Process Reengineering for the Product Development Process at an Analytical Instrument Manufacturer

by

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Abstract

In an analytical instrument manufacturing company, the new product development process was analyzed with the objective of reducing time to market, to full scale production of new products and to improve project management and communication in the organization. Several problem areas were identified in the study and the thesis focuses mainly on the systems level changes that the organization would have to make in order to address the identified issues. The problem areas in the organization were the lack of categorization of development efforts, lack of a clear project plan to guide the development effort, functional integration issues and the lack of activities for process evolution. In order to address the lack of categorization of development efforts, a categorization strategy based on the product being developed and the associated deviations in the development process for each of the categories are discussed. To tackle the issue of no project plan, an up-front project planning process which should precede the development effort is laid out for the organization along with templates of the tools that could be used as aids in the process. Finally, to address the functional integration challenge, a dedicated development team that would be responsible for the project over the entire project timeline is recommended which would also help in achieving better communication across different functional units working on the same project. It is expected that the up-front work of project planning and development effort categorization would help in reducing the time to market and full scale production by having a more structured and specific development process for the new product and also by appropriately utilizing the existing knowledge in the organization. The other changes are expected to primarily advance the project management and communication challenges faced by the organization.

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Chapter 1

1. Introduction

The thesis explores the existing product development process followed at an Analytical Instrument Manufacturer. The major activities and stages involved in the process are studied in detail and compared to academic literature to help improve the process while focusing on the reduction of time to market of a new product.

1.1 Motivation

Waters Corporation is an Analytical Instrument Manufacturer, headquartered in Milford Massachusetts and is a leader in complementary analytical technologies — liquid chromatography, mass spectrometry, rheometry. The organization designs, manufactures, sells and services high and ultra-performance liquid chromatography instruments, chromatography columns and chemistry products, mass spectrometry systems, thermal analysis and rheometry. The headquarters of the organization focuses exclusively on liquid chromatography products, a segment in which the organization is widely regarded as one of the market leaders.

Independent company analysis indicate that the strength of the organization is their broad and diversified customer base which include the pharmaceutical, environmental, food testing and chemical sectors. Another strength indicated in the analysis is the company’s robust sales and service network which has a footprint in 54 countries. Besides these, the strong research and
development capabilities of the organization are considered to be their strength in the liquid chromatography market.

Nearly 60% of the organization’s revenue is generated from Instruments & Software and the senior management at the organization has identified an opportunity for the company to drive its sales through new product launch. And to drive the new product launches there is significant strain on the existing new product introduction process at the organization.

The current development process followed at the organization is being thought of as, inefficient with respect to resource utilization, time to market and time to full-scale production. The organization is experiencing long ‘time to market’ for new products from the point in time that their feasibility has been verified. In addition there are concerns about conforming to national and international standards required of medical instrument manufacturers.

1.2 Process Overview

The major stages in the current new product introduction process can be seen in Figure 1. At each of these stages there are several activities that are performed by the various stakeholders involved in order for the new product to move through the stages. Broadly, the conceptual model stage is essentially where the feasibility studies need to be conducted for the new product. At the alpha stage generally a ‘works-like’ and a ‘looks-like’ prototype can be expected. By the beta stage, generally a refined ‘works and looks like’ prototype is expected. At the pre-production stage, the idea is to start sourcing the parts/components and prepare to ramp up the production of the product in order to officially start shipping to customers and to enter the production stage where sustainability studies on the product should start. A more detailed explanation of each of
these stages and the various activities required to be undertaken at each stage are discussed in detail in Chapter 3.

![Conceptual Model Diagram]

**Conceptual Model**

- Alpha Stage
- Beta Stage
- Pre Production
- Production

*Figure 1: Stages of the new product introduction process*

1.3 Objective

The main objective of the project was to improve the existing product development process at the organization. The key areas where the improvement was expected to impact were

- Reducing the time to market for the new product
- Reducing the time to full scale production
• Addressing the project management and communication challenges in the development process

1.4 Preliminary Exploration and Scope

Through preliminary investigation which primarily involved interviewing various employees at the organization, the scope of the project was modified based on the shortcomings discovered. From this initial investigation of the process, major shortcomings were discovered in the supply chain wing of the new product introduction division. In addition it was identified that the overall process being followed to develop new products too had shortcomings, addressing which could lead to a shorter time to market. Thus three key areas of focus were determined to investigate further so as to achieve the desired objectives of reducing the time to product release, reduced time to full scale production and achieving better communication in the development process. These three areas were

• The supply chain process which focuses primarily on the procurement process
• The internal processes post procurement of the material, at Waters
• The new product development process as a system for new product introduction

With regards to the product development process, the organization’s product development plan is extremely broad as it attempts to create broad and generic guidelines that can be applicable to any product being developed which could range from chemistry, software, instruments to servicing equipment. However, the emphasis of this work is primarily on the instrument development process since that is the area in which most of the problems/concerns were found to be occurring at the company. Thus, although the recommendation and changes
suggested here on refer to product, most of the study is centered around instrument development at the organization rather than chemistry, software or servicing equipment being developed by the company.

1.5 Problem Statement

As mentioned earlier there are several key stakeholders involved in each of the phases of the new product introduction process which includes the designers and engineers of the research and development team, the supply chain team, the manufacturing team, the inspection team as well as the quality management team. However, at each stage/phase the involvement of each of these stakeholders is to a different extent, e.g. at the alpha stage the engineers and designers of Research and Development are much more actively involved than at the Pre-Production stage.

This varying extent of association with the project creates several issues due to inadequate documentation and information transfer from one stage to another. In addition, there is significant interaction between the processes of various stakeholders which is not accounted for in the current product development process, e.g. the quality inspection plan produced has great implications for the inspection team although they both have different stakeholders with regards to the creators of the document and the end-user. Thus, the emphasis of the thesis will be on developing processes and structures that focus on ensuring effective and streamlined interactions between various processes and information transfer at each stage of the process.
1.6 Task Division

As mentioned above the project is broadly divided into three main areas: the supply chain procurement process, the internal processes at the organization post procurement of the material and the new product development process; each team member was responsible for one of these three areas. The supply chain process was looked at in complete detail by He Yan [1] who focused on the supplier selection process. The processes followed by the organization, post procurement of a material, were explored and analyzed in detail by Aditya Ranjan [2]. The author focused on the new product development process, addressing the shortcomings within the existing process. Although the three areas may seem independent at first glance, there was however, substantial interaction between each of the three areas and the authors worked closely to emphasize and address the relevance of these interactions.
Chapter 2

2. Understanding the existing process and the problems

Following the preliminary interviews, the team approached the issues with a process reengineering perspective to solve the problems. To this end the team utilized several different approached to understanding the existing process rather than simply relying on documentation. In the process of understanding the development process, several of the gaps were identified and supporting data was collected. Following this solutions to address these problems/issues were proposed and are discussed in later chapters. This chapter discusses the first part of the methodology followed in this study, where the existing process is understood and the underlying gaps are highlighted.

2.1 Learning the existing process

In order to understand the existing product development process at the organization, information was collected primarily through four main approaches that are indicated in Figure 2.
Each of the four approaches to gather information regarding the current development process is essential and they combine together to create a holistic view of the current 'as-is' and 'as-expected' product development process. The documentation of the existing product development process served as the basic guideline of the expectations of the current process from varying stakeholders at different stages of the product development process. Through the interviews and by following some of the processes in the development process like drawing reviews, valuable insight into how the employees/stakeholders had modified the existing guidelines laid out in the
documentation were gained. The data collection was aimed at, firstly, getting a broad idea of where in the development process most of the problems originate and secondly, to get specific examples of some of the recurring issues that occurred either due to a shortcoming in the process or due to the modifications in the process followed by the people involved/employees.

This procedure of understanding the existing process through these various approaches albeit time consuming, was essential for this project as it helped in clearly highlighting the problems with the existing development process. Besides, the insights gained into how the people/employees at the organization were implementing generic as well as specific guidelines helped in creating improved process plans that not only addressed the existing issues with the development process but also could be easily and readily adopted by the employees. To this end, the data collection process defined earlier was extremely useful as it helped support the argument of whether there is a need for a change in the process or how it had been traditionally executed. In fact, this data collection was fundamental to resolving one of the biggest challenges in implementation of the process, i.e. convincing the employees at the organization of a need for change. Thus, the importance of this approach of understanding the existing process was critical to the success of the project.

2.1.1 Interviews

Several interviews were conducted with various stakeholders ranging from the project managers at research and development to the buyers that procured the material, to the people at incoming inspection who inspected the incoming material and the supplier quality engineer. A good mix of the major stakeholders involved over almost all the stages of the product development process were interviewed to get an idea of the various activities that they are involved with and to get an idea of their perspective of the product development process and how
they used it. In order to bring objectivity into the interviews, a list of questions were prepared for
the interviews and every interviewee was asked to answer this same set of questions. The
standard questionnaire used for this purpose can be found in Appendix A-1, ‘Standardized
Questionnaire for Interview’.

2.1.2 Following the process

The team also attempted to participate in some of the processes that were repeatedly
mentioned, during the interview process, as not delivering the adequate results and or
deliverables. One such process that the team participated in was the drawing review session for
one of the new products being developed. This helped the team to understand how the employees
executed a formal process defined and required by the current instrument development process.

2.2 Documented Process

The existing product development process, as followed at the organization, broadly has the
major stages shown in Figure 1 earlier. However, the exact development process followed at the
organization is a phase-gate review model and there are expected to be six phases and five gates
that every new product/project must go through as explained in the documentation at the
company. The new product development process is many times referred to as the ‘new product
pipeline’ to convey the idea of the organization having a continuous supply/stream of new
products coming through at any given time. This ‘new product pipeline’ is essentially the project
portfolio of the organization discussed in Chapter 4. The phase-gate process followed at the
organization is shown in Figure 3, and a brief description of each of these phases as per the
documentation and plans laid out by the organization follows.
2.2.1 Feasibility Phase

At the feasibility stage, the company is attempting to achieve a proof-of-concept and is trying to establish the viability of the project. In addition to this, the general direction of the project is decided through ‘Project Scoping’ meetings, which serve as the basis for the preparation of the preliminary requirements and functional specification documents as well as the project risk and plan documents. Although it is not a requirement, physical builds of the product are encouraged at this stage to display the feasibility of the design. All of these documents and mock-ups are expected to make a valid case for the project and to strengthen the business plan in order to obtain project funding.
At the end of the stage, there is a stage-gate review called ‘Feasibility Phase Review’ where all of the above mentioned documents as well as some additional ones are reviewed and a decision on the project funding is made.

2.2.2 Specification and Planning Phase

At the specification and planning stage, the aim is to provide the detailed specifications and plans for future product development activities. Two of the major documents prepared at this stage are the Systems Configuration document, which details how the instrument would interface with one another, and the Product Architectural documents which define the configuration of the applications under development. An important activity at this stage is the assessment of any Intellectual Property (IP) involved in the project with regards to innovation and/or infringement. In addition to this, an estimate of the number of units of the product to be built at the beta stage is decided upon at this stage.

At the end of this stage, the Specification & Planning Phase Review occurs where all of the existing documents including project scope, business plan, project plan, project risks and the operational plans and scheduling of the project are reviewed. At this point the plans are approved and resources are allocated to the project to move forward.

2.2.3 Design and Engineering Phase

The aim at the design and engineering phase of product development, is to create the first detailed designs of the product. The most important activity at this stage is the construction of an engineering model, which need not have the final form factor; however it must perform the critical functions required off the final product. Other activities that are initiated during this stage
include preliminary design verification which is expected to be completed in this stage, hardware and software design reviews, hazards and failure modes and effects analysis (FMEA) and the use-case documentation.

At the end of this stage, the Design and Engineering Phase Review takes place where the emphasis is laid on the results of the preliminary design verification and prior documents are iterated over for consistency. In addition, decisions regarding further resource staffing, testing, procurement, etc. allocation and progress are to be made at this review. Following these activities the product is moved to the Alpha stage.

2.2.4 Alpha Phase

At the alpha phase the intent is to produce first complete units capable of meeting the core performance criteria laid out in the Market Requirements and Functional Specifications documents created in the earlier phases. To this end, the Design organization evolves the hardware, electronic, and software product designs to a point where a functioning unit, referred to as the Alpha 1.0 Release, has been created. This alpha 1.0 is then tested for several Test Cases to verify that the core performance requirements laid out in the Market Requirements and the Functional Specification documents are met by this prototype. This testing helps determine the project's state of readiness for subsequent transition into the Beta phase. In addition to this, if the design team feels confident in the stability of the design and feels that the design has reached an acceptable level, the material procurement process for meeting the Beta build requirements can be initiated. The purpose of initiating the procurement process before the material has actually transitioned to Beta build is to meet long lead times of some of the items being purchased.
Individual piece parts and assemblies that make up the product may transition into the Beta phase ahead of the full product.

At the end of this phase, the Alpha Phase Review takes place and several of the documents created earlier are revisited and reviewed according to the Test Summary Report created in this stage from the test cases. Accordingly, the Project Plan is updated and future resource allocation and timeline are updated.

2.2.5 Beta Phase

The aim of the Beta Phase is to deliver Beta unit prototypes that indicate the completion of design activity of the Design organizations Mechanical, Electrical and Software and that the product meets the required/desired specifications. In the preliminary stages of the Beta phase, design changes are intended to focus on stabilizing the product’s configuration to previously-defined specification and not new discovery. During this phase all mechanical, electronic and software configuration documentations are released to the entire Waters organization. An important activity that takes place at this stage is a meeting that is headed by the project manager where a consensus regarding the final readiness is reached upon by the various design organizations through discussions on full evaluation readiness. Actions to mitigate existing uncertainties are documented and assigned to the appropriate/concerned organization/people. Following this the Full Evaluation of the prototype can begin.

At the end of the Beta Phase, the Beta Phase Review takes place where all outstanding prior phase deliverables are reviewed and any existing unaddressed uncertainties are reviewed as well. Product hazards are the major concern at this review besides the functionality and product costs. Following the successful completion of this review the product is moved to the next phase.
2.2.6 Pre-Production Phase

During the Pre-Production phase, the focus is on stabilizing the manufacturing process. The mainstream production personnel are trained, field support infrastructure is confirmed and the product hazard summary report is completed as well. Besides this, the pre-production units are used for various validation tests and for reliability testing. Decisions regarding addressing the issues encountered or any deviations in the process of production to mitigate defects and/or uncertainties found during pre-production are made before an approval for initial shipment can be achieved. Following the initial shipment, the new product introduction team transfers the product into the sustained manufacturing environment, at which point the product is considered to have gone through the entire new product development plan, called the ‘Corporate Instrument Development Process’ at Waters.

The major responsibilities and activities that need to occur at each of the phases shown in Figure 3 by the various stakeholders that Water’s expects to be involved in most instrument development efforts can be seen in Table 1.
Table 1: Typical tasks and responsibilities of key stakeholders during each phase

<table>
<thead>
<tr>
<th>Concept</th>
<th>Feasibility</th>
<th>Definition</th>
<th>Development</th>
<th>Product Verification</th>
<th>Design Validation and Validation</th>
<th>Post Release</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product Management</td>
<td>Screening Tool</td>
<td>Marketing Phase Data Report</td>
<td>Preliminary Hazard Analysis</td>
<td>Design Verification Test Plan</td>
<td>Design History File Index</td>
<td>Post Release Notes (Product) I-1 and II-1</td>
</tr>
<tr>
<td>Reliability Engineering</td>
<td>Reliability Engineering Plan</td>
<td>Reliability Test Reports</td>
<td>Reliability Test Reports</td>
<td>Reliability Test Reports</td>
<td>Reliability Test Reports</td>
<td>Post Release Notes (Process) II-1 and III-1</td>
</tr>
<tr>
<td>Finance</td>
<td>Request for Proposals</td>
<td>Financial Model Update</td>
<td>Request for Proposals</td>
<td>Financial Model Update</td>
<td>Request for Proposals</td>
<td>Post Release Notes (Process) II-1 and III-1</td>
</tr>
</tbody>
</table>
2.3 Data Collection

An important discovery from the interviews conducted and from the processes followed was that the existing process did not have any localized checks that would ensure that a new product going through a particular phase had conformed to all the requirements of that phase right up until it reaches the phase-gate associated with that phase. The reason for these problems not showing up until the phase-gate is that activities in a phase actively get micro-managed with only the phase-gate in mind which leads to a narrow field of view of the development process and starts to create problems downstream. This problem is also indicative of the lack of understanding and clarity regarding the interactions that must exist between the various design departments across phases for a successful product development effort, i.e. there was a lack of synergistic efforts by the various design organizations. This essentially hinted that problems would be more clearly visible at the downstream end of the product development process than at other locations i.e. at other upstream processes/activities.

With regards to the product development process, the most downstream process can be considered to be incoming inspection where the parts/items received from the vendor are verified for correctness. Thus at the inspection process, issues are clearly visible because items get rejected when they fail to pass the inspection and it is at this point in the development process that flags in the system, are raised. Following this rejection a root cause analysis is conducted at Waters to determine the cause of the rejection at incoming inspection which leads to the issues being brought to the attention of the concerned person/department. Besides incoming inspection, the other downstream processes where these faults are identifiable as well, includes the product assembly and the testing phases. At either of these two stages as well, problems that started earlier on in the development process are clearly visible. An example of this issue is presented in
Figure 4 where the case of tolerance issues in a component/part drawing is highlighted; through design iterations. The concept of the part/component gets transformed into a drawing that is sent to a vendor for production. The vendor has the ability to communicate with the designers and iterate on the existing design. Very often these iterations are not captured on the existing drawings stored in the database and the only time when this discrepancy is identified is when the part/component arrives for incoming inspection process and when it gets rejected or if the part doesn’t assemble appropriately or in the worst case it fails in the field during operation. Most of the time incoming inspection is the location where several such issues get highlighted. The high frequency with which such issues are identified at incoming inspection is the cause of significant backlog at incoming inspection and misleads several people at the organization to believe that the incoming inspection is the bottle-neck in the overall process.

Figure 4: Problem visibility in the development process
Thus, for finding the problems and for obtaining specific examples of a particular issue the incoming inspection data was analyzed and then by backtracking through the development process for each of the issues, the root cause of the issues was uncovered. This method although time consuming was the only possible way that problem in the process could be identified at Waters as there is little to no data for all other activities in the new product development process, at Waters, besides incoming inspection. In addition, this analysis also allowed the team to quantify the issues that were being caused because of the relevant processes in the new product development process. The focus of the project was modified accordingly so as to lay emphasis on reengineering the processes that were resulting in the maximum number of issues downstream.

2.4 Problems

Based on the understanding of the development process, the major problems identified at a systems level with the development process are listed below. Each of the following chapter deals with one of these existing issues and compares them to industry practices and/or solutions proposed by academic literature. The major problems with the existing product development process that are looked at in greater detail include

- The existing new product development plan is too generic and does not provide guidelines for approaching/handling different types of development efforts.
- There is a lack of product planning at the company that makes the allocation of resources to particular projects purely subjective and often injudicious.
- The existing development plan lacks processes to ensure that the new product developed is designed for manufacturability.
• The development plans also lacks guidelines for project management and for team organization for new product development. In addition, organizational environment that must be safeguarded and nurtured in order to have effective product development are not highlighted.

Each of these issues were discovered through the four approaches, explained at the beginning of this chapter, followed in order to understand the existing process and the following chapters explore the above mentioned issues in greater detail and propose solutions.
Chapter 3

3. Process Comparison

As explained in Chapter 2 earlier, the company follows a phase-gate development process that is laid out in their documentation of the 'Corporate Instrument Development Plan'. Here, the generic product development process is explained in greater detail first and then compared with the instrument development process laid out by Waters.

3.1 Generic Product Development Process

The generic product development process typically consists of six phases as shown in Figure 5. Essentially, the project begins with a planning phase that creates a broad outline of the project scope which in turn helps guide future research and development efforts that eventually culminate with the launch of the product. In addition, like Table 1 the major responsibilities and activities that need to occur at each of the six phases shown in Figure 5 by the marketing, design and manufacturing departments can be summarized in the form of a table. Other functional departments like finance, sales, services, etc. are only involved in certain discrete phases of the development process, however they are generally not needed at all phases of the development process. The six phases of the generic development process are discussed briefly below.

![Figure 5: Generic Product Development Process [3]](image)
3.1.1 Planning

The planning activity takes place during the project planning stage, discussed further in Chapter 4, which is expected to take place before the actual product development process is initiated. The planning phase generally starts off with the identified opportunity that will be pursued further by the organization, which are decided based on several criteria discussed in the next chapter. The objective of the planning phase is to develop a mission statement for the identified opportunity that would help guide the future development activities as the mission statement specifies the value proposition, the target market, business goal, etc. which are explained in Chapter 4 along with a template for the mission statement. In addition to this, the kind of development process suitable for such a project/product must be decided on and a process flow diagram for the development process must be created.

3.1.2 Concept development

Using the mission statement developed in the planning phase earlier, several possible product concepts are generated and evaluated by the development team. The most promising concepts are pursued further by the team and further resources are spent on their development and testing. A concept at this stage is generally a description of the form, function and features of the new product. It is also a good practice to have a set of specifications, an analysis of competitive products, and an economic justification of the project at this stage with respect to the concepts being considered.

3.1.3 System-level design

The system-level design phase of the development process focuses on the definition of the products architecture and the product's decomposition into sub-systems and components. Preliminary designs for the key component must also be created here. Additionally, plans for the
production system and final assembly need to be defined during this phase as well. The output of this phase generally includes the functional specifications of each of the product’s subsystems/modules, geometric layout of the product and a preliminary process flow diagram for the final assembly process.

3.1.4 Detail design

The detail design phase of the development effort is where all of the components of the products and/or subsystems are designed i.e. the complete specification of the material, geometry and tolerances of all of the unique parts in the product. Components that are to be reused from existing products as well as standard parts that need to be procured from suppliers are identified. Also, process plans should be established and tooling should be designed for parts that require these details. The output of this phase is the control documentation for the product—the drawings or computer files that completely describe each part including the geometry, the production tooling, the specifications of the purchased parts, and the process plans for the fabrication and assembly of the products. Three critical issues, material selection, production cost and robust performance should be addressed and specified during this phase.

3.1.5 Testing and refinement

The testing and refinement phase comprises of the construction and evaluation of multiple pre-production versions of the product. Generally there are two kinds of prototypes built by organizations, the alpha and beta prototypes. The alpha prototypes are built with production-intent parts, these are parts that are essentially the designed parts from the previous phase except that they are/need not be fabricated with the actual process required/specified for the production parts. Whereas, the beta prototypes are built by the parts supplied by the intended production process but they need not be assembled as per the final assembly process indicated in the detailed
design phase. These two prototypes are generally tested with different goals in mind. Alpha prototypes are tested to determine whether the product will work as designed and whether the product satisfies the key customer needs. Whereas, beta prototypes are more extensively evaluated internally and are also typically tested by customers in their end-user environment. The goal for the beta prototypes is usually to answer questions about performance and reliability in order to identify necessary engineering changes for the final product.

3.1.6 Production ramp-up

During the production ramp-up phase, the product is to be made using the intended production system. This phase essentially aims at achieving a sustainable manufacturing operation for the product. To this end the ramp-up phase focuses on training the workforce and to resolve any remaining problems in the production processes. Products produced during this phase are generally offered to preferred customers for careful evaluation and to help in the identification of any lingering flaws in the product. There is a gradual transition from production ramp-up to ongoing production and at some point in this transition the product is launched in the market. [3]

A post-launch project review that includes an assessment of the project from both commercial and technical perspectives generally takes place shortly after the launch. The review is intended to identify ways of improving the development process for future projects. This is discussed in greater detail in Chapter 6.

Comparing this generic development process with the instrument development plan as documented by Waters, a few phases and activities vary whereas for the most part the two development processes appear fairly similar. One of the major differences is that product
development effort at Waters specifically includes the ‘project scoping’ within the development effort rather than having a distinct project planning process, prior to the product development process, earlier to clearly lay down the requirements of the development effort. This creates a lack of clarity about the development effort in the various design/development teams working on the project. This problem is further compounded by the fact that the people involved in the project scoping process are not involved in the later development processes and important knowledge/intent about the development process is lost. The need of a project planning process and a dedicated team to be accountable for a project is evident and guidelines for these are discussed in Chapter 4 and Chapter 6, respectively.

Another major shortcoming of the existing process is that the Design and Engineering Phase of the development process is essentially the Detail design process of the generic development process, however Waters development process does not explicitly mention that the components need to be designed in complete detail in that stage and that the focus at that stage should be solely on the design of the components of the product. Similarly, the Alpha stage does not explicitly suggest that it is essentially an integration phase, component development should not be the focus of the organization at this point and instead it should focus on integrating the components and resolving any integration challenges, which is not the case at Waters.

Also, the development process at Waters lacks a phase dedicated to testing and refinement; instead the organization’s development process has a Beta phase which essentially suggests further design work. It is generally expected at that stage that the design of the product would be fixed/stable as beta units would have been assembled and the focus must be on ensuring that the product can satisfy all the test cases laid out earlier during the systems design phase. The lack of a formal ‘design-freeze’ causes a lot of chaos in the development process as the design team
continues to modify and update designs when the beta units are to be manufactured. The organization must ensure that a formal ‘design-freeze’ take place at a suitable time, generally around the alpha phase, in order to address this design discipline issue. Also a review activity at the end of the development process should be institutionalized in order to evolve the development process, the guidelines of which are discussed in Chapter 6.

3.2 Adapting the Development Process

The process laid down by the organization does not provide any guidelines or examples of how development efforts should/could be different and what kind of effects they would have on the generic development process. The existing instrument development process simply states, ‘that some defined deliverables may not be required for every instrument development effort’. This statement causes a lack of clarity and specificity among the concerned development people regarding modifying the current development process to suit a particular development effort. The generic product development process explained in the previous section is essentially for a market-pull development effort where the product being developed is aimed towards an existing market opportunity. In addition to the market-pull process explained earlier, there are several other variations of the development process that are defined in existing literature. [3] These include processes for technology-push products, platform products, process-intensive products, customized products, high-risk products, quick build products and complex systems. The organization finds itself lacking in this regard as it does not categorize its development efforts at all, neither does it categorize its final products. Thus, the company is unable to clearly indicate/highlight the differences in the development efforts, required for a particular product type. Hence for the organization to start differentiating its development efforts, they must first
differentiate their products being developed into categories and then lay out a development process accordingly. Some of the possible categories, as mentioned above with a focus on the difference in the resulting development process, are explained below. A brief summary of the prescribed categories along with the resulting deviation in the development process is shown in Table 2.

- Technology-Push Products: These are development efforts where essentially a new technology created by the organization ‘pushes’ the development. In this scenario basically a technology is chosen before the development process starts and then an appropriate market for the technology is found e.g. finding unique applications for material, processes, software. The development effort then attempts to address this market by developing a product that embodies this new technology that is pushing the process. In the project planning associated with such a development effort the mission statement, discussed in Section 4.2.5, should highlight the technology that needs to be ‘pushed’ to the market and the associated market that is being addressed with that technology. This consideration of finding the appropriate market should continue into the planning phase of the generic product development process as shown in Figure 5 and the remainder of the process after the planning phase can be followed while laying emphasis during the concept development and system level design on assessing and ensuring that there truly is a competitive advantage from using the specific technology in the product.

- Platform Products: These are products built for existing technological subsystems/platform, e.g. the operating system for mobile devices, the disposable razor blade for shaving instruments, etc. The idea is to create a product for an existing
platform that has already proven itself in the market with regards to meeting customer needs and during development had consumed significant resources of the Company. The process for this kind of a product is very similar to that for a technology-push product, where the only difference is that emphasis is now laid on developing a product for a proven platform/subsystem. Thus, throughout the development process the emphasis should be on compatibility and integration/interaction with the existing platform.

- Process-Intensive Products: These are products, whose design is heavily constrained by the production process required. For such products, the production process is designed much earlier during the concept development stage along with the product itself rather than in the later stages of product development. Thus, the production process must be well defined before entering the detailed design phase of the development process. In fact ideally, during the concept generation phase the production process must be considered/developed simultaneously. Alternatively, the development effort could be structured so as to create a product that can conform to a specific production process, which could have been decided during the project planning process and subsequently laid out in the mission statement. These products are generally “produced in high quantity and bulk as opposed to discrete goods” [3]; examples include chemicals, paper, and cereals.

- Customized Products: These are products that are slightly different from a generic configuration and are generally created due to a specific demand/request from the customer. For such products, a very detailed development process must exist with all the specific activities/processes laid out in a clear sequence. For such products, the
generic development process is enhanced by adding highly detailed description of the activities required in each of the phases of development, [3] examples include switches, motors and containers.

- High-Risk Products: These are products that have high uncertainty regarding any one of the risk categories associated with product development, which are technical risk, market risk, schedule risk and financial risk. The development effort for such projects is designed in a manner so as to address the biggest/greatest risk earliest in the process. To this end the design reviews should regularly assess the risk levels and ensure that the risk levels decrease over the progress of the project and are not simply being postponed to be addressed later. Thus, the development process could be organized so that at each phase, important/significant risks associated with the project are addressed. This kind of a project need not be like the generic development process at all, in-fact the risks associated with the project could be categorized and each of the phases of the development process could be dedicated to mitigating or minimizing each of the several risks associated with the project/product.

- Quick-Build Products: These are products, generally electronic or software, that need to be built and tested very quickly such that the design-build-test cycle can be iterated over several times within the development time frame. By making use of the quick cycle time through the design-build-test iterations the development process as a whole can be made a lot more flexible and responsive to fulfill the evolving market conditions in this field. The idea being that with increasing number of iterations of this design-build-test cycle, the development team would continuously reduce the cycle time for each iteration due to the inherent learnings learnt from the previous
iteration(s). Thus, eventually the iterations would happen a lot faster and the design would essentially ‘spiral down’ to the final one and hence this process is referred to as the ‘spiral product development process’. In such a development effort, typically the product is decomposed into high, medium and low priority features and beginning with the high priority items the design-build-test cycles are initiated. [3]

- Complex Systems: These are products that have a lot of interacting subsystems and components. Hence systems level integration is the biggest challenge in such projects. The systems-level design phase is critical for such projects, as is the integration done once the detailed design of the components is complete. During the planning stage, teams should be assigned to design the components and a unique team must be made responsible for integrating components into subsystems and subsystems into the overall system/package. This team is generally comprised of systems engineers that are responsible for managing the interactions between the various components being developed simultaneously. Also the testing and verification phase is generally more expansive as testing and validation is to be done of not only the components developed but also of the subsystems and the system as well.
<table>
<thead>
<tr>
<th>Process Type</th>
<th>Description</th>
<th>Distinct Features</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Generic (Market-Pull) Products</strong></td>
<td>A market opportunity is identified and the product development attempts to come up with a solution using appropriate technologies</td>
<td>As shown in Figure 5 process includes planning, concept development, system-level design, detail design, testing and refinement, and production ramp-up phases</td>
</tr>
<tr>
<td><strong>Technology-Push Products</strong></td>
<td>A technology that the organization wants to find new and unique applications for is chosen and a suitable market is found.</td>
<td>During the planning phase the technology and the target market are fixed and concepts developed must cater to that market while using that specific technology.</td>
</tr>
<tr>
<td><strong>Platform Products</strong></td>
<td>An existing platform, for which the organization wishes to develop a new product where the new product needs to be centered around interacting/interfacing with an established technological subsystem</td>
<td>During the planning phase the platform is decided and the concept development phase must be centered around interacting or interfacing with the specific platform. Interfacing and interaction testing with the platform must be done much earlier.</td>
</tr>
<tr>
<td><strong>Process-Intensive Products</strong></td>
<td>The product is severely constrained by the production processes.</td>
<td>Either an existing production process must be specified from the start, or both product and process must be developed simultaneously from concept development phase.</td>
</tr>
<tr>
<td><strong>Customized Products</strong></td>
<td>New products are slight variations of the existing configurations.</td>
<td>There must a highly structured and explicitly laid out development process.</td>
</tr>
<tr>
<td><strong>High-Risk Products</strong></td>
<td>The product has a high-risk associated with one of the risk categories.</td>
<td>Risks are identified early and are assessed and evaluated at each phase. Testing and analysis to mitigate these risks must take place earlier.</td>
</tr>
<tr>
<td><strong>Quick-Build Products</strong></td>
<td>Rapid prototyping and modeling techniques enable several design-build-test cycles leading up to the final product/prototype.</td>
<td>Design-build-test iteration cycle is repeated several time until the desired design is achieved or the project’s budget/time runs out</td>
</tr>
<tr>
<td><strong>Complex Systems</strong></td>
<td>System must be decomposed into several subsystems and consisting components.</td>
<td>Systems decomposition and systems integration are key. Subsystems and components can often be developed in parallel, followed by system integration and validation involving the Systems Engineers</td>
</tr>
</tbody>
</table>

Table 2: Product categorization and corresponding deviations in development process [3]
The organization needs to first start differentiating its end product, of the development effort, into categories like the ones explained above in order to start differentiating the actual development efforts. The idea behind such an effort is to have the product requirements guide the deviations needed in the specific product development process. In order to achieve this, a clear and comprehensive definition of the product or the mission statement must be achieved during the planning phase in order to highlight the deviations required in the development process. Figure 6 shows some of the development processes suitable for some of the product categories defined above. The generic development process used for the market-pull products (i) along with the spiral product development process (ii) and the complex systems development process (iii) are shown as process flow diagrams in Figure 6.
(i) Generic Product Development Process

Planning → Concept Development → System-Level Design → Detail Design → Testing and Refinement → Production Ramp-Up


(ii) Spiral Product Development Process

Planning → Concept Development → System-Level Design → Many Iteration Cycles

Mission Approval → Concept Review → Cycle Plan Review → Build → Test → Production Ramp-Up

Cycle Review → Project Review

(iii) Complex System Development Process

Planning → Concept Development → System-Level Design

Mission Approval → Concept Review → System Review → Design → Test → Integrate and Test → Production Ramp-Up

Test → Project Review

Figure 6: Development processes modified for product categories [3]

These are examples of some of the common development processes used in the industry and it must be understood that in no way are these the only processes that the organization needs to adhere to. These are only guidelines for the organization to help in creating clearer development processes. After the creation of such process maps it is essential that they be used to explain the process to each member/department involved in that product development effort.
Chapter 4

4. Product Planning

Product planning is an activity that starts even before a project is formally approved by the management and before any significant resources are assigned to the project. Product planning considers the portfolio of projects that an organization could pursue and helps define the projects that the organization should focus on as well as the time line. This activity can help a lot in key decision making by senior management by providing a complete representation of the new product development 'pipeline'. This is a major shortcoming of the organization, the lack of a centralized database to maintain records of the new products currently being pursued by the organization. This creates several challenges for management in making decisions due to incomplete and non-uniform distribution of knowledge i.e. not all divisions are aware of all the products being developed or being considered at any given point in time. In addition, product planning also helps ensure that the product development efforts are streamlined with the business strategy of the company. Thus the organization must initiate a product planning process in order to move towards a more structured, comprehensive and clearer development process.

The product plan is a periodic effort that considers all the development opportunities that have been identified by the organization through its various sources including marketing, research, customers, benchmarking of competitors and other forms of suggestions. From these opportunities, the portfolio of projects is chosen, resources are allocated and a timeline is highlighted for the projects. This activity is then repeated and the product plan is thus updated regularly to reflect the changes in the technology, information from customers regarding developed products and competitive environment. It is generally a good practice to involve the
senior management of the organization in the product planning decisions as the project plans are representative of the organization's goals, capabilities and competitive environment. [4] Some of the inefficiencies associated with the lack of such a project planning process were visible at the organization, including

- Poor timing of market introductions of products
- Inappropriate distribution of resources among various projects being pursued
- Frequent changes in the direction of the project.

Hence to address these issues, it is essential that the organization start a product planning process at the earliest. To this end, the product plan and the various tools that can aid in its creation are discussed below to guide the organization in developing such a planning process.

4.1 Development Project Categories

For the product planning process, development projects i.e. opportunities identified need to be classified into categories, that are different than the ones defined in the previous chapter, which were the product development process categories that dictate the development process. These categories are much more general like new platforms, derivatives, improvements and fundamentally new which are briefly explained below.

- New Product Platforms: The key characteristic of such projects is the idea of developing a product family for a new, common platform. The new product is expected to cater to familiar markets and product categories.
- Derivatives of existing product platforms: These are projects that utilize existing product platforms to fulfill a market opportunity through one or multiple products from the development efforts.

- Incremental improvements to existing products: These are generally projects that require minor addition or modification of features to an existing product to maintain its competitiveness in the market place.

- Fundamentally new products: These are projects that involve the development of completely new/unique products that address a new and unfamiliar market opportunity and thus inherently involve more risk. However, the long term success of an organization hinges on these projects and the learnings from them.

An example of a product plan listing all the various project categories that an organization could be developing is presented in Figure 7.
4.2 Product Plan Process

The steps followed in a product planning process, along with the various tools that can be used to aid in the activities are shown in Figure 8. Several opportunities are identified by the organization which are then evaluated and prioritized to decide the promising projects which the organization would be pursuing. These selected projects are then assigned resources and their time frame are indicated. These planning activities focus on several possible opportunities and projects that a company is or could possibly be pursuing. Following this, a mission statement for each of the selected projects is created. It is at this stage when the product plan and mission statement of a project are ready that the project can proceed to the product development process explained in the previous chapter. It must be clarified here that the process of identification of
opportunities and the allocation of resources is an iterative process. The product plan must be reevaluated frequently so as to ensure that latest information from the development teams, production, marketing, research laboratories and service departments is taken into account in the product planning. Another important feature of this product plan is that the people involved downstream of the process, i.e. primarily the people actively involved in the product development process are most often the first to figure out inconsistencies with the plan or a project’s mission and thus their involvement in the creation of this product plan is important. The adaptability of the product plan over time is vital for the long-term success of an organization.

[4]

Figure 8: Product Planning Process Outline [4]
4.2.1 Opportunity Identification

The product plan begins with the identification of possible product development opportunities, as explained earlier, these could be either suggestions from department of the organization, customers or market environment. However, an active effort must be made by the organization to generate these opportunities and they need to be tracked as well. The use of suggestions boards is already extensive in the company and a dedicated suggestions/ideas board aimed at new product development could easily be implemented in the company to aid in opportunity identification.

4.2.2 Evaluation and Prioritization of the Opportunities

The second step in the product planning process is the selection of opportunities that are or at least seem, at the time, to be most promising for the company and its future. In the process of evaluation and prioritization of these opportunities four basic perspectives, competitive strategy, market segmentation, technological trajectory and product platform planning can be used to guide the evaluation and prioritization. Competitive strategy is essentially a company's approach to markets and products with regards to the competitors. Market segmentation is an approach to target specific opportunities with respect to product development in specific segments of the total addressable market e.g. university laboratories vs. drug manufacturing companies. [4] Technological trajectories refer basically to the decision of an organization of when to adopt a new technology and then to create products based on this new technology. Product platform planning is the decision of the organization to pursue either a new platform or to continue creating products for an existing platform.
4.2.3 Mapping the Portfolio

There are several methods explored in literature to help map an organization’s portfolio of development efforts, mapping approaches involving dimensions such as technical risk, financial return, market attractiveness, etc. are described by Cooper et al. [5]. A very simple and useful approach for mapping, called the product-process change matrix, is described by Wheelwright and Clark [6]. As the name suggest, this mapping method plots the projects on a plot along two dimensions, change in product line-up required for the project and the amount of change required in the production process for the project. A template for such a matrix is shown in Figure 9. The benefit of this mapping process is the relative ease with which imbalances in the portfolio of projects being considered can be highlighted, e.g. an organization can easily see on these plots that it doesn't have any breakthrough opportunities in its portfolio or it lacks projects aimed at incremental improvement of existing products.
It must be understood that there is no ‘best portfolio’ map for a company to replicate at any given point in time. Instead the firm’s management and their vision will mostly determine the appearance of this map.

4.2.4 Resource Allocation and Project Timing

An important finding from the interviews conducted was that the employees felt that the projects were, nearly always, moving along too quickly and were often not allocated appropriate and or sufficient resources. A key part of the project planning process is to allocate sufficient resources and to create a time frame for the project before it can be approved. To suitably
allocate the resources, the organization must have a list of all available resources types that would be utilized by that particular product development effort. Most of the time, it is primarily the efforts of the development staff that needs to be managed, including mechanical designers, electrical engineers, manufacturing engineers, software/firmware developers, etc. which are generally expressed in person-hours or person-months. Other resources like testing facility, pilot production lines, prototyping equipment etc. must also be considered during resource allocation.

In estimating the resources required for every project being considered or existing in the portfolio of new projects the organization gets a clearer understanding of their finite resources and can even help in determining the resource type most needed by the organization in the future. To help gauge this ‘resource crunch’ the capacity utilization can be calculated over the horizon of the portfolio projects being considered and resources which consistently have a capacity utilization of over 100% must be carefully monitored to determine the need of further resource acquisition. A representation of such an aggregate resource planning can be seen in Table 3 where a few of the possible resources required for a project are indicated.
Table 3: Aggregate resource planning template [4]

<table>
<thead>
<tr>
<th></th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project X</td>
<td>155 160 105 75</td>
<td>210 160 140 80</td>
<td>125 140 160 90</td>
</tr>
<tr>
<td>I-1</td>
<td>30 25 10 5</td>
<td>25 20 5 6</td>
<td>5</td>
</tr>
<tr>
<td>Der A</td>
<td>60 24 25</td>
<td>20 15 15</td>
<td></td>
</tr>
<tr>
<td>Der B</td>
<td>55 60 44 25</td>
<td>75 65 50 40</td>
<td>45 40 60 20</td>
</tr>
<tr>
<td>Resource Demand</td>
<td>300 269 184 105</td>
<td>330 260 210 126</td>
<td>170 180 225 110</td>
</tr>
<tr>
<td>Resource Capacity</td>
<td>250 250 200 100</td>
<td>250 250 200 100</td>
<td>250 250 200 100</td>
</tr>
<tr>
<td>Capacity Utilization</td>
<td>120% 108% 92% 105%</td>
<td>132% 104% 105% 126%</td>
<td>68% 72% 113% 110%</td>
</tr>
</tbody>
</table>

In determining the time frame for the projects the project planning team must consider a few key factors, including timing of product introduction, technology readiness, market readiness and competition. A key item that must also be considered here is the display of new/upcoming products by the organization at trade shows and expos. The senior management at Waters is always very enthusiastic about presenting new products at these expos and shows, however the project planning team must present a realistic assessment of the expected readiness of a technology/product before such key events that the organization is participating in. It might also be a good idea to indicate these events on the visual representation of the new product portfolio shown in Figure 7. Following these activities, the project plan should then be approved officially and agreed upon by both the project planning team and senior management.

4.2.5 Pre-Project Planning

Once the project has been approved and has reached this stage of the process, there is essentially a ‘hand-off’ from the project planning to the dedicated development team, discussed in detail in Chapter 6, which would carry the project through the entire development process.
detailed in the previous chapter. Thus, this is a critical juncture in the project where known flaws can be easily fixed. To this end the core team should create a detailed mission statement for the identified opportunity and work with the project planning team/people to ensure that the mission statement is in accordance with the ‘intent’ of the approved project plan. The mission statement is a critical document as it is the primary source of guidance for the dedicated product development team to navigate the development process. A template for such a mission statement is presented in Table 4 and a brief description of each of the categories indicated in the template follows. Other possible categories could also be added to the mission statement based on the project.

Table 4: Product planning deliverable template [4]

<table>
<thead>
<tr>
<th>Mission Statement: Project X</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product Description</td>
</tr>
<tr>
<td>Value Proposition</td>
</tr>
<tr>
<td>Key Business Goals</td>
</tr>
<tr>
<td>Primary Market</td>
</tr>
<tr>
<td>Alternate Market</td>
</tr>
<tr>
<td>Assumption &amp; Constraints</td>
</tr>
<tr>
<td>Stakeholders</td>
</tr>
<tr>
<td>Environmental Constraints</td>
</tr>
</tbody>
</table>

As shown in the template some of the categories defined in the mission statement should be Product description which should identify the basic function of the product while refraining from implying a specific concept. The value proposition i.e. the reason why customers would purchase the product. The key business goals category includes the project goal that support the organizations strategy as well as other goals like time to market introduction, product introduction, cost and quality. The target market identifies the primary market, and secondary if possible, for considerations during the development effort. The assumptions and constraints
category helps the development team to understand the project scope; care must be taken in defining this category as they can restrict the range of possible product concepts. The ‘stakeholders’ category explicitly lists out all the groups/departments that need to be involved in order to address the subtle development issues associated with the project and who are affected by the success or failure of the product. In addition to these categories, other categories like certifications, environmental goals, service objectives, etc. can be added depending upon the project being considered.

4.2.6 Assessment of Results and the Process

At the end of the process, it is essential for continuous improvement and evolution of the process, that the team assess the quality of both the process and the results. A sample questionnaire to aid in this process can be found in Appendix A-2, ‘Product Planning Process and Results Assessment’. The suggestions and feedback from this process after sufficient trials must then drive a process improvement effort to improve the project planning process and continue its evolution.
5. Manufacturing involvement during Design

While attempting to understand the existing process, there were clear indications that the incoming material audit/incoming inspection was being considered a major bottleneck in the process of product development. The inspection department of the organization was nearly 300 lots behind schedule at the time and their explanation for this backlog was the large number of rejects of the incoming parts. The team thus went ahead and explored the causes of these high rejections of incoming material at inspection. To quantify the results of this exercise, rejection data available from the incoming inspection was analyzed by the team to determine the shortcomings in the development process. He Yan in her thesis [1] looks at the rejection data that indicated the shortcomings in the current supply chain process at the organization whereas Aditya Ranjan in his thesis [2] looks at the rejection data that indicates the shortcomings in the inspection process. Meanwhile the author looked at rejection data to find any shortcomings in the design process. The findings of Aditya and the author were fairly similar and indicated the lack of a process/activity in the new product development process. This process was collaboratively created to accomplish the final goal of fewer rejections at incoming inspection and also to aid in quicker inspection.

5.1 Data Analysis

As explained in Chapter 2 earlier, using the rejection data from incoming inspection and other downstream activities like assembly and testing, the root cause categories of problems were
found and the origin of the problems was traced. Following the rejection of a part/item, at any one of the above mentioned downstream activities, a ‘disposition’ meeting takes place twice every week where a decision regarding the future course of action for these rejected parts is made. Waters has historically inclined towards using the rejected parts, known as ‘use-as-is’ case as most often Waters is either in a hurry to continue building the prototypes as they are operating behind schedule as per the project plan laid out in the development process or alternatively there is some minor issue which doesn’t affect the design or functionality of the part and was most likely the result of some undocumented communication as explained in Figure 4 earlier. The former problem is a systems level problem where the whole product introduction process must be looked at as a whole to address the issues that cause this situation to arise, which are discussed in Chapter 4 earlier. However, for the latter issues it is clear that some analysis can be done to find out the reason as to why the parts were rejected at incoming inspection although they were eventually used-as-is by the organization.

For this kind of analysis, data recorded by Waters about the root cause of rejected parts/items that were dispositioned ‘use-as-is’ was looked at to understand the break-down of which departments were responsible for these rejections. The results of this analysis are shown in Figure 10 where the data analyzed was rejected parts by Waters from January, 1 2013 to June 20, 2014.
Figure 10: Rejection 'use-as-is' breakdown

It can be seen in Figure 10 that the top three causes for this kind of rejection are design issues, supplier issues and procedure issues in that order. Seeing the large difference between the quantities of rejects attributed to these three categories versus the other categories in Figure 10 the focus of further analysis for the team was specifically on these three categories, however for the author the main focus was on the design category. The design category was then further analyzed to better understand the constituents that composed this broad category and its breakdown can be seen in Figure 11. The top three root causes for rejection encountered by the incoming inspection attributable to the design department errors were dimensional issues, feature missing on inspection drawings and incorrect drawing/specifications.
However, as seen in Figure 11, the categorization done during the disposition process is too subjective and there are no clear guidelines to categorize the root causes. Hence the data obtained from the Trackwise software at Waters regarding rejection of incoming parts/components is not very useful directly as it is indicating every possible problem from design that have cause a rejection. Thus the data was first organized into more logical and broader categories to begin the process of error categorization. The results of this effort are displayed in Figure 12 which is
basically a modified Figure 11 as the same data set of rejected parts, over the same time period, was used in both the cases and thus the percentages are fairly similar too. These broad categories were created by collecting a lot of the constituent specific issues which are displayed as pie charts as well.

![Pie chart showing categories of design team errors leading to rejection at incoming inspection]

**Figure 12: Design team errors leading to rejection at incoming inspection**

As seen in the chart, dimensional errors contribute the most towards incoming rejects, the category dimensional mainly consisted of incorrect/inappropriate tolerances and dimensioning on the drawings thus, further breakdown of it is was not possible, however the second and third most frequent causes of incoming material rejection i.e. incorrect drawing and incorrect documentation could be broken down further to their constituents and their contribution to rejection at incoming inspection. This breakdown for the incorrect documentation and incorrect drawing is shown in Figure 13 and Figure 14, respectively.
From the breakdown of the incorrect drawing and incorrect documentation categories into their constituents it is clear that there is no one single category which is causing the bulk of rejections at the organization, therefore the even distribution is actually indicative of a flawed process/activity. The activity/activities in the product development process which are expected to
filter issues like the ones indicated in Figure 11, Figure 12, Figure 13, and Figure 14 are the design review and drawing review processes. The team was actively involved in the drawing review process/activity of a new product being developed by the organization and thus developed a clear understanding of the process and its shortcomings, most of which are addressed in the solution proposed in the next section.

5.2 Design and Drawing Review Process

Two of the most common issues found during the data analysis were extremely tight tolerances and missing dimensions on the drawings. To address the first issue of tolerances, the design process of the organization must be modified so as to utilize the expertise of manufacturing engineers and production personnel in addition to the product designers to layout the guidelines for tolerances. The current product development process does not actively engage a manufacturing engineer throughout the length of the development process and this hampers the development process from a Design for Manufacturing standpoint, more details of people to be involved in the development effort are discussed in Chapter 6 along with a discussion of the dedicated development team. The main difference between a design review and a drawing review is that in a design review it is the design of the component/subsystems that is being critiqued whereas in a drawing review, the actual drawings created by the drafting group are being reviewed and not the design on the drawings. Two examples of drawings that passed the drawing reviews and caused rejections at incoming inspection are shown in Appendix B, the errors have been highlighted with a bold black box in the drawings. In the first example drawing, several dimensions were missing in the previous version of the drawing as highlighted this is revision B, all drawing documents start with revision A, in fact there were several cases where
even at revisions F and beyond dimensions were found missing on the drawings. In the second example presented, not only are there missing dimensions being added during revision C but also there are important features missing from the drawings like missing feature and tolerances. Also the tolerances on this part were originally too tight and were relaxed during revision C. Ideally all of these errors should have been addressed during either the design review or the drawing review. To achieve this, a new process for addressing the two key problems mentioned above is discussed below.

The way the current drawing review sessions are held at the organization is fairly unstructured and the outcome of the session is not clear to all the attendees. In addition, the mixed attendance combined with a lack of a clear objective for these sessions delivers very little impact to the overall development process. Instead, it is recommended that more targeted drawing reviews be held so as to target a few of the specific categories listed in Figure 11 through Figure 14 in each of the sessions. Also the audience of these sessions must be decided based on the particular categories being focused on in that session. For example, when a session is primarily focusing on appropriate labelling and revision number mismatch among various drawings, design engineers need not be the bulk of the attendees. The number of the drawing review sessions and the recommended attendance for each session must be planned for in advance, preferably after the detailed design phase has been completed. Besides, it is critical that these drawing review sessions occur before the sourcing process for these components is initiated, which is not always the case at the organization. Due to attempts of parallel processing of activities in order to save time it was observed that components whose drawing reviews were not initiated had already arrived from the vendor and were waiting for inspection due to the drawings. A better process flow map for the development effort as explained in Chapter 3 would
help ensure that all team members are aware of the sequence of the various processes/activities. This would greatly help in ensuring that the desired sequence of processes/activities is adhered to by all the various teams involved in the project.

As explained by Aditya in Chapter 6 of his thesis [2], there is also a need for the design team to come up with a list of critical dimensions for the product in order to help in the process of creation of a quality inspection plan. Thus, two essential documents must be created from the design efforts i.e. the design review and drawing review activities; these are the design tolerances document and the critical dimensions document. The reason for creating the critical dimensions deliverable, at this stage of the development process is that the drawing reviews and the design reviews are activities where a lot of discussion regarding the existing designs is taking place and therefore the designers are a lot more confident about a design following a design review. Thus, a separate drawing review session should be held where the critical dimensions of the product must be laid out according to the templates discussed by Aditya. A process map indicating a possible process that delivers these documents is shown in Figure 15.
Figure 15: Process map for delivering design tolerance and critical dimensions of product

There are several shortcomings in the company that were discovered while attempting to understand the processes being followed. Some of the main ones like the lack of a dedicated project team for a development effort, the existing organizational structure that can hamper product development, the lack of post-process reviews for process evolution and the lack of metrics to evaluate success are discussed in the following sections.

6.1 Product Development Team

The most critical component that determines the success or failure of any product development effort undertaken by an enterprise is the product development team. Currently the development process laid out by the organization does not have a single dedicated development team that is involved with the new product from the initial planning phase to the ramp-up phase. Instead, the way the process actually works can be thought of as the product moving from one phase of the process to another and different people working/contributing to it at each of the phases. One of the reasons behind the lack of a structured team selection process is the fact that the processes laid out by the organization have not evolved along with the organization itself over time. Also many of the processes were laid out over a decade ago and have never since been revised whereas the organization has seen tremendous growth in the same period. For an organization that is releasing as many as 15 to 20 new products every year, it is critical that a team be assigned to every new project being pursued. This will also help in inculcating the culture of accountability and bottom line implication in the product development process, something which is greatly amiss currently in the development process at the organization.
To address this therefore a team must be assigned to each new project that the organization is pursuing. Generally these projects have a single team leader and a dedicated development team that is aided in the development effort by an extended team. The composition of this dedicated development team is generally decided upon by the requirements/challenges of the project as determined during the project planning process. Another guideline in deciding the core team is that the core team members should be involved in the decisions made at each of the stages of the development process. Although the amount of contribution at each of the phases could vary for each of the members of the dedicated development team, it is essential that they are aware of the decisions made during the development process. The dedicated development team should generally be small enough to meet in a conference room in order to work effectively. The extended team can however consist of as many members as needed by the project. The composition of a sample product development team for an electromechanical product is shown in Figure 16.
The existing product development process's approach towards product development teams causes significant information/knowledge loss. According to the current development process there are two project managers that are involved in every new product development project, one from the Research and Development department and another from the New Product Introduction department. The challenge arises not because there are two separate project managers but because of the varying stages of their involvement in the project, i.e. neither of the project managers is involved from start to finish of the development effort. There is almost a 'hand-off' of the project from one project manager to another during/nearly two-thirds of the way through the development process. The existing process does not suggest any activities that would aid in
the appropriate knowledge and information transfer from the first project manager to the second either. The problem is best depicted by Figure 17 which indicates that there isn’t sufficient time (or activities) for the new project manager to functionally integrate into the development process and thus there is information loss at this juncture in the development process. Thus the second project manager very often faces the challenge of making decisions without having complete information and without being completely aware of the design intent or the intent of the project. Having a single project manager from the start of the development effort to the end would address this issue or alternately having both project managers be involved in the project from the planning phase could also lead to desired results.

Figure 17: Functional integration challenge for project managers
6.2 Product Development Organizations & Structures

To be successful at new product introduction organizations should not only focus on creating an effective product development process but should also attempt to organize its resources that would support the development process. A product development organization is the way in which individual designers, developers, engineers, etc. are linked together into development team. With regards to a product development effort the links among individuals is not as relevant as their classification. Individuals can be classified according to the functions or according to the projects that they are involved with; functions here refers to the primary responsibility of the individual like marketing, manufacturing, etc. Thus, as explained earlier in the previous section about project teams, it is clear that people/individuals from various functions work together on the same project and individuals from a function could be involved with several projects at any given time as well. Two classical organizational structures arise upon aligning the organizational links according to the function or according to the projects. In functional organizations, the organizational links are chiefly among individuals in the same function whereas in project organizations links are among individuals involved in the same project. Here organizational links mainly refers to links like reporting relationships supervisor and subordinate, financial arrangements and physical layout. The structure of an organization dictates who has the most influence on the individuals in an organization, is it the project manager or the functional manager. The organization being studied is a traditional functional organization where most organizational links among individuals is for people in the same function/department and thus as expected communication is one of the biggest challenges with the development effort at the organization while functional units have significant competencies.
In addition to these two classic organizational structures the matrix organizational structure was developed as a hybrid of the functional and project organizational structures. The idea behind this structure is that firms tend to have both functional managers as well as project managers that individuals report to, however eventually either one of these managers tends to dominate as they are constrained by the limited resources available to them. Thus there are two variants of the matrix organizations exist as defined by Hayes [8] i.e. the Heavyweight Project Matrix Organization which contains strong project links and the lightweight Project Matrix Organization which contains weaker project links and relatively stronger project links. The organizational performance factors that are considered most critical for success should be used to guide the firm in selecting the appropriate organizational structure. Generally these factors include the importance of cross-functional integration, relevance of cutting edge functional expertise towards business success, duration of utilization of individuals from various functions and product development speed. Essentially the difference between functional organizations and project organizations is the trade-off between deep functional expertise and coordination efficiency/quick product development. The idea in implementing such a structure is to have a carefully selected weight assigned to the evaluations received from both the functional managers as well as project managers in order to determine which organization structure is followed.

6.3 Project Evaluation

In order for the development process to evolve it is critical that after the completion of the development effort the product development team, primarily the dedicated development team have a post-project review that evaluates not only the project’s outcome but also the development process itself. This review must be open-ended and should discuss the strengths and weakness of the project plan, the quality of execution, development processes employed and
commercial and technical results. A sample questionnaire that can be used to guide such a discussion can be found in Appendix A-3, ‘Post Project Assessment Questions’ [9].

Following the discussion a post-project report must be created that is almost like a ‘learning from the project’ document. The idea is to use these reports in future project planning process to help team members understand what to expect and to help them identify the pitfalls that need to be avoided, this would bring the idea of ‘generational learning’ into the development process as well. Also these reports form a repository of historical data on the organization’s product development process and can be very helpful for future studies and assessment of the process. Also, suggestions/flaws in the process that appear regularly in such reports can help drive ‘process improvement initiatives’ i.e. these reports can also be used as a continuous improvement tool.

The company being studied does not have any such practices of reviewing the processes at the end, thus even though the firm has created several new products, and hence had several development efforts over the years, no information about the processes and their shortcomings is actually recorded. Thus, it is extremely difficult to analyze the development process without having any information from people that actually went through the process and hence the company should ensure that post-project reviews occur and the corresponding reports are documented as well.

6.4 Measuring new product success

The organization being studied did not have any metrics that it monitored or used to determine whether a product was a success or not. This was a huge surprise as essentially the
company did not have an objective way of defining whether a new product was successful or not. The idea behind having an effective, world-class product development process is generally to deliver successful products. Although the definition of a successful product may not have direct impact on the development process, however the product planning process needs to consider how the company would define the product a success in order to help complete the mission statement template shown in Table 5. Several studies [10, 11, 12, 13] have been done to indicate the various objective metrics that are used by organizations and researchers around the world to determine new product success/failure.

Overall there are about 16 total metrics that are most commonly used for determining success and failure and these can broadly be classified into four main categories, customer acceptance measures, financial performance, product level measures and firm-level measures. [14] The metrics in each of these categories is presented in Table 5. The company must decide how it wishes to define its new product success/failure and which of these metrics are most appropriate for its competitive environment and in line with its corporate strategy. A major challenge for the organization in adopting most of these metrics however will be the assessment of resources consumed. Currently the organization has no way or logical procedure for estimating the resources that it is utilizing for a given development project and this must be addressed before most of these metrics can be utilized for defining new product success/failure.
Table 5: Metrics for evaluating success/failure of a new product

<table>
<thead>
<tr>
<th>Customer Acceptance Measures</th>
<th>Financial Performance</th>
<th>Product-Level Measures</th>
<th>Firm-Level Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customer Acceptance</td>
<td>Break-even time</td>
<td>Development Cost</td>
<td>Percentage of sales by new product</td>
</tr>
<tr>
<td>Customer Satisfaction</td>
<td>Attain margin goals</td>
<td>Launched on time</td>
<td></td>
</tr>
<tr>
<td>Met Revenue Goals</td>
<td>Attain profitability goals</td>
<td>Produce performance level</td>
<td></td>
</tr>
<tr>
<td>Revenue Growth</td>
<td>Return on Investment</td>
<td>Met quality guidelines</td>
<td></td>
</tr>
<tr>
<td>Met market share goals</td>
<td></td>
<td>Speed to market</td>
<td></td>
</tr>
<tr>
<td>Met unit sales goals</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Chapter 7

7. Summary & Recommendation

A brief summary of the key findings and proposed solutions along with the recommendations are discussed briefly below:

7.1 Summary

The aim of the research was to study and improve the commercialization process of the organization. The new product development process was carefully studied and compared with the generic development process explained in literature and it was found that the organization’s development process lacked a design freeze stage. Further investigation uncovered the lack of a project planning process and the absence of specific documents that should guide the development effort. From existing literature a process for project planning was laid out in a manner that led straight to the product development process and the template of a document, the mission statement of the project, was laid out to help guide the future development process. Also this up-front effort in the development process is expected to significantly reduce some of the confusion in the downstream activities of the development process. A shortcoming in the design and drawing review process which was causing rejections at the organization’s inspection of incoming components was identified through data analysis and an improved process map for the activity and deliverables was presented. Certain other key issues discovered during the data collection process were addressed and/or identified for the organization. Thus, although the product development process could not be studied in detail due to the lack of data, a structure to help in data collection from development efforts as well as other up-front processes that the
organization should focus on, were laid out explicitly along with process maps for certain key activities that were adversely affecting the development process with regards to time.

7.2 Recommendations

Some of the main recommendations for the organization with regards to the study conducted are listed below

- Initiate post-project reviews and reports to help in the evolution of the development process and to institutionalize good practices across various groups
- Create a mandatory design freeze step in the development plan to ensure design discipline and to allow sufficient time for testing and refinement
- Make arrangements for the project planning process to be introduced to ensure that the development process is more structured and better understood by the people involved in the process
- Create specific teams that are involved over the entire development process of the project to aid in project 'ownership'
- Find best approach to find/estimate resources spent on a development effort in order to evaluate product development success/failure as well as development process efficiency
- Start recording the time spent in each phase of the development process and categorize development efforts to develop an understanding of the resources used for a specific category of development project
Appendix A

A-1: Standardized questionnaire for interview

What is your name and designation?

Duties & Responsibilities

1. What are your key responsibilities at the –
   a) Alpha stage of the development process
   b) Beta stage of the development process
   c) Pre-production stage

2. At what stages of the development process are you (actually) involved?

3. How many projects at any given time are you involved with?

4. What key deliverables are being driven by you and require your input?

5. Do you feel projects are always coming through at a breakneck pace and there is always a time-crunch?

6. Are you aware of the stage at which you are involved in the development process?

7. Are you happy with the stage at which you get involved in the project? Is it too early or late or just right?

Communication Channels

1. How is the information communication to you (with regards to documentation) from-
   a) RD&E
   b) Supply chain (buyers, procurement people, commodity managers, etc.)
   c) Incoming Material Audit
d) External vendors (if required)

2. Are you involved in the drawing or design reviews?

3. What are your thoughts about the current drawing and design reviews?

Tools and SAP Integration

1. What tools (including modules of SAP) do you use to aid in your daily tasks? Are there any such tools that you wish were available to you?

2. Do you feel that you get adequate information that would aid your responsibilities?

Data Metrics for Decision making and Evaluation

1. What sort of assessment process are you involved with for your work? Are there any metrics for such an assessment?

2. Are there any metrics that are focused on with regards to the product development process?

3. Are there any data metrics that aid or guide you in fulfilling your responsibilities?
A-2: Product Planning Process and Results Assessment

- Can the opportunity identification rate be improved? Is there a need to improve it?

- Does the current product plan cater to the existing market opportunities? Is it ensuring a competitive advantage is maintained by the company?

- Are there sufficient resources available for the new products over the immediate future?

- Is the mission statement being too specific or too leading towards a concept?

- How can the product planning process be improved?
A-3: Post Project Assessment Questions

- Was the team able to create a product that aligns with the mission statement of the project? If not, why?

- Where did the project perform well and where was it lacking? What were the reasons for these?

- What were the major challenges of the project? How were they handled? Could they have been handled better?

- What activities/processes of the product development process were most useful in accomplishing a product that conforms to the mission statement? Are there practices in these processes that can be institutionalized?

- What were the key learnings from the project, both technical and non-technical? How can they help the future development efforts?
NOTES:

1. MATERIAL: .040 THK CRS PER ASTM A1008 CS TYPE B (.10% MAX CARBON), OR .050 THK CRS PER ASTM A1010 CS TYPE B (.08 - .13% CARBON)

2. FINISH: ZINC ELECTROPLATE PER ASTM B433, TYPE III, THICKNESS CLASS SC3

3. FABRICATE PER WATERS SHEET METAL SPEC WAT022557 TOLERANCES UNLESS OTHERWISE SPECIFIED:
   \[ \pm 0.01 \]

4. RoHS: MUST COMPLY WITH WATERS ROHS REQUIREMENTS DOCUMENT 735001207

ECR # 010220c; circled items were missing
References


