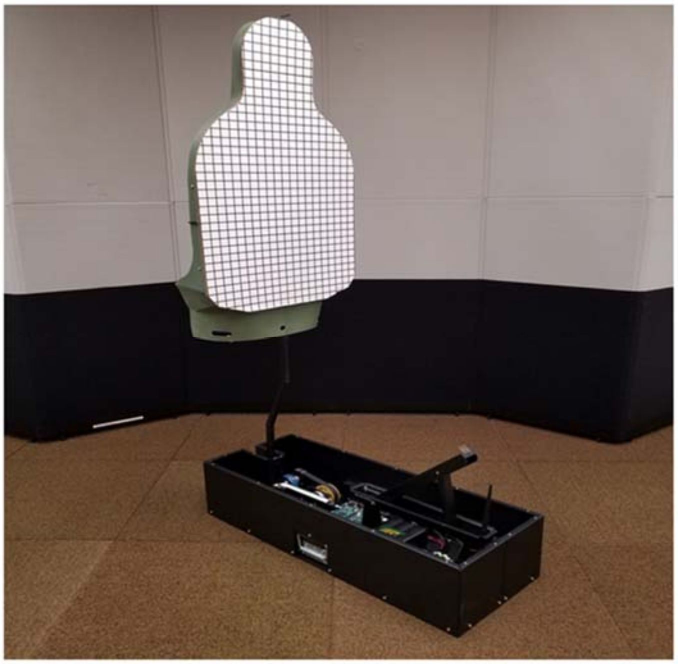

Figure 9: Target Scoring System Pop-up

a quote of $125,000 and 4 months for the delivery of the prototype while the second company responded with a quote of $175,000 and 6-9 months for the delivery of the prototype. The RFP sought to skip Phases I, II and III of Stage 3 (Figure 1) and proceed directly to Stage 4 (final product design) in the product development process. The prototype was to be the near final design and neither company was asked to quote the unit cost of the production version. Although the first company with the cheaper quotation and shorter delivery time was initially awarded the project, the second company was approached 2.5 years later to re-quote the project using the uncompleted work of the first development company. Following an evaluation of work accomplished during the 2.5 elapsed years by the first company, the second company conducted steps from Phases I & II of the product concept process and concluded that the design was flawed and unusable. Therefore, the second company re-quoted the project arriving at roughly the same cost and time to completions as was originally provided at $175,000 and 6-9 months for the delivery of the prototype. Interestingly, the customer refused again to perform a production cost estimate and rejected the performance of a market evaluation or assessment of market risk and technological risk as described in Phase I of the *product concept process*. The customer was confident about the market need and that the estimation of unit cost was not an important issue if the features that the customer wanted could be delivered. During Phase II of Stage 3, significant technological difficulties resulted in a 3-months delay to produce the alpha unit and the customer rushed production by omitting the performance expectation step of Phase II recommended by the second development company and proposed the building and field testing of 3-5 prototypes at different sites. As such, the customer has created a strong probability for a failed product launch. This product is still under development.

4.3 MEDICAL WASTE DISPOSAL SYSTEM (CASE STUDY 3):

The third case study is an on-site medical waste disposal system. To highlight the importance of market evaluation steps during Phase I of the development process (Figure 2), this manuscript describes a product development effort that bypassed market evaluation steps. The small electronic product design in question included a floor or countertop canister and sterilization unit designed to collect, contain and safely dispose of biohazardous medical waste items generated in a clinical setting. The sterilization unit included safety features that shielded the user from ~~the~~ waste until the sterilization cycle was complete and a label printed for record keeping purposes. At the conceptual stage (Phase I of Stage 3), the customer required that the disposal receptacle design to have the shape and dimensions of a one-gallon paint canister. This seemed to be a reasonable idea to the development company given that canisters are readily available, inexpensive and do not require mechanical tooling investments. An added advantage was that the product could withstand 375 ˚F heat for longer than 20 minutes for the sterilization of biohazardous content, i.e.

to destroy infectious material in biological waste for safe disposal. When the final product was introduced to the market, users found the product design to be problematic since the round canister configuration did not allow for easy and complete insertion of syringes and/or other tubular waste products. Consumers were accustomed to a trap door mechanism that did not work on a round canister. As a result, the development company terminated operations, did not pursue product re-design and ceased to exist. A sample of a market survey that could have been employed to determine the market acceptance of this product is shown in Table 2.

1) How would you prefer to collect the sharps and medical waste?
   a) Presently used oblong trap door devices
   b) Round 1 gallon paint can type container
   c) Other configuration
   Comment:

2) What is the maximum footprint that you would foresee as to be acceptable?
   a) 12"x12"
   b) 18"x18"
   c) Other
   Comment:

3) What is the maximum height that you would foresee?
   Comment:

4) Would you expect to use this device in one location? Yes ___ No ___

5) Would you expect to move its location frequently? Yes ___ No ___

6) Do you feel that an "on premise" medical waste disposal system is a benefit to your work? On a scale of 1 (no) to ten (very much), Please indicate your opinion.

7) There would be an automatic lock out system once the heating process is initiated. Do you feel that this is important?

8) At the conclusion of the heating cycle, a label is printed that will be attached to the processed container. The heat used to sterilize the contents will cause the collection container label to fall off so that the container no longer is labeled "hazardous medical waste". Do you think that this feature is necessary and adequate? Yes ___ No ___

Table 2: A sample market evaluation questionnaire from Phase I of the *product concept process*

4.4 MAN WEARABLE 1 (CASE STUDY 4):

For this case study, a customer provided design specifications to any company willing to develop the product. The same development company that developed the successful sniper detection system described in the first case study gauged that the design specification submitted by the customer would not produce a successful product. In the case of the sniper detection system (case study 1) the development company produced a highly successful technological product by acknowledging their limitations in the design and execution of the product packaging and seeking the services of an experienced design and manufacturing company with extensive experience in both the design and manufacturing of products.

During product development for case study 4, the development company changed directorship of the engineering department who put together a new design group despite the fact that they had never worked together and had minimal manufacturing experience. Furthermore, this new team did not accept the use of external services and opted to generate their own specifications and present the finished product when completed to the end customer for the first time.

The development company envisioned a device that would mount on each shoulder of a combatant as opposed to a single device mounted on one shoulder as the original specification described. The logic was that detection accuracy of an incoming shot will be compromised by a single detection system mounted on one shoulder by the direction a combatant was facing at the time the shot was fired. Indeed, by employing two detectors, the accuracy of shot direction detection was improved. However, a major disadvantage of this first design transgression was the need for wires that transgress the back of a combatant and provide battery power as well as carry shot information to a central processing module located on the combatant's belt.

The end user required a waterproof system as combatants had to often cross rivers and lakes. This resulted in the use of very expensive cable connectors. The second design transgression from the customer's specification was the location of the visual read-out display for the direction, distance and elevation of the incoming shot. Instead, they opted to display this information on a watch type device worn on the combatant's arm near the wrist. This required additional wires to be threaded down the sleeve under the outer wear. The original design specification called for a pendant directly wired to the shoulder unit. In field testing, the technical portion of the system worked very well and out-performed devices by all the competitors. However, the number of wires employed by the design that the user had to wear was very cumbersome.

Time to market was critical as the customer was planning for a major competitive bid proposal within a few months of this testing. The development company decided to fully tool the design for production despite the fact that the customer never viewed or evaluated the design, a decision they made before pricing out the manufacturing cost of the design. In the absence of complete development information and market feedback, the development company proceeded down a costly and irreversible path.

Following design completion, the manufacturing cost exceeded the targeted selling price by two to one. Furthermore, the system was extremely bulky, difficult to wear, uncomfortable and restraining. These negative attributes could have been easily addressed during Phase II of Stage 3 of the development process. Four imposed criteria prevented the successful development of this product: Time to market, myopia regarding the envisioned product as opposed to seeking market or outside input, an inexperienced design team that lacked synergy and a project leader that allowed this to occur.

Although the product performed well with respect to accuracy, the project failed. The end–user customer rejected the design and awarded the contract to a competitor that produced a less accurate product. Subsequently, the product development company submitted the same product to other customers for evaluation but was rejected by all due to its shortcomings as noted above. As a result, the development company could not sell any systems even though they were fully tooled and ready to produce. A significant wasted effort and expense could have been minimized or avoided if the guidelines of the *product development process* had been employed.

4.5 MAN WEARABLE 2 (CASE STUDY 5):

The product development company that developed the sniper detection system described in case study #1 was successful. The same company with a different design and engineering team and approach developed a man wearable sniper detection system (case study #4) that failed to meet the customer's needs. The same development company decided to re-address the product design from case study 4 but with a change in the design approach. This time around, they implemented the customer's design specification instead of their own product ideas. The first unsuccessful man wearable design (case study 4) was completely scrapped and very little of the tooling and documentation was considered in the new design given the completely different configuration.

The new design was to consist of a single, small, lightweight unit that would reside on one shoulder of a combatant shown in Figure 10. This shoulder unit would consist of six microphones arranged in an array. The output of these microphones is electronically processed. This output is connected to a display that hangs down the combatant's chest so that they could read direction, distance and elevation of the source of the incoming shot. In addition, an ear bud would be available for the combatant to hear those incoming shot parameters. The system also employs a Bluetooth transmitter that could communicate with a central command unit and inform on wearer location, as well as the parameters of incoming shots. This feature was not included in the original customer design specification but based on extensive knowledge and experience, the development company knew that this option would be valuable and could be the feature that could secure the company as the selected vendor.

The development company determined that there were no associated technological risks since they had performed similar work on other projects. Thus, between meeting the customer's specification and presenting the product design concept to the customer, the company had fulfilled

Figure 10: Man Wearable 2

all the steps described in Phase I (conceptual stage) of the product concept process. It is inexpensive to showcase the design of a device that is to be injection molded before expending thousands of dollars on the actual plastic injection mold. In Phase II (development stage), the company produced an alpha unit that is very close in design to the final design unit. Once again, time to market was a driving motivation. Since the company produced a number of alpha units, they were able to generate fairly accurate BOMs that resulted in accurate product unit production costs. The company was not concerned with the development cost because with their knowledge of the manufacturing cost and of the market price point, they estimated that the ROI exceeded their requirements.

Since the development company produced an alpha unit that was close to a production prototype, they performed in a sense the steps of Phase III in the product concept process. They accomplished this by employing experience from the original sniper detection system and some knowledge and parts from the first failed man wearable project. The field live fire tests were successful largely due to the company’s experience and knowledge gained from the first sniper detection system. As a result, the company won the competition against their competitors and sold thousands of units Lessons learned are listed below:

- Time to Market is very important but not at the expense of quality and performance. Designing a product based solely on internal intuition and market knowledge is risky, as was explained in case study 4 with the man wearable1 sniper detection system.
- Market input is essential.
- Designing with an experienced team is always beneficial as it can prevent missteps as well as provide knowledge of previous work that can be beneficial to a project.
- Often times, relying on intuition can be helpful. The decision to build in the Bluetooth capability in case study 2 with the target scoring system was game changing because it enabled the company to provide features and options that the competition was unable to. This resulted in more product sales as well as the sales of a number of add-on options.

4.6 SNIPER DETECTION SYSTEM OPTION (CASE STUDY 6):

In using the original sniper detection system (case study 1), the customer incurred loss or damage to all seven microphone assemblies employed. The original sniper detection system was intended for mounting on a Humvee, a vehicle that at the time was heavily used in Iraq. The acoustic detection system employed a mast mounted on the rear of the Humvee. On top of the mast, the unit called a hub was mounted and that had seven microphones, each seven inches long. Located inside of the hub was an analog printed circuit board that processed the microphone output and sent it to a digital printed circuit board that converted the signal to digital form for transmission to the control/display unit mounted on the Humvee windshield.

Humvees with the tall communication whip antennas were placed under tarp shelters in the evening. This required bending the antennas and securing them with a bungee cord in order for them to fit under the shelter. However, after removing the Humvees from the evening shelter and releasing the bungee cords, the antennas would snap erect, often destroying one or more of the microphones. The customer requested that design company configure a solution to correct the problem. Supply chain employees from the design company sought a recommendation from a current vendor who proposed a solution within all but one of the restrictions placed on the design:

1) Assembly should not mount to the mast. The weight of the system added to the weight of the hub and the microphones places a large mass on a thin mast which may result in an unstable swinging structure that may not meet the shock and vibration requirements of the system. (The current vendor did not feel that their simple, light weight solution which mounted on the mast, would cause the mast to fail the shock and vibration tests)
2) Unit must cost less than fifty dollars.
3) Reconfiguration must not interfere with or degrade the performance of the system.
4) The system should be easy to install without the need to disassemble the system from the Humvee.
5) The system must meet the requirements of a desert environment.
6) Cost for tooling must not exceed $50,000.
7) Cost for non-recurring engineering (NRE) must not exceed $50,000.

Although an external vendor devised a rapid solution (2 days), the engineering department of the design company ordered the vendor to cease and desist any further design efforts since they preferred to design a solution in-house. Unfortunately, this decision was made before examining the solution submitted by the vendor and without notifying key personnel of the division responsible for generating the solution. After a significant delay in the presentation of a new solution by the engineering department and following pressure from the design company executives and managers, the engineering department provided a complex arrangement of vertical bars and a cage surrounding the hub/microphone assembly. This resulted in frustration and disappointment and the company did not submit the solution to the customer for the following reasons: The NRE would exceed $100,000; the tooling would be greater than $75,000; the unit cost would be between $100 & $300 dollars per unit and the installation will be time consuming and complex. The disappointment was magnified when the design company executives learned for the first time that an external vendor had indeed provided a solution 2 months prior. With very little time to present a product solution to the customer, the design company viewed for the first time the vendor's solution which was in their possession all along with the supply chain employee.

Figure 11: Sniper Detection System Option

Despite the fact that the vendor design did not find a solution for one of the restraints, i.e. mount the sniper detection unit directly on the mast, they nevertheless provided a simple, elegant and light weight design that would not cause the mast assembly to fail the shock and vibration test (Figure 11). Furthermore, the vendor solution cost less than $25 per unit, the NRE was less than $5000, the solution was simple to install directly to the mast and was suitable for the desert environment, the tooling was less than $25,000, and the solution would not cause degradation of the performance of the sniper detection system. With that, the company presented the vendor's solution to the customer and was given an order and approval to proceed with the design. The solution worked well and the mast assembly did not fail shock and vibration. The product was a success and thousands of units were sold.

CHAPTER 5: PRODUCT TESTING AND RESULTS

Testing strategy described in this chapter are meant for validating product performance for the six case studies at varying stages of the product development process. Many of these tests were performed during Stage 3 on the proof of concept or Alpha units as well as on the final design units.

5.1 SNIPER DETECTION SYSTEM TEST PLAN:

To address whether the product performs as required, a 22 caliber rifle is fired perpendicular at a target located within 3 feet of the system and at range distances of 100, 200, 300, 400, 500 and 1000 ft. Rifle elevation is also tested at 0, 20, 40, and 60 ft. Multiple shots are fired at the target and the system response is recorded. Variations in the data or lack of repeatability from the system output report (display) are monitored and recorded. The cause of any variation must be determined and corrected. Shot angles of 15, 30, 45 and 60 degrees are also introduced and testing is repeated as described above. Switching to a 50 caliber rifle, testing with the varying heights and angles (described above) are repeated, results are recorded and observed inaccuracies are addressed. Additional tests that evaluate the sniper detection system response when the target is 20, 40, 60, 80 and 100 ft. from the system are also conducted as described above. If the system reports consistent results, then the product performs as required. Sources of any inconsistencies must be corrected. In addition to actual shot testing, the system will also be tested under various environmental conditions such as temperature, humidity, shock and vibration.

The sniper detection system test results were exceptional. Every shot was reported with an accuracy within ±5° of location and ±100 feet of distance. The system did not miss reporting any shots that resulted in a shock wave passing by the microphone array. Shots in the air were ignored. Elevation reporting of shots were also accurate to ±5 %.

Testing was conducted both on the "proof of concept" in Phase II of Stage 3 as well as on the final design in Stage 5. The final system ~~of~~ (Stage 5) was ~~subjected~~ exposed to high and low temperatures, 95% humidity and 5 g's of shock. The system did not malfunction and the testing was considered successful. The product was released for manufacturing and thousands of units were sold.

5.2 TARGET SCORING SYSTEM TEST PLAN:

The durability of the target scoring system is tested by raising and lowering the target at least 1000 times. This test evaluates battery capacity and endurance capability of the moving parts and fasteners. The test also evaluates if changes occur in the time needed to raise or lower the target. The accuracy of the scoring response is evaluated by firing at the active area of the target with a 22 caliber rifle. These tests are repeated with a 45 caliber pistol. The target will consist of a grid of 1/2 inch boxes. The system must record the presence of a shot hole within ±1/4 inch. In addition to actual shot testing, the system must be tested under various environmental conditions such as temperature, humidity, shock and vibration. Also, a complete test program must be developed to test the smartphone application that configures the course scenario that the customer is developing.

At this time, the target scoring system alpha unit is undergoing field testing. The product development company has retained an external product design company for the design of a production (beta) unit that reflects the attributes and performance determined from field testing and market survey from Stage 3 (Phase II) testing as shown in Figure 2. The release of the final design will not take place until the alpha unit testing is completed. The current emerging plan is that the development company will purchase 6 alpha units, five of which will be tested by two different customers before the beta (final version) unit is released. Tests performed on the alpha unit will be repeated on the beta unit. The sixth unit will be retained by the design company to use for continuously updating the operational software.

5.3 MEDICAL WASTE DISPOSAL SYSTEM TEST PLAN:

Testing of the medical waste disposal system is planned for various physicians' offices that handled varying compositions of biological waste loads. Feedback is needed for whether the waste disposal system is easy to use, take too much space, could handle the various waste products without producing objectionable smells or by-products. Could a one container system be sufficient for an average office space to cycle numerous loads in a normal workday and process all of the medical waste generated, is not a fire hazard and well insulated to prevent burns, and could be used in an office environment? During the test period, each of the processed containers will be examined by the manufacturer to ascertain that the waste product was heat neutralized and safe for disposal and whether the containers could be re-used right after processing.

Testing of the medical waste disposal system at Stage 5 was short lived because it was soon discovered that the users objected to the use of round paint cans to collect the medical waste including needles (sharps). Placing medical waste into the can when the can was partially full was problematic and the user could easily be pricked by a needle. The original plan was to place beta units in several different medical practices so that a variety of different medical wastes could be tested for their ability to be rendered completely biologically inactive. The plan was well thought out with respect to biological waste neutralization but was terminated nevertheless when objections to the use of gallon cans became clear.

Test site personnel felt that using this disposal system increased the risk of being stuck with the collected needles. The company suspended testing and ultimately shut down the project due to the market's rejection of the collection system. A redesign was considered but ultimately, the company was not unwilling to invest further in the project. This unfortunate turn of events could have been avoided if proper market evaluation had been exercised in Phase I of Stage 3 of the product development process.

5.4 MAN WEARABLE 1 TEST PLAN:

Testing of the man wearable 1 product is conducted almost identically to the sniper detection system as described in section 5.1 with the following exception: for safety purposes, a dummy is used and in each shot test, the dummy is turned 90 degrees to check for significant (more than a few feet) differences at each position. The shot information is recorded.

Test results of the man wearable 1 during Stage 5 were quite impressive because the live firing results met or exceeded the required specifications. However, the extensive amount of wiring that the user had to accommodate was unreasonable. The conclusion from field tests was that even though the system performed well, the product was not practical for combat. The company scrapped the design and started the design process over again described directly below.

5.5 MAN WEARABLE 2 TEST PLAN:

The testing of the man wearable 2 is quite extensive. It duplicates testing of the original sniper detection system, as well as the tests conducted on the man wearable 1. Additional tests are conducted to confirm that the shadowing of the detector microphones by the body of the user as the user turns away from the shot origin does not significantly reduce the accuracy of system performance.

Testing for man wearable 2 was conducted in the same manner as the man wearable 1 and the field firing results during stage 3 were similar. These results surprised the design group given the significant differences in shot reporting due to shadowing of the one shot detector worn by the dummy versus the original two shot detectors. These tests were performed on an alpha unit during

Stage 3 (Phase II). Observations from this case study illustrates the need to perform testing of the concept as early as possible in the product development process.

5.6 SNIPER DETECTION SYSTEM OPTION TEST PLAN:

The shot testing portion of the microphone protection device is a duplicate of the original tests described for the sniper detection system. The testing of the sniper detection system option consists of four parts:

1. Snap the whip antennas and release them in all quadrants to determine if the guard effectively protects the microphones. Drive the vehicle over the roughest terrain to see that the microphones are protected.
2. Repeat all of the field tests of the original Sniper Detection System with the option installed on the mast to ascertain that the performance of the system is not compromised.
3. Repeat all of the shock and vibration tests to determine that the option does not cause problems due to its added weight on the mast.
4. Have a number of different people install the option on the mast to determine if there are difficulties in the installation process or instructions.

Testing is a major requirement in the NPD process. Significant testing is performed in two areas of the NPD process, at the development stage (Stage 3, Phase II) and in fabrication and Testing (Stage 5).

The sniper detection system option passed all of its testing goals:

1. Field testing in an attempt to break a microphone demonstrated that the option protected the microphones from damage.
2. The presence of the option on the mast did not interfere with the shot detection. In fact, there was no discernable differences in the reporting results.

3. The mass of the option did not cause a mast failure during the shock and vibration tests.

The option proved to be easy to assemble by the users. Some of the product testing described above is in progress and preliminary results are recorded and analyzed. Product performance inconsistencies and/or inaccuracies are noted, addressed and corrected. Given that two of the six cases are products in development, it is possible that tests need to be repeated multiple times especially if redesigning a product is required. Ignoring the slightest anomalies could be the precursor to product failure or recall.

CHAPTER 6: SHORTCOMINGS OF PRESENTED CASE STUDIES

A primary goal of the work described in this dissertation is to analyze the outcome of new product development when a rigorous step-by-step *product development process* is not followed. As mentioned above in Chapter 4, most of the presented case studies did not follow the exact proposed *product development process* in its entirety (Figure 6). Therefore, the impact of bypassing critical steps in each case study is analyzed below.

6.1 SNIPER DETECTION SYSTEM:

The impact of bypassing cost analysis: Generally speaking, a "proof-of-concept" design does not provide sufficient information for determining development cost, ROI analysis, performance expectation or product cost estimation (Figure 4). The proof-of-concept method should be employed only if one can render a reasonable copy of the product that can provide the necessary data to perform the four steps of Phase II (Stage 3) outlined in Figure 2 [3, 4]. A risky scenario of bypassing cost analysis is that a perfectly working product can be priced beyond what the market is willing to pay. This product is currently at Stage 5 of development and it is anticipated that results will reveal the impact of bypassing cost analysis for the sniper detection system.

6.2 TARGET SCORING SYSTEM:

The impact of bypassing market analysis: A key stage in the *product concept process* is the conceptual stage (Phase I) of Stage 3 that describes steps needed in the performance of market risk analysis (Figure 2). These steps explore enthusiasm about the product idea, capability to introduce all requested features, profitability, competition with existing similar products, viability, technological risk assessment and effects of regulatory and compliance issues. The target scoring system is still in the prototype stage Stage 3, Phase II of development and it is anticipated that results will reveal the impact of bypassing market evaluation, market risk evaluation and especially the determination of the product cost versus what the market is willing to pay for the target scoring system. There is still time to retrieve market feedback regarding product pricing if the pressure of time-to-market does not displace this important market feedback.

6.3 MEDICAL WASTE DISPOSAL SYSTEM:

The impact of bypassing market evaluation (Stage 3; Phase I): It is unfortunate that this product was entirely developed without seeking market input. Skipping market evaluation at Stage 3 (Phase I) of the *product concept process* resulted in this product to suffer market failure and a large expense to the investors. Developing a proof-of-concept followed by field testing as is the case with the sniper detection system would have generated feedback that enabled product concept modification before proceeding far into the product development process. As it was, the product was designed and tooled before it was introduced to the market. As a result, the product failed and the company collapsed.

6.4 MAN WEARABLE 1:

The impact of bypassing market evaluation (Stage 3; Phase I): The product developed in this project suffered similar market failure as the medical waste disposal system. The design team was confident with the product concept and did not perform the market evaluation step described in Stage 3 (Phase I) and as such they designed a product that was rejected by the market and lost their tooling investment. However, because the company decided to try again to develop a man wearable shot detection system, there was some valuable knowledge that was attained from the previous failure and could be applied to the man wearable 2 project described below.

6.5 MAN WEARABLE 2:

Following all steps of the product design process: This project followed all the steps described in Stage 3 of the *product concept process* (Figure 2). The product then went on to Stage 4 and the final product was retested in Stage 5. The design team had the advantage of product operational knowledge gained from the failed effort of the previous man wearable 1 project. The design team wisely added a GPS and Bluetooth feature that was not in the original specification which provided valuable position information to central command. These additions combined with this project's superior performance, resulted in a successful project.

6.6 SNIPER DETECTION SYSTEM OPTION:

The impact of bypassing collaborative market input Stage 3, Phase I: The product in-house design team performance failed on this project by not generating a viable product concept at Stage 3, Phase I. Thus, the company executive sought external input for a better outcome. Ironically, this valuable external input was available to the internal team leader earlier in the process but was ignored due to the lack of collaborative ideals prevented the pursuit of a logical resource. This case study illustrates the importance of listening to all inputs and to choose the best option without considering the source. All inputs should be considered that promote the well-being of the project and the company.

CHAPTER 7: LESSONS LEARNED

The *product development process* tool proposed in this body of work is not ironclad but a method that facilitates the development of a successful product. It is a guide and a framework of the items that should be considered in the *product development process*. Some lessons learned from the presented case studies may appear to contradict the *product design process*. These contradictions are highlighted and explained below:

7.1 SNIPER DETECTION SYSTEM:

In the case of the sniper detection system, a formal market and cost analysis was not performed before designing a proof-of-concept prototype. However, by building a proof-of-concept prototype for frequent testing in diverse settings and with a variety of different customers, the product designers attained significant market feedback. The company used their "proof-of-concept" system for field testing where they interfaced with the customer to perform their market analysis. Thus, the company learned that the cost of the system was secondary to its performance and proceeded to develop the product with the aid of an outside development firm. This abundant market feedback was continuously forwarded to the design team during the development of the final sniper detection unit up until completion of the final design. In this case, the advantage of skipping a formal market analysis resulted in a more rapid time to market. Nevertheless, the design team established the market requirements during the prototype testing program. Although the company did not follow Phase I steps of Stage 3 in the order presented, they accomplished the intent that resulted in developing a very successful product.

7.2 TARGET SCORING SYSTEM:

The end result for the development of the target scoring system is yet to be determined. The development company did not seek market input save for the opinions and experiences of the company's principals. The direct design of a finished target scoring system product prior to conducting market analysis and receiving market feedback may have negative consequences. Unit cost targets were not generated during the design phase (Stage 3) believing that if the product performs as envisioned, the market will pay the price although the limit for an unacceptable price was not defined. It is a very high risk to undertake a product development without knowing the market price that the product must not exceed or the maximum manufacturing cost that the product must meet. Another potential misstep is the lack of a defined field test plan in Phase II steps of Stage 3 of the product concept process. The company developed an alpha prototype that if properly field tested could serve as an invaluable source of market feedback as was the case in the sniper detection system. These issues should and can be addressed before the product is finalized. Omitting these steps from the *product development process* could result in product failure.

7.3 MEDICAL WASTE DISPOSAL SYSTEM:

The medical waste disposal system is a great example for outcomes of developing a product before seeking market input. The gallon can collector idea sounded great to the development company but was immediately rejected by the market. Unfortunately, the product was completely developed before it was market tested resulting in the demise of the company. Significant funds were spent on tooling to develop the vacuum formed front panel, the stamped aluminum heat chamber, the engineering design of the product housing, the engineering design of the control logic printed circuit board, and the significant number of hours to write the operational software. Over one thousand engineering man-hours were spent for a product that was never presented to the market until after the design was completed. This product failure was catastrophic and the development company lost the enthusiasm for starting the process again with the product concept. Proceeding directly to a finished product design before conducting comprehensive market analysis is an extremely risky product design approach. It proved to be the undoing of the Medical Waste Disposal System. All of the expenditures in the design of the product and in the tooling to produce the product were wasted because the waste collection system was rejected by the market.

7.4 MAN WEARABLE 1:

Failure of the man wearable 1 project is a good example of why the best interest of the company and/or customers' is a priority. Since the development company had previously developed a successful sniper detection system, they erroneously assumed that they knew best what the market desired and ignored the customer's requirements. Furthermore, the development company attempted to design this product with an inexperienced design team. While the product performed well, it was considered over-priced, burdensome to wear and impractical which resulted in product failure. The design team violated almost every step in Phase I and II of Stage 3 of the *product concept process* and paid a heavy price. The company missed their time-to-market and their price point. Furthermore, customers rejected the complexity of using the product and therefore, the product did not sell.

7.5 MAN WEARABLE 2:

The development company (directly above) learned from their errors in the design of man wearable 1 and readdressed the problems using customer input which led to the success of the man wearable 2 project. They were fortunate that some of the circuitry of the man wearable 1 was useable in the man wearable 2 design. The company sought marketing input along with an infusion of their ideas such as the inclusion of GPS and Bluetooth capability. By adhering to the specification requirements of the customer and following most of the Phase I and Phase II steps of the *product concept process* they were able to deliver a product that was widely accepted. The design team elected to bypass the formal steps of Phase III but accomplished the intent by designing the alpha unit almost as if it was a preproduction version of the final product. Although risky, the company had a great deal of experience in designing this type of product and achieved product performance success similar to that of the first sniper detection system. Despite the marketing failure of man wearable 1, the man wearable 1 product performed well and the design team used that knowledge to jump start the development process in the design of the man wearable 2. However, the company did not invest in expensive tooling until they had a workable and accepted unit.

Although customer requirements are important, they must not constrain logical thinking and design experience. The design team of the development company believed that including a GPS in the man wearable 2 design would be a great future benefit even though it was not included in the original customer design specification. This feature was desirable and resulted in a successful product.

7.6 SNIPER DETECTION SYSTEM OPTION:

Risks can be taken if proper calculations and experience guide the decisions and if there is a method for mitigating the risks. In the case of the sniper detection system option, customer specification did not allow for the microphone protection solution to be mounted on the mast. However, the design team developed a light weight solution that met all of the other design criteria. The design team did not believe that the weight of the proposed solution would cause the mast to fail its shock and vibration requirements. Shock and vibration testing proved them right.

The unwritten part of the *product design process* is that it serves as a guide and not a system cast in concrete. All of the proposed steps must be considered but maybe minimized or skipped over if the intent of the step has been accomplished.

CHAPTER 8: CONCLUSIONS

If Stage 3 and Gate 4 in the *product development process* are properly and thoroughly performed, there should be no surprises in Stage 4 with the possible exception of the cost analysis. In performing the mechanical and electronic designs, “feature creep” that works its way into the product can occur. These are additional features that the design team adds to a product that were not in the original design concept. These features must be evaluated for both positive and negative market impact. If these features have a significant impact on the product cost, a comprehensive review must be conducted to determine the value of these added features and decide if the additional costs will jeopardize or enhance the marketability of the product. Testing of a product as best as the product can be simulated during the design process should be conducted throughout the design stages. Constant feedback should be judiciously analyzed and improvements instituted where practical. As some of the six case studies illustrated, all of the steps in the design process do not necessarily have to be performed in the sequence shown in Figure 2 and Figure 3 to have a successful product but at some point in the process the intent of each step must be accomplished.

Stage 4 can be very expensive to accomplish. If external industrial designers are employed, thousands of dollars could be expended just on that one step. The mechanical, electronic and software designs could consume hundreds or thousands of person hours. The tooling expenditure for molds, displays and fabricated items could cost hundreds or thousands of dollars. Before expending exorbitant hours and funds, it is important to carefully evaluate Gate 4 following Stage 3 and Gate 5 following Stage 4 to assure that the project has a high probability of market and financial success. The product can’t be successful if the product costs are out of line with what the market will pay.

The development of a product is an extensive and complicated process where hundreds of decisions are made. The use of a disciplined documented time proven process with feedback loops can significantly reduce the chances of product failure. Market needs, quality performance at an acceptable price with reasonable profit and reasonable return on investment serve as a simple goal for any product development. However, many products do not accomplish those seemingly simple goals. Following a predefined course with many checkpoints and feedback loops will minimize the risk of market failure. The design groups must recognize and record any shortcomings or potential weaknesses or marginal performance in their area of responsibility and address and correct them. Often times this is not easy to accomplish due to time constraints, political pressures, budgetary restrictions and an unwillingness to collaborate. Often times, courage and patience is required to follow a disciplined plan.

The application of this *product development process* is an important discipline that I garnered from my learning experiences in the pursuit of my Ph.D in Technology Management at the University of Bridgeport. The goal of Technology Management is to condense complicated endeavors into easy to understand systematic stages or paths so that the results are positive and predictable. Following this modified stage-gate process will render those results or prevent the expenditure of unnecessary expenses in pursuing a project that will not result in a successful product launch.

Figure 12 is a graphic representation of all of the variables introduced during the *product development process* [3, 4].This representation captures the interaction and inter-dependence of these variables on each interaction as to how they affect product development and cost. All of the variables affect the time frame, which directly affects the product development and cost. Figure 12 captures the rigor and importance of performing all steps in the *product development process.*

The steps within Figure 2, Figure 5 and Figure 6 are directly related to Figure 12 and do not have to be executed serially but they all have to be considered before the project is completed. Some steps can be minimized as long as the consequences are evaluated and understood. However, Figure 12 does not display some attributes that can greatly affect the execution and outcome of a project such as the experience and breadth of the various groups working on the project, the vision combined with open mindedness of the leadership and the participants, and the ability of the group to work together for the benefit of a successful project.

Successful product development processes manifest themselves as a well thought out balance of required/desired features at acceptable costs with a time to market consideration. After completion of Phase III (Stage 3) analysis, there are four choices to consider: proceed with the project, modify the project, postpone the project or abandon the project. If the project receives the green light to proceed to the final design process, it is important to note that many factors will have an impact on its outcome and ultimately affect product cost. There are four clusters of variables that affect product development cost and end product cost. Cluster #1 is the design specification which derives from market requirements, the type of library functionality required (storage and replay of programs), operational software performance, and types of options and add-ons. Design specification is directly affected by variables in Cluster #2 and Cluster #3. Cluster #2 consists of quality requirements that include environmental performance consistency, test results feedback, and various agency requirements. Cluster #3 consists of design team inputs that include engineering, marketing and sales, outside consultants, industry associates, and customers. Cluster #4, the time frame, is affected by the variables from all four clusters. Understanding these relationships allows for control of time-to-market, product cost, product quality, and ultimately market acceptance of the product. Each variable in Figure 12 has an impact on the others thus making each of them an independent as well as a dependent variable but they all affect the product development and manufacturing cost. If the decision is to abandon the project, it is important to perform an evaluation of reasons for discontinuance and to document and archive lessons learned. If the decision is to postpone the project, in addition to documentation of postponement reasons, it is important to consider consequences of delaying the time to market. If the decision is to modify the project, it is important to evaluate and understand why the project proceeded so far before that conclusion was reached.

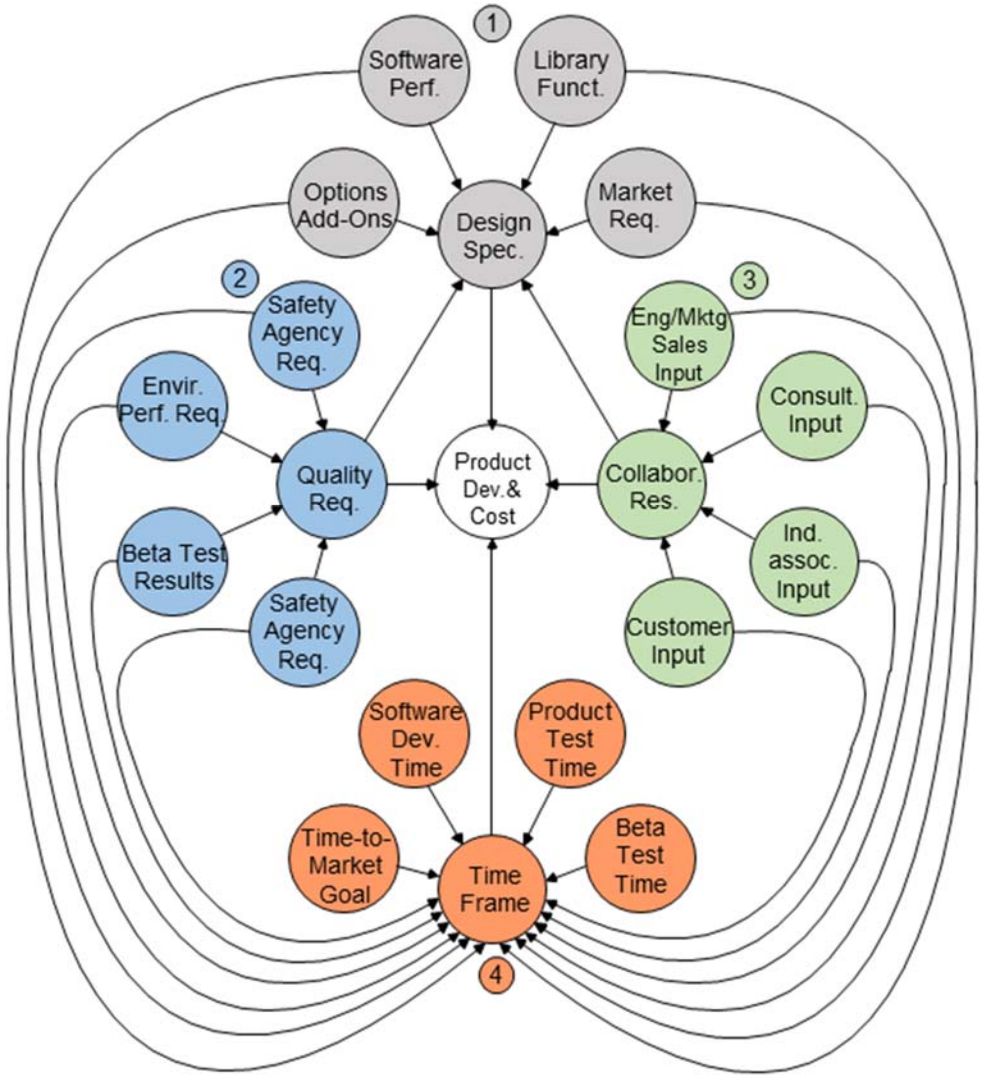

Figure 12: Interdependence of the five primary product design clusters.

Success in the NPD process can be construed as any of the above conclusions. Obviously, the goal is to manage the development process to result in a successful product launch.

Discontinuing a project that has a high potential for failure can be viewed as a success because it could prevent the spending of large sums of money, save an enterprise's reputation or redirect resources to a more productive endeavor. Terminating a project during any step of the product development process can be viewed as Dr. Sarkis' "well-intended failure" [55].

CHAPTER 9: QUALITY STATEMENT

The proposed stage-gate system does not include a quality stage or gate for the simple reason that each gate, stage, phase or path must contain its own inherent quality metric. Whether or not the teams comprising the individual stages or gate checks contain dedicated quality personnel, the team at each work center must place emphasis on the quality of work output and product result. At each step in the process, the following questions must be asked: “have we covered all of the issues?”, “are we overlooking something?”, “is there more that we should do?”

In the proffered schematic of the Stage 3 and Stage 4 processes, there are feedback loops at each and every action center. These feedback loops emphasize the need for constant evaluation of work output at each center and allows for upgrades and improvements. A major feedback loop is from the “Testing” step because it shuttles product development to the beginning of the *product design process.* However, if the quality of previous steps were judiciously monitored, feedback from the testing center should be minimal. Recognizing and correcting design issues at the early stages or even at a late stage is much simpler, less expensive and better for corporate reputation than discovering shortcomings in the product after it is released to the market.

CHAPTER 10: FUTURE RESEARCH

Significant benefit can be gained if each stage in the New Product Development (NPD) process as proffered by Cooper and others was formulated into an integrated, interactive step by step schematic format as the work described in this manuscript has done for Stage 3 , Stage 4 and Stage 5. It is easier to follow a disciplined roadmap for a product development that begins as an exploratory idea, developed into a business case at which point the *product concept process* as defined in Stage 3 begins. Stage 4 and Stage 5 complete the product design and test process. A roadmap for product launch could be developed that feeds back to the original product scoping and business case development. Stage 1, Stage 2 and Stage 6 (product launch) are interrelated but separated by the product concept process, actual product design and the product testing. The entire New Product Development process should be a continuous flow with feedback loops interconnecting all of the Gates and Stages that result in a product with a high potential for success.

The entire NPD process could be arranged in a software program that consisted of modules for each Stage and Gate. Each module would have branches and paths which start at one or more general concepts such as Stage 3 Phase I, Stage 3 Phase II & Stage 3 Phase III. These general concepts would proceed serially to each step in its respective Phase. At each step there would be questionnaires that lead down various paths or branches until the step was completed or a feedback path is selected. Upon completion of the step, the program would proceed to the next step until the Phase was completed. Then the next Phase (module) would be started.

Each Gate would consist of questions concerning the previous Stage. This process would continue until all of the Gates and Stages were evaluated. This software program would consist of different Chapters for analyzing different kinds of products. A mechanical product would have different modules than an electronic product.

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