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To address aggressive global competition, retain customers and increase revenue, firms are required to pursue New Product Development (NPD) projects. Ventures of this nature are risky and fail often. Numerous factors influence the survival of a project. In this research, 16 factors have been identified and selected as indicators of success. The work involved an industry partner that uses an alternative New Product Development process not previously documented, termed the Reference Design (RD) process. Through the use of an exploratory study, interviews with subject matter experts were conducted to gather information about the Reference Design process.

A comparison between the processes confirms that the Reference Design process is a form of NPD. The RD process involves two firms to complete the process; one firm provides a design and essential subcomponents to another firm that manufactures the product. It is also found that the RD process is driven by the same factors that drive a traditional NPD process. These findings offer the RD process as an alternative solution to introducing to market a new product.

Defining and Comparing Risks and Success Measures of the Reference Design Process and Traditional New Product Development Processes

by
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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Tasha M. Larson, Author

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Definitions

New Product Development: a business process for efficiently and effectively bringing an innovative good to market.

Reference Design: a tool a chip manufacturer can use to demonstrate to an industry partner that the new chip set is capable of performing the required tasks.

Form-Factor Reference Design: a Reference Design that could be a consumer product. An example of this would be a fully functioning device that looks and feels like a product that could be sold to an end customer.

Non-Form-Factor Reference Design: a Reference Design that demonstrates functionality, but is not in the form of a customer product. An example of this would be a functioning circuit board that proves functionality of some components, but does not demonstrate how it would work in a completed device.

Success in New Product Development: entering into a targeted market at a strategized time with an innovative product that a customer base desires, in the demanded quantity.

Risks in New Product Development: factors that can impede the success of a New Product Development project.

Original Device Manufacturer or Original Equipment Manufacturer: a company that manufacturers a product and puts another brand name on the product.

Rambus: A new computer memory system project taken on by a computer chip manufacturer that struggled to succeed.

Reference Validation Board: a circuit board manufactured to prove the circuitry and cooper routing functionality

ARM: a computing architecture that defines how information is routed within a computer.

System on a Chip: integrated computer chip, could have digital, analog or mixed signaling.

Acronyms

NPD: New Product Development

ODM: Original Device Manufacturer

OEM: Original Equipment Manufacturer

RD: Reference Design

RVB: Reference Validation Board

SOC: System on a Chip

T-to-M: Time to Market

CHAPTER 1: INTRODUCTION

This chapter provides an introduction for the work herein. Research motivation and a basic introduction to the topic of New Product Development is presented. Research goals and methods are briefly discussed, while a more detailed review is given in Chapter 3. Also found in this chapter is an outline for the thesis.

1.1 Motivation

New Product Development (NPD) is an effective strategy for firms to generate profits [1], [2]. The success of NPD projects is low in general, with about one in four succeeding [3]. The failing projects consume money, time, and resources without providing a positive contribution to a firm's portfolio. Increasing the success of these projects is an ongoing challenge for many companies due to the high number of internal and external variables that are contained within a project. Variables include dynamic customer requirements, supplier schedules, project team members and competitive high-tech markets, among other factors.

According to Eisenhardt and Tabrizi NPD is "a process of navigating through unclear and shifting markets and technologies using experiential and improvisational tactics" [4]. One such tactic provided by an industry partner, termed the Reference Design process is to be documented in the work herein.

1.2 Background

The competitive global market requires firms to introduce new products to remain competitive [1], [5], [6]. New product development has been defined as a business process for efficiently and effectively bringing an innovative good to market [1], [5], [7]–[12]. High failure rates, well over 50%, force firms to accept paying for projects that will never turn return a profit [3]. A chip manufacturer, which was a partner in this research, had been successful in introducing two innovative technologies to market: desktop and laptop computers. When investigating the process used to introduce the products, a previously undocumented process was discovered, termed the Reference Design process.

The Reference Design process makes use of two firms. The first firm manufactures a subcomponent of a product, in this case, a set of computer chips (chipset). To prove the functionality and usefulness of the subcomponent (e.g., chipset), the first firm designs an entire device (e.g., laptop) that is supported by the subcomponent. This final product design is then given to a device manufacturer for the purpose of producing final products while using the supplied subcomponent from the first firm. The product design and testing times are reduced because the first firm has dedicated and experienced personnel in the design of the high-tech components and devices. The production times are reduced because the second firm is solely dedicated to the production of the final device.

Providing companies with an alternate, proven method could help increase the success rates of NPD projects and therefore the profits of companies. A Reference Design process is one such alternative. The examples given in the work herein are limited to high-tech products and it is not determined if a Reference Design process would be as effective in a low-tech environment.

1.3 Research Objectives

The primary objective of this research was to identify the risk factors that influence the success of a New Product Development project. Once these risk factors were determined, the Reference Design process, which was yet to be documented in scholarly literature, was evaluated using these risk factors to determine if it is an alternative process to bring new products to market. By confirming that a Reference Design process is an alternative solution to bringing new products to markets, a firm may choose to implement a Reference Design process to collaborate with another firm to successfully bring to market a new product.

1.4 Research Tasks

The following task were outlined to guide the identification and comparison of risk factors that affect the Reference Design and NPD processes.

Task 1: Establish a strong conceptual foundation of the New Product Development (NPD) , it is important to conduct a detailed specification of the current process, with focus on the factors that make projects fail or succeed. The research field of New Product Development is large. The goal of this task is to conduct a detailed and comprehensive, but non-exhaustive review of NPD research and to extract information that improves understanding of the status of NPD research. Specifically, the focus of this task is on factors that affect the success or failure of an NPD project.

Task 2: Establish a foundational understanding of the Reference Design process and the associated risk and success measures. This task is accomplished by conducting interviews with industry experts who have experience working on a Reference Design project. This form of exploratory study is a common research approach for collecting information about undocumented methods [13].

Task 3: Compare the measures of success in NPD projects to the measures of success in Reference Design projects. If the same success measures impact both types of projects, then it can be argued that a Reference Design process is an alternative way to approach the NPD process. This knowledge will provide information to researchers and practitioners on ways to adapt and apply the Reference Design process more effectively in high-tech industries.

1.5 Research Methodology

In addition to literature review, the research was conducted in two studies within the integrated circuit chip manufacturing industry. The first study was conducted with one individual to achieve a better understanding of the use and purpose of a Reference Design. The second study was an exploratory study conducted using eight interviewees. The goal of this study was to define what risk factors enhanced success for Reference Design projects. The flow for the exploratory research is documented in Figure 1.1.

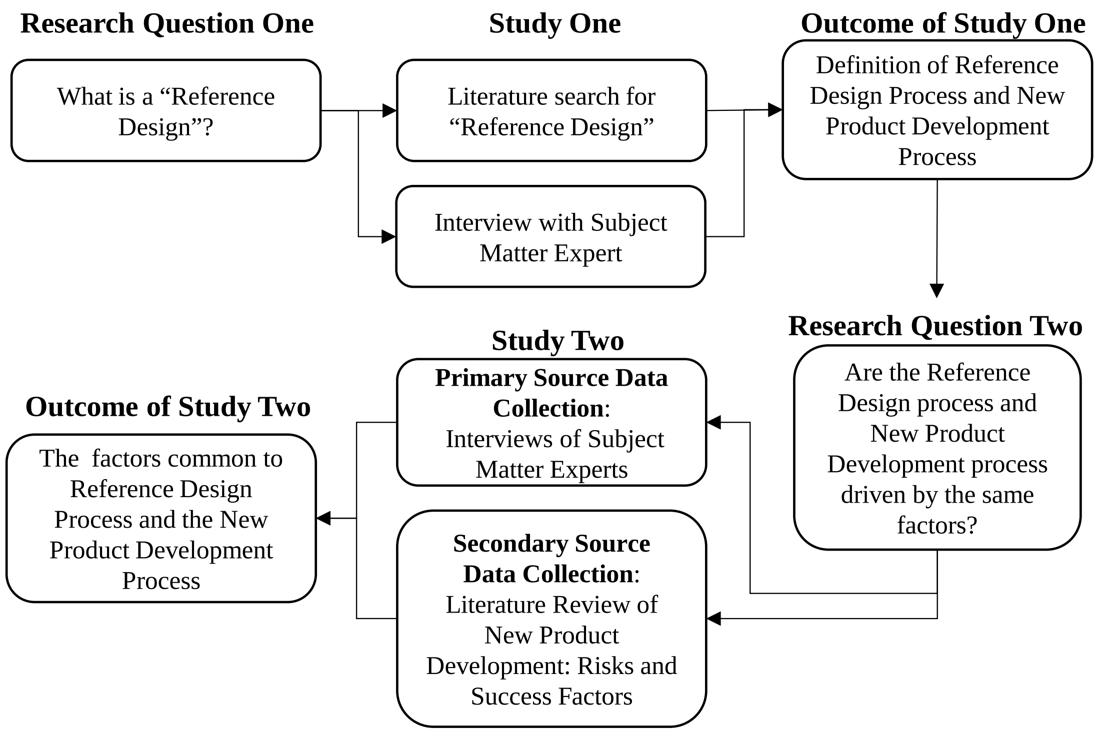

Figure 1.1: Flow of Exploratory Research

1.6 Thesis Outline

In Chapter 1, an introduction to the topic, understanding the risk and success measures in Reference Design and the New Product Development process, is presented. The Reference Design and NPD processes are also defined, and the research objective and tasks are discussed.

Chapter 2 provides a review of the current research in New Product Development. Within this chapter, NPD and related success measures and risk factors are defined by examining prior definitions reported in literature. Factors that impact NPD projects are discussed with additional sources offered for further reading.

Chapter 3 includes a manuscript, to be submitted to a peer-reviewed journal, that formulates a foundational definition of New Product Development and the current NPD processes documented in research. The risk factors that influence the NPD process are extracted from prior research, with 16 risk factors selected for the comparison of the two processes. A Reference Design process is then presented, and compared to an NPD process with regard to the selected risk factors.

Chapter 4 summarizes the research methods and offers additional discussion on the findings. The conclusions and research contributions are presented, concluding with a discussion on opportunities for future work.

Appendixes include details about the interviews and additional work not presented in previous chapters. Appendix A offers the questionnaire used for the interviews. Appendix B summarizes the findings from the interviews. Appendix C contains additional support to the review of literature. Appendix D provides additional support for the research methodology. Appendix E offers additional literature on how the success measures influenced the three levels of technology evaluated. Appendix F discusses how the relationships of the computer chip manufacturers and the device manufacturers have changed. Appendix G contains additional support for the research results.

CHAPTER 2: LITERATURE REVIEW

Discussed in this chapter is prior research in the field of New Product Development (NPD). Success measures and risk factors in NPD are defined from prior research. Factors that influence NPD, as recorded from prior research, are compiled. A total of 6 success measures and 16 risk factors are selected to use for the research evaluation.

2.1 Defining New Product Development

To formulate an understanding of what New Product Development entails, the first step required is to define the process itself. Initial searches of prior research in the area of NPD resulted in a range of definitions. As a result, a collection of New Product Development definitions was gathered (Table 2.1). The use of these definitions contributed to the definition: New Product Development is a business process for efficiently and effectively bringing an innovative good to market.

Table 2.1: Definitions of New Product Development

Definition	Source
"NPD is a business process for developing new products for a company, whether it is and upgrade of an existing product, or a new concept (either for the company or the customer)"	Mehrjerdi and Dehghanbaghi [1]
"Bring to market new products"	Nepal et al. [14]
"…new or improved device or system"	Jensen [7]
"Products are physically tangible….The degree of newness is an indicator of the difference between the new product and the existing one."	Murthy et al. [8]
"Quickly produce high quality new products, reduce the cost of the new product development process and make new products with strong market competition….NPD is a complex, dynamic and continuous process"	Zhang and Ma [15]
"In response to competitive pressures, firms have used innovation as a source of differentiation and have sought to increase the pace with which innovative products are introduced to the market"	Jayaran and Narasimhan [9]
"to create something new…high level of risk that most distinguishes NPD projects from other types"	Szwejczewski et al. [10]
"Engineering design is the process of establishing requirements based on customer needs, and transforming them into performance specifications and functions, which are then mapped and converted into design solutions that can be economically manufactured using creativity, scientific principles, technical knowledge and experience."	Wang et al. [11]
"a new product is usually anything that is introduced into the market by the firm, regardless of the extent and type of newness."	Balachandra and Friar [16]
"Innovation refers to the creation of a product, service or process"	Veryzer [17]
"The most unambiguous definition of new products is to only recognize products that have been cleared by the appropriate regulatory agency (FDA, EPA, or Dept. of Agriculture) and reached the market as 'products'."	Deeds et al. [18]
"…used here, 'new' generally refers to products or services with significant change that are substantially new (for instance, believed to be patentable)."	Stevens and Burley [19]

While gathering definitions of NPD from prior research, it became apparent that various NPD processes were documented throughout literature. These variations of the NPD process were gathered and are presented in Table 2.2. These processes, along with insight from an industry partner, resulted in the definition of a four-phased NPD process: 1) Concept, 2) Design, 3) Prototype Build and Test, 4) Manufacture, Market and Sell. A further discussion of these phases follows.

Table 2.2: Various Documented NPD Processes

Source	Process Terminology	Function
Murthy et al.[8]	1) Front End 2) Design 3) Development 4) Production 5) Post-Production	Decision Making
Millson and Wilemon [20]	1) Preliminary Design Review 2) Preliminary Manufacturing Process Review 3) Develop Prototypes and Pilot Models 4) In-house Testing 5) Trial Production 6) Full-scale Production and Start up	Entry Strategies Risk Management
Ma and Zhang [15]	1) Idea Generation 2) Idea Filtration 3) Concept Formulation 4) Product Development 5) Marketing Test 6) Commercialization	Risk Management
Nepal et al. [14]	1) Need Recognition 2) Design Specifications 3) Concept Development 4) Detail Design 5) Testing and Refinement 6) Production 7) Marketing	Application of Lean Principles
Peng et al. [21]	1) Conceptualization 2) Prototyping 3) Matured	Reliability Assessment
Matheson and Matheson [22]	1) Opportunity Identification 2) Design and Development 3) Testing 4) Introduction to Market 5) Life Cycle Management	Decision Making
Urban and Hauser [23]	1) Opportunity Identification 2) Design 3) Testing 4) Introduction 5) Profit Management	Proactive Management Strategy

Table 2.2 Continued: Various Documented NPD Processes

Cooper [24]	1) Opportunity Identification 2) Design and Development 3) Testing 4) Introduction to the Market 5) Life Cycle Management	New Product Development Management
Galanakis [25]	1) Idea Generation 2) Research Design and Development 3) Prototype Production 4) Manufacturing 5) Marketing and Sales	Innovation
Unger via Yadav et al. [26]	1) Planning 2) Concept Design 3) System-level Design 4) Detailed Design 5) Integration & Testing 6) Release	Cross-phase Interactions via Spiral
Park [27]	1) Idea Generation and Strategic Evaluation 2) Feasibility Study and Set up Team Members 3) Project Planning and Risk Reduction and Performance Improvement Plan 4) Implementation of Project and Validation of Project 5) Product Realization and Performance Feedback	New Product Development Management
Millson et al. [28]	1) Idea Generation 2) Product Screening 3) Product Development 4) Commercialization	Time-to-Market Reduction
Himmelfarb [29]	1) Idea Generation 2) Feasibility 3) Development 4) Production 5) Release 6) Post-Release	Quick New Product Development

Table 2.2 Continued: Various Documented NPD Processes

Barczak [30]	1) Generating Ideas 2) Screening Ideas 3) Concept Definition and Testing 4) Business Analysis 5) Development of Product Prototype 6) In-house Prototype Testing 7) Customer Prototyping 8) Market Testing 9) Market Introduction	Telecommun-ications Industry
Page [31]	1) Concept Search 2) Concept Screening 3) Concept Testing 4) Business Analysis 5) Product Development 6) Product Testing 7) Commercialization	Establishing Norms
Cohen et al. [32]	1) Concept Generation 2) Product Design 3) Engineering Analysis 4) Process Analysis and Design 5) Prototype, Production, and Testing	Product Performance

2.1.1 Concept Phase

The *Concept Phase* could also be described as the idea generation phase. During this phase, a market is determined to have a need, which the firm chooses to fulfil [15], [23], [25], [28]. Basic customer and design requirements are determined to guide product design.

2.1.2 Design Phase

During the *Design Phase*, requirements are used to create a concept product [5], [26], [32]. According to the industry partner, during this phase computer models are generally used to create the product digitally. The intended use of the product and desired customer target groups structure dimensional requirements and material selection for the design [17].

2.1.3 Prototype Build and Testing Phase

The *Prototype Build and Testing Phase* produces an initial physical product [25], [30], [31]. This physical product is then used for quality and reliability testing. Depending on the product, this can include both physical components and software support [27], [32]. The prototype build is used to validate the design, identify manufacturability concerns, and develop and evaluate assembly and test fixtures [23]. Depending on the level of technology being developed and the technical know-how this cycle can become iterative [26], [33].

2.1.4 Mass Manufacture, Market and Sell Phase

Once a product has passed through prototype build and testing, it moves to the *Mass Manufacture, Market, and Sell Phase*. At this phase, the product is produced in a volume according to internal demand forecasts. The product is then marketed to the public with the goal of selling as many units as possible [22], [24], [31].

NPD processes have been presented and a process has been formulated to be used for the work herein. The next section will explore the success measures and risk factors that impact the performance of a NPD project.

2.2 New Product Development: Measures of Success

New Product Development projects are known for having low success rates [3], [24], [34]. Prior researchers have defined or discussed success in NPD in many ways (Table 2.3). For the purpose of the work herein, success in NPD is defined as entering into a targeted market at a strategized time with an innovative product in the demanded quantity that a customer base desires. To provide bounds on the success measures that influence NPD success, six success measures will be evaluated: budget, time-to-market, profit, quality, market acceptance, and market share. These success measures are discussed in the following sections.

Table 2.3: Definitions and Summaries of Success in New Product Development

Definition of Success in New Product Development	Source
"Necessary for successful NPD 1)top management support for innovation 2) R&D, marketing and manufacturing competence and coordination 3) involvement of suppliers and customers in the design process 4) product quality 5) nature of the market 6) development time"	Afonso et al. [35]
"New Product Development Success: market share, profitability, break even time"	Jayaran and Narasimhan [9]
"companies that innovate both product and processes consistently emerge at the top, in terms of profitability"	Yadav et al. [26]
"develop and produce exactly what customers want, when they want it"	Ogawa and Piller [34]
"factors affecting success in NPD: product quality, product cost, development time, development costs, and development capabilities"	Iamratanakul et al. [36]
"measures of new product performance include: financial objectives, market share objectives, technical objectives"	Montoya-Weiss and Calantone [37]
"measures of success: effectiveness (market success), efficiency (meeting budgets and schedules), and speed-to-market"	Sivasubramaniam et al. [38]
"a project's value is a function of performance, cost, time, market requirement and market payoff"	Huchzermeier and Loch [39]
"success dimensions: project efficiency, impact on customer, direct business and organizational success, and preparing for the future"	Shenhar et al. [40]
"Success can be measured in terms of market achievement, technical achievement and financial achievement…success criteria: technical performance, efficiency of project execution, managerial and organizational implications, personal growth, project termination, technical innovativeness, manufacturability and business performance."	Freeman and Beale [41]
"The company's allover new product performance depends on: process, organization, strategy, culture, and commitment…NPD performance is a multidimensional concept"	Cooper and Kleinschmidt [42]
"Engineers make sense of the success or failure of their nascent products by constructing common narratives, not by conducting a routinized cost-benefit analysis."	Smith-Doerr et al. [43]

2.2.1 Budget

Prioritizing projects helps a firm choose where to focus its time and resources [44]. Budget refers to the financial resources a firm has to dedicate to a project [45], [46]. An important aspect of setting a budget is knowing when to start a project. Project start dates could impact the cost of operations and should be taken into consideration [39]. Many companies implement a Failure Modes and Effects Analysis (FMEA) to evaluate the status of a project's budget and to discover if the project is on track to be completed under that budget [47]. Shenhar et al. found that low technology projects tended to be finished under budget, whereas high technology projects struggled to keep within budget due to new technology use and development [40].

2.2.2 Time-to-Market

Time-to-market (T-to-M) can be defined as a strategy to limit the time it takes a product to go from an idea to being able to be purchased by the end user [48][49]. Reducing time to market makes use of strategies that include reducing manufacturing times, which can directly affect the design of the end product. A simple example of this would be the use of snap-fits in place of screws in a design; this is an example of Design for Assembly (DFA). Katz et al. presented various time-to-market strategies reported in literature including concurrent engineering, focus on value-added activities, and the use of cross-functional teams [48].

Teams composed of experienced members shorten time-to-market [38]. Millson et al. identified five steps to streamline the NPD process when applied to the entire process and all departments involved: simplify tasks, eliminate delays, eliminate steps, speed up operations, and execute parallel processes [28].

Being the first to market reduces the amount of time a company is able to spend developing its product and strengthening its supply chains [48]. Pioneering development costs are usually taken by a leader in the market in order to retain its "persistence of leadership" [50]. There are documented trade-offs between time-to-market and other measures (e.g., quality and cost) [51], [52]. Rushing a product to market can result in low quality, e.g., from not establishing robust reliability testing, and an increased production resource costs to compensate for reduced design time [45], [53]. With global markets demanding increased quality, balancing the various design factors and process decisions is a challenge for many firms [21].

2.2.3 Profit

Firms participate in NPD projects to increase the income or profit that they receive from selling goods. A study by Barczak found that 78% of firms are either first or early movers into a market; this is done to increase their potential profits [30]. Entry strategies have been found to be deciding factors in potential profits [33], [54], [55]. Entry strategies investigated by Evanschitzky et al. included product development within a single company, acquisitions, licensing, alliances and joint ventures [6].

2.2.4 Quality

The quality of a product is a subjective measure that many researchers and firms have tried to quantify [33], [56]. Garvin defines quality as pleasing the customer; his research indicates eight levels quality can be evaluated: performance, features, reliability, conformance, durability, serviceability, aesthetics, and perceived quality [56]. In a survey with 131 responses, Millson and Wilemon found the use of various entry strategies differed significantly in terms of perceived risk; acquisitions and licensing proved to be perceived as less risky and as being of a higher quality product, moving the NPD cycle from internal development to relying upon external sources [20].

2.2.5 Market Acceptance

The timing of a market entry for a company can be a strong indicator of how successful it will be in that market and how likely the market will receive or accept the new product [49]. Research suggests that entering a market just one month earlier can increase profits over the life of the project by more than 3% [49]. Research done by Bayus et al. for example, has found that it is possible to maximize profits by being a later-entry company if the later product has increased performance [57]. There are also various external factors that affect the success of a product if the market is a new or existing market [16]. Research shows that market competitiveness has a large effect on the success of a product, but the research into why this correlation exists has not been well documented [37].

2.2.6 Market Share

Markets are dynamic environments that require companies to adopt and change as needed to retain customers [58]. Market share is a way to measure the influence of a firm on a market [55]. Firms that have a smaller market share are generally viewed by the customer as not being worth the investment of purchasing the product [24]. Operating in a market with many competitors creates a challenge of increasing market share; more choices tend to make customers more willing to change or try a new brand of product [59]. The innovativeness of a product contributes to the market performance of the product [60].

2.3 New Product Development: Risk Factors

The literature includes a range of definitions for risk in NPD. A selection of the definitions or observations are included in Table 2.4. For the purpose of the work herein, risk factors in NPD is defined as factors that can impede the success of a New Product Development project.

Table 2.4: Definitions and Summaries of Risk in New Product Development

Definition of Risk in New Product Development	Source
“Risk refers to the possibility that a newly developed product might fail due to various uncertain factors”	Mu et al. [61]
“Risk has three basic components: the amount of a resource that might be lost, the probability that a specified amount of a resource might be lost and the degree to which a resource is exposed to loss.”	Millson et al. [20]
“Risk is actually that all possible consequences that we can beforehand learn and the probability of occurrence in all consequences…New product development risk usually induces to product development failure.”	Zhang and Ma [12]
“Risk usually refers to the likelihood of a negative or undesirable outcome….in R&D much of the risk comes from a lack of knowledge…a project management matter”	Szwejczewski et al. [10]
“realize what could go wrong in the product design and development project at any given point of time during the project”	Gosnik [62]
“uncertainties about the market, the technology, the cost of production and the process development itself”	Balachandra and Friar [16]
“an event, which should it occur, would have negative effect on the achievement of a projects objectives”	Wideman [63]
“Risk considered were categorized into eight areas: schedule, technical, external, organizational, communication, location, resource, and financial”	Kayis et al. [64]

While gathering definitions of risk to NPD projects, it was observed that different risk factors were identified that impacted NPD projects. These risk factors have been documented in Table 2.5. By identifying potential risks, firms can generate more robust designs and therefore increase their overall success [65].

Table 2.5: Risk Factors that Impact the Success of NPD

Risk Factors	Source
-Technical and Production Synergy and Proficiency -Marketing Knowledge and Proficiency -Newness to the Firm -Product Uniqueness/Superiority -Market Competitiveness and Customer Satisfaction -Marketing and Managerial Synergy	Cooper [24]
-Product Advantage -Technological Synergy -Company Resources -Strategy -Marketing Synergy -Proficient Technical Activities -Proficient Marketing Activities -Protocol -Top Management Support/Skills -Professional Pre-development Activities -Speed to Market -Financial/Business Analysis -Costs -Market Potential -Market Competitiveness -Market Environment -Internal/External Relations -Organizational Factors	Montoya-Weiss and Calantone [37]
-Marketing Resources and Skills -Competitive and Maker Intelligence -Technical Resources and Skills -Proficiency of Technical Activities -Product Quality	Calantone et al. [6]
-Emphasize Marketing -Marketing Technologies and Strengths -Competitive Environment -Technology Strategy tied to Business Strategy -Process Well Planned -Training and Experience of Human Resources	Balachandra and Friar [16]

Table 2.5 Continued: Risk Factors that Impact the Success of NPD

Risk Factors	Source
-Product Change -Source of Idea -Newness to the Market -Newness to the Firm -Product Offering -Technology Change -Market Research -Market Testing	Goldenberg et al. [66]
-Product Advantage -Market Knowledge -Clear Product Definition -Risk Assessment -Project Organization -Project Resources -Proficiency of Execution -Top Management Support	Tidd and Bodley [67]
-Quality Variation -Production Cost Variation -Development Timing Variation -Human Resource Variation -Productivity Variation -Technical Difficulties -Learning Abilities -Technology Changes -Changing Project Requirements -Changing Project Team Members -Changing Organization Priority -Changing Management Commitment -Conflict within Organization -Changing Customer Needs -Market Size and Growth -Competitors -Changing Economic Condition -Changing Social Conditions -Supplier Reliability -Incompatible Fit with Supplier -Part Production Cost -Supplier Quality Variation -Supplier Part Production Realization Timing -Changing Supplier Relations	Park [27]

Table 2.5 Continued: Risk Factors that Impact the Success of NPD

Risk Factors	Source
-Clarity of Project Objectives -Project Timeline -Employee Perceived Management Authority	Gosnik [62]
-Customer Demand Forecast -Market Structure Change -Value Chain Integrity -Technical Foreground -Technical Effect -Technical Lifetime -Enterprise Strategy -Resource Plan	Ma and Zhang [15]
-Personnel Resources -Economic Investment -Political Issues -Supplier Problems -Management Delays	Dehghanbaghi and Mehrjerdi [1]

In collecting risk factors that effected the success or failure of a project, Cooper established categories of the different success measures and variables or risk factors [24]. For example, Cooper stated that technical and production synergy and proficiency were dependent upon a firm’s resources, proficiency of process activities, information acquired (technical and market knowledge), and the commercial entity itself.

After reviewing over 300 NPD projects, Calantone et al. formed a model of managerial controlled factors: marketing resources and skills, competitive intelligence, technical resources and skills, proficiency of marketing activities, product quality, and proficiency of technical activities. Introducing market effects was out of the scope of the study. Evaluations of these factors to the responses to the surveys resulted in the model being a good fit for industry [6].

Ma and Zhang identified 3 major classifications of risk in NPD with subsets: 1) market risks, which include customer demand forecast, market structure change and value chain integrity, 2) technical risks which include technical foreground, technical effect and technical lifetime, 3) management risks, which include enterprise strategy and inaccurate resource plan [12].

2.4 Chapter Summary

This chapter has presented prior research in the field of New Product Development (NPD). A collection of NPD definitions was gathered and a new definition for NPD was presented based on the prior research and input from an industry partner. The goal in creating the definition was to identify what fields of research would support research into the Reference Design process and to identify what fields this work could contribute to. In particular, the work herein focuses on developing products, rather than services. Another goal in defining NPD was to create a definition that did not include the defining words, as was common in literature. In viewing Table 2.1, it can be seen that many of the definitions contain the word new or product, resulting in weak definitions.

Next, a collection of NPD processes are offered (Table 2.2) and an NPD process is presented that is based on prior research and input from an industry partner. This process is presented to support the definition of a Reference Design process. Prior NPD process definitions have not been proposed that support the use of two firms to complete the product cycle as the Reference Design process does.

Finally, defining the success measures and risk factors associated to NPD resulted in identifying many risk factors that influence NPD projects (Table 2.5). To evaluate a Reference Design process and a traditional NPD process, 16 risk factors have been selected (Table 3.2). These risk factors were derived by the importance placed by prior research on the risk factor, with input provided from an industry partner to ensure correlation between research and practice.

The next chapter provides the manuscript to be submitted to a peer reviewed journal which describes the work completed as a part of this research to better understand the Reference Design process and its similarities and differences to the New Product Development process.

CHAPTER 3: EXAMINING THE REFERENCE DESIGN PROCESS AS A NEW PRODUCT DEVELOPMENT PROCESS

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To be submitted to a peer reviewed journal.

Abstract

More than half of all New Product Development projects are never brought to market. Project stakeholders in unsuccessful projects might perceive money and time invested in the projects as a waste. This perception could create a frustrating environment for all contributors to the project. However, failure is an integral part of new product development and especially for highly innovative products. As a result, there is a challenge to devise methods that help identify failed products early in the design process. The ability to make early “go/no-go” decisions can reduce the cost of the full NPD process by mitigating the need for feedback after market release. Thus, increasing the proficiency of NPD projects is a necessity for companies to remain competitive in today’s global economy. An exploratory investigation of a new approach to high-risk product development, called a reference design process, is conducted herein. Specifically, factors that impact the success or failure of NPD projects are identified and compared to those for the Reference Design process. The results show that the Reference Design process is driven by the same risk factors as the traditional NPD process, but that different factor dependencies exist. It is concluded that the Reference Design process is a method to assist companies in bringing new products to market, while reducing the risk inherent to the traditional NPD processes. To enhance transferability of the concept, additional fundamental research is needed to better specify the reference design process.

3.1 Introduction

New Product Development (NPD) is a process internal to a company to introduce a product to market. Each company has its own way of achieving this goal. Methods of achieving project success vary from company to company, and a common language has not been established. This lack of standards inhibits clear communication among firms and researchers. The definition of NPD project success also differs across industry, and is dependent upon a company's organizational goals. One company, for example, may value high profits, whereas another company may focus on being the first to market with a product. The work herein addresses these issues by reviewing research into current NPD methods, and defining success and risk factors for NPD projects. An NPD process involving two companies, called a Reference Design, is then evaluated using these risk factors to determine if it is driven by the same risk factors as a traditional NPD project.

3.2 New Product Development

The available research on the topic of New Product Development (NPD) is extensive and explores many different industries [1]–[3], [5], [6], [9], [26], [34], [12], [68], [69]. The current rate of NPD projects successfully being introduced to market is only about 25% [3]. Prior research has been used to identify six success metrics and 16 risk factors that affect six major success measures that drive NPD projects (Table 3.2).

3.2.1 New Product Development Process Definition

The continuous development and introduction of new products is essential for a company to remain competitive in today's global market [1], [2], [5], [6], [70]. A new product can refer to a variation in the design of a current model or to an entirely new product concept [49]. Prior research has defined the process of new product development (NPD) [1], [5], [7]–[12]. However, no single NPD process has been established as an industry standard [12].

The lack of widely accepted NPD standards has led to an array of solutions and procedures for successful completion NPD projects (Table 3.1). NPD is a continuous process that is often tailored to the requirements of different markets. Consequently, a single standardized process might be unsuitable for all NPD efforts [15]. For example, a high tech gadget requires different design aspects than a garment from the fashion industry. Not only are the product attributes very different, the customer demand also varies. As a result of lacking NPD standards, no common terminology has emerged to assist designers, engineers, and other stakeholders in communicating across NPD projects [36], [65]. In this environment, there is no shared meaning, so it is difficult to share lessons learned, or to communicate best practices.

For the purposes of this work, *New Product Development* is defined as a business process for efficiently and effectively bringing an innovative good to market [1], [5], [7]–[12]. A collection of NPD processes follows, concluding with a selection of terms related to risk and success that will support the work reported herein.

3.2.2 New Product Development Process Terminology

No apparent standard process was found in academic or industrial research literature to support new product development and to ensure product success. Prior research has attempted to define the multi-staged and iterative NPD process, as summarized in Table 3.1. The goal of this prior work was to assist in the creation of a variety of new products that could be successfully marketed and sold for a profit.

Although the number and naming of process steps differ among the definitions, the intent of the overall NPD process is largely unchanged among the various established definitions. For example, the first step in the NPD process defined as “opportunity identification” by Matheson and Matheson [22] has an equivalent meaning to “need recognition” defined by Nepal et al. [5]. It may be noted that not all NPD process definitions begin with this step; some processes begin with the generation of ideas or a preliminary design review [9], [33]. Thus, the line dictating the start of an NPD project can be blurred [55]. No research was found to support one documented NPD process over the others, and this ambiguity only adds to the difficulty of successfully initiating, conducting, and completing an NPD project.

Table 3.1: NPD Process Phases and Purpose

Source	Defined NPD Process Phases	Purpose
Murthy et al. [8]	1) Front End 2) Design 3) Development 4) Production 5) Post-Production	-Design Decision Making
Millson and Wilemon [33]	1) Preliminary Design Review 2) Preliminary Manufacturing Process Review 3) Develop Prototypes and Pilot Models 4) In-house Testing 5) Trial Production 6) Full-scale Production and Start up	-Entry Strategies -Risk Management
Ma and Zhang [15]	1) Idea Generation 2) Idea Filtration 3) Concept Formulation 4) Product Development 5) Marketing Test 6) Commercialization	-Risk Management
Nepal et al. [5]	1) Need Recognition 2) Design Specifications 3) Concept Development 4) Detail Design 5) Testing and Refinement 6) Production 7) Marketing	-Application of Lean Principles
Peng et al. [21]	1) Conceptualization 2) Prototyping 3) Matured	-Reliability Assessment
Matheson and Matheson [22]	1) Opportunity Identification 2) Design and Development 3) Testing 4) Introduction to Market 5) Life Cycle Management	-Design Decision Making
Urban and Hauser [23]	1) Opportunity Identification 2) Design 3) Testing 4) Introduction 5) Life Cycle Management	-Design Decision Making
Cooper [24]	1) Opportunity Identification 2) Design and Development 3) Testing 4) Introduction to the Market 5) Life Cycle Management	-New Product Development Management
Galanakis [25]	1) Idea Generation Research 2) Design and Development 3) Prototype Production 4) Manufacturing 5) Marketing and Sales	-Innovation

Extensive research has been conducted on New Product Development projects [8], [26], [33], [34], [45], [57]. Table 3.1 outlines several specifications for the NPD process. For this study, the NPD process is specified as the 1) Concept Phase, 2) Design Phase, 3) Prototype Build and Test Phase, and 4) Manufacture, Market, and Sell Phase (Figure 3.1). This definition of the NPD process and terms used for the various phases were influenced by the prior work reviewed above, and considered the input from the industry partner for the case study presented in Section 4 in support of the research. The selected process model is similar to that reported by Galanakis, the phases are defined and discussed in later sections [25].

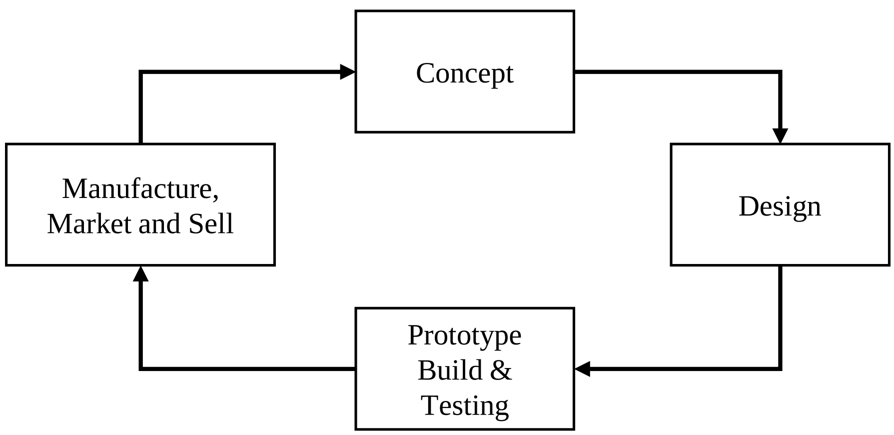

Figure 3.1: New Product Development Process

During the *Concept Phase*, a need is determined that requires a solution, initial ideas are generated, and basic design requirements are determined. Creation of product requirements occurs in the *Design Phase*, where computer models are often used to create a product digitally. The *Prototype Build and Test Phase* transforms the digital product into a physical product, which is then used for quality and reliability testing.

The prototype build is used to address concerns of manufacturability and to develop and evaluate assembly fixtures and test fixtures. If there are faults found with the prototype, the project will cycle back to the design phase to address the issues. This iterative cycle continues until a defined level of quality is reached.

Once a product has progressed through the Prototype Build and Test Phase, it moves to the *Manufacture, Market, and Sell Phase*. In this phase, the product is manufactured in volumes according to the expected demand for the product. The product is also marketed to the public with the goal to meet the expected demand through commensurate product sales. That is, the manufacturer wants to avoid overstocking, but also wants to meet all customer demand.

New product development is critical for a firm's continued success, but NPD projects can be a potential source of failure (e.g., negative return on investment or limited market share due to limited market acceptance). New product development projects report about 25% or fewer projects achieving a market presence [34]. Thus, it is advantageous for a company to understand the risk factors that contribute to NPD project success [69].

3.2.3 Success Measures and Risk Factors in New Product Development

Defining the success in NPD is considerably difficult. Much like the NPD process itself, definitions of NPD success vary from company to company and from market to market [40]. NPD success has been defined as follows: long-term shareholder value (Starbucks) [71], exceeding customer expectations (Disney) [72], and net customer satisfaction (Microsoft) [73]. For this research, *Success in New Product Development* is defined as entering into a targeted market at a strategized time with an innovative product in the demanded quantity that customers desire [9], [26], [34], [35]. Several risk factors commonly play a critical role in the success of an NPD project [3], [5],

[33], [49], [51], [68]. For this study, six relevant success measures were identified from reviewing prior research: 1) Budget, 2) Time-to-Market, 3) Profit, 4) Quality, 5) Market Acceptance, and 6) Market Share.

The budget that a firm sets is calculated by evaluating resource planning and predicted material costs, and then adding a safety buffer [74]. An increased budget allows for more experienced personnel and the use of higher quality parts. Increasing a budget, however, increases the break-even cost. Time-to-market is the strategy that a firm uses regarding the timing of market entry, and can determine the success of a project [26], [35]. Profit is the financial gain that a company envisions with the sales of a product [68]. The quality of a developed product, as defined by Garvin, includes eight measures [56]: 1) Performance, 2) Features, 3) Reliability, 4) Conformance, 5) Durability, 6) Serviceability, 7) Aesthetics, and 8) Perceived Quality. Market Acceptance refers to the ease of which a new product is embraced by industry [33]. Market Share is a measure of influence that a company has on a particular industry [68].

The interactions between the six selected success measures can be seen conceptually in Figure 3.2 [3], [16], [41], [75]. A solid line in the figure represents a positive correlation (for example, an increase in budget reduces the time-to-market, increasing the success of both measures). A dashed line in the figure represents a negative correlation (for example, the increased cost of high quality has a negative impact on the budget for the project [33]).

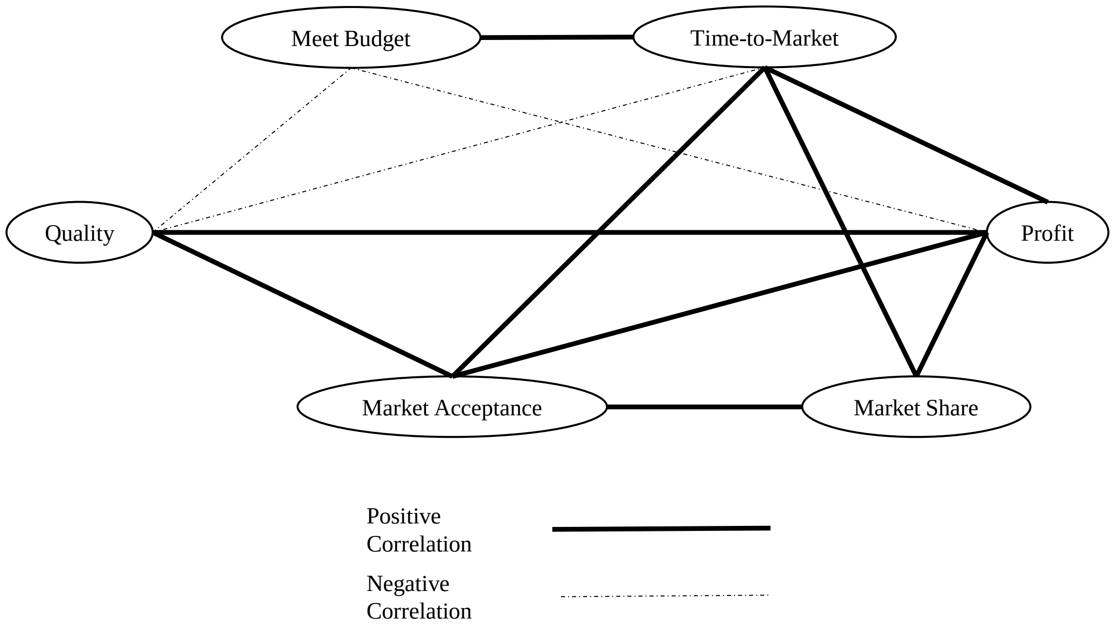

Figure 3.2: Interactions of Identified NPD Success Measures

The various interactions highlight why determining one NPD process to produce a new product is not easy. It can be seen, in addition to being interrelated, that the influencing factors can also be in competition. Thus, trade-offs must be made in arriving at final project decisions. Mutually exclusive trade-offs force a firm to prioritize desired outcomes. For example, as a firm works toward a decreased time-to-market, the budget for the project must increase to fund more personnel, overtime, and other measures to reduce design time [68].

NPD projects are essential for a company to remain competitive and retain customers. However, there are many risk factors in NPD projects that can lead to failure. *Risk factors in New Product Development* projects can be defined as factors that can impede the success of a NPD project [1], [2], [10], [33]. Little research has been conducted in risk management with regard to NPD projects [1]. It has been established that a risk management strategy can increase NPD performance, but understanding and classifying risks is challenging [61]. Identifying potential risks serves to create more robust designs, creating a better end product [12].

Various research efforts have been published describing different risk factors in NPD [1], [6], [24], [12], [62]. Several factors utilize different terminology to indicate similar issues. For example, Cooper [24] refers to “Market Need, Growth, and Size,” whereas Ma and Zhang [12] define “Market Structure Change” to address the uncertainties within a market. A concise list of the risk factors has been collected from prior research (Table 3.2), and will be used to evaluate different NPD projects resulting from the case study below. The placement of “X” in (the table) signals that a relationship exists between the risk factor and the success measures as reported in prior research. For clarity of the table, abbreviations have been made for the success measures as follows: budget (B), time-to-market (T), profit (P), quality (Q), market acceptance (MA), and market share (MS).

Table 3.2: Effect of Risk Factors on Success Measures in NPD

		Success measures					
Risk Factor	**Definition**	B	T	P	Q	MA	MS
Customer Demand	The willingness and desire of a customer for a product			X		X	X
Economic Investment	Purchase of goods or capital	X		X	X		
External Political Issues	Laws, regulations or restrictions that are outside of company control			X			
Internal Political Issues	Culture, processes, personnel structure that are within company control	X	X		X		
Management Authority	Personnel with influence to prioritize, create or cancel projects, hire or fire other personnel.	X	X				
Management Delays	Unproductive time loss waiting for Management to make decisions and communicate to project teams		X				
Market Structure Change	Number of firms producing similar products increases or decreases		X	X		X	X
Marketing	Company promoting a product or service	X		X			X
Personnel Resource	People employed by a company	X	X				
Project Clarity	Defined schedule, priority, goals, resource allocation and budget of a project		X				
Project Scheduling	Start, milestone and end dates of a project	X	X				
Supplier Selection	Choosing a producer of a good that is required for a project	X	X		X		
Technical Focus	Company's specialization in a field				X	X	X
Technical Lifetime	Time a product is design to function over				X	X	
Technical Skills	Proficient abilities to perform specific tasks	X	X			X	
Value Chain Integrity	A balanced, fluid system of firms, resources, information, activities and goods that work toward a common goal	X					

In summary, budget, time-to-market, profit, quality, market acceptance, and market share have been established as success measures for the work herein [1], [5], [6], [10], [33].The success measures can be negatively affected by the risk factors as outlined in Table 3.2. The following section will provide details of the method used for the exploratory research.

3.3 Research Methodology

A two-part exploratory method was selected to gather information from an industry partner about the NPD process. The partner employs an NPD process they term the Reference Design process. There is a lack of subject matter experts within the current field of research on NPD. Limited documentation and knowledge of the Reference Design process has led to poor understanding and, ability to effectively manage the process. The aim of this study was to 1) describe the Reference Design Process and 2) identify similarities to and differences from traditional NPD processes.

To describe the Reference Design process, an in-depth exploratory study (Study 1) was undertaken. The study was primarily conducted through snowball interviews of experts in Reference Design. Interview responses were transcribed into a case study. The case study was then analyzed based on the factors that impact success of failure in normal NPD processes. The ultimate goal of this study was to determine if the factors that contribute to success or failure in the Reference Design process are similar to those in traditional NPD processes. The Reference Design process is undocumented in research literature. Thus, to collect information about the process, an exploratory investigation of the Reference Design process was required and undertaken within a silicon chip manufacturing company.

The exploratory study approach is common in research that seeks to describe new, and previously uninvestigated practices [13]. The investigation was composed of two studies. The first study, focused on achieving a basic understanding of the Reference Design process. The second study, focused on comparing the Reference Design process to a traditional NPD processes. The flow of research can be seen in Figure 3.3.

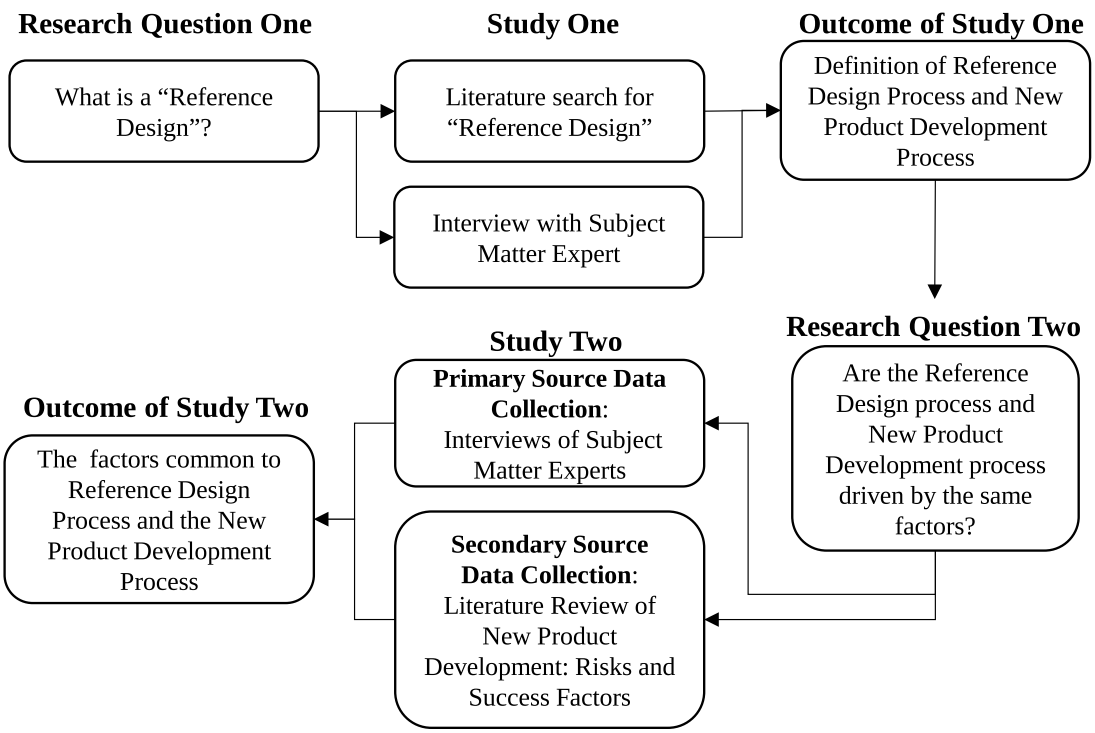

Figure 3.3: Flow of Exploratory Research

3.3.1 Industry Setting

The chip manufacturer studied was successful in developing and establishing two key technological advancements in the market: silicon computer chips for desktop computers and the laptop computers. In each case, slightly different NPD approaches were used. These NPD approaches followed the Reference Design process (Section 3.2). In the new smartphone and tablet market, however, the company struggled to achieve success with the Reference Design approach. Thus, in order to manage the transition to the smartphone and tablet market, the company desired to identify underlying success measures of the Reference Design process. First, it was necessary to investigate if the Reference Design process is driven by the same success measures as the traditional NPD process. To learn more about the Reference Design process and its historical progression of NPD within the company, an exploratory interview investigation with subject matter experts was conducted.

3.3.2 Study Participants

Eight subject matter experts who had extensive experience with the Reference Design process were recruited and agreed to participate in interviews. Participants had been with the company for 12-27 years. Table 3.3 records the employment start date at the company for each interviewee, along with the Reference Design projects in which the interviewees had participated during their employment. Six of the eight experts had project exposure to desktop technology, four had exposure to laptop technology, and five of eight had exposure to smartphones and tablet technology.

Table 3.3: Summary of Interviewee Experience

Interviewee	Start Year	Desktop	Laptop	Smartphone/Tablet
1	1987	X	X	X
2	1995			X
3	1995	X	X	
4	1996	X		X
5	1997	X	X	
6	1998	X		
7	1998		X	X
8	2002	X		X
Total	144 years	6 of 8	4 of 8	5 of 8

3.3.3 Procedures

The study was approved by the Oregon State University Institutional Review Board. An introductory email was sent to each participant, and agreement to an interview was taken as consent. The developed questions were then sent to the participants prior to the interview. Interviews lasted from 30 minutes to an hour, depending on the participant, and each was asked the same set of questions (Appendix A). During the interview, participants' verbal responses were recorded as digital audio files (.mp3 format), and later transcribed verbatim into digital text files (MS Word). At the conclusion of each interview, the interviewee was asked if he or she knew of another person who would have sufficient knowledge of the Reference Design process to contribute to the study. This snowball effect allowed for the interviewer to contact participants who were otherwise unknown to the interviewer.

3.3.4 Interviews and Data Extraction

To accommodate participants' schedules, one-on-one, face-to-face interviews were conducted in November and December of 2013. Pre-designed questions were used to start the interview. There were deviations from the script when the interviewee would make an unexpected comment, and the interviewer could chose to collect more information on the new subject. Formulated questions were as follows:

- How does the (Desktop, Laptop, or Smartphone and Tablet) Reference Design product differ from a product of the traditional NPD process?
- How was the project (i.e., Desktop, Laptop, or Smartphone and Tablet) successful?

- How did it fail?
- What risks did the project face?
- What improvements would you have made if you could?
- What role did external partners/supply chain make to the success/failure of the project?

The recorded responses were classified according to the research questions above, since they pertained to the three levels of technology investigated. Of special interest was the interviewee's identification of risk factors experienced by each of the projects. Identified risk factors from prior research were later compared to the findings from the interviews, as described below.

3.4 Results of the Two Studies

The first study was initiated to identify the Reference Design process that was unknown to the researchers, although commonly used by the chip manufacturer. The second study used the results from the first study, which identified the Reference Design process in use as a NPD process. The first study led to the research goal of the second study, which was to determine if both processes were driven by the same measures of project success. The details of both studies are presented below.

3.4.1 Study One

In discussing their NPD process, the chip manufacturer used the term "Reference Design" as a universally understood term, but the term is not commonly used nor is the process documented in the literature. To gain understanding of the Reference Design process, a discussion and a process walkthrough was conducted with a single subject matter expert who had 15 years of experience with the chip manufacturer. This individual had experience with the desktop and smartphone and tablet Reference Design processes. To reduce skewing of broader interview results, this expert did not participate in the second study.

Based on the discussion, the Reference Design process was found to be a method of bringing new products to market that is fundamentally different from the traditional NPD process. The Reference Design process has one key difference from previously identified NPD processes: it involves two companies to bring a new product to market. The Reference Design process (Figure 3.4) also differs from the traditional NPD process (Figure 3.1) by adding a revision step that assists with the communication between the two companies. The use of a Reference Design process allows for a single company to become specialized in either the design or manufacturing of advanced technology.

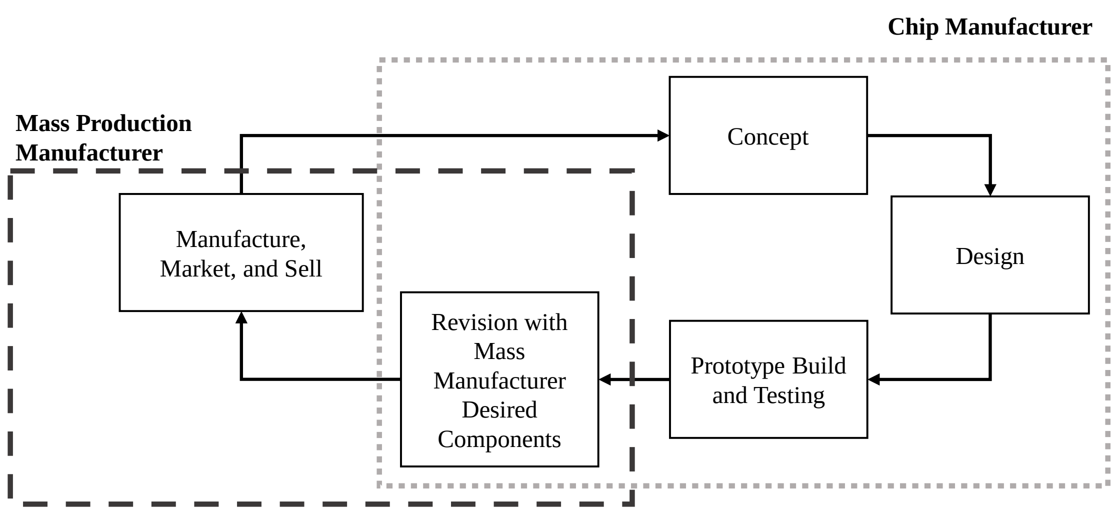

Figure 3.4: Reference Design Process

A literature search was conducted to gain better understanding of the Reference Design process and to determine what prior research had been conducted in this arena. The literature search was conducted by searching a set of keywords within the Web of Science database (Table 3.4). Results obtained in this manner did not fit the use of the term described by the subject matter expert (Table 3.4). While the topic "Reference Design" resulted in over 400 results, these results primarily focused on the use of a Reference Design, and not the process of bringing a new product to market. It should be noted the results of *Reference Design* and "*Reference Design*" are different because the use of quotations in a database search forces the search for the two words together, whereas without quotations the database searched for each word individually.

Table 3.4: Keyword Search from Web of Science Database

Keyword	Number of Results	Top Topic Areas
Reference Design (Topic)	52,045	Electrical Engineering Electronic, Medicine General Internal, Automation Control
"Reference Design" (Topic)	408	Nuclear Science Technology, Physics, Engineering
Reference Design (Title)	631	Electrical Engineering Electronic, Automation Control Systems, Nuclear Science Technology
"Reference Design" (Title)	52	Electrical Engineering Electronic, Nuclear Science Technology, Computer Science Interdisciplinary Applications

It was also found that terminology has different meanings in different fields. For example, the use of the word "reference" can refer to a locational state [76], while a "reference design" can refer to circuitry [77]. The concept of a reference design for electronic circuitry is used to describe a set of rules used to create a product. The lack of information in literature about the process used to create a Reference Design sparked the need for more information to be gathered on this topic from subject matter experts.

3.4.2 Study Two

Given the apparent industry clustering (automation, electrical, computer, and nuclear) in Table 3.4, it is possible that a Reference Design process can be applied to manufacturing activities across various industries. The Reference Design process described above displays several similarities to the traditional NPD process, e.g. as described by Galanakis [25]. In study two, the focus was on comparing the risk factors that drive Reference Design projects and NPD projects to elucidate any operational similarities and differences.

The primary goal of an NPD project and a Reference Design project is to bring an innovative product to market. The Reference Design process used by the chip manufacturer also serves to validate the functionality of the chipset within a variety of devices (e.g., desktops, laptops, and smartphones and tablets) and to demonstrate the capabilities of the integrated platform to potential mass production manufacturers. The discussion that follows takes a closer look into the success measures for each of the three technologies analyzed in this study: desktops, laptops, and smartphones and tablets.

3.4.2.1 Technology 1: Desktops

In the 1970s, computer manufacturers performed fully integrated operations; they created circuit board layouts and component selection in-house. The computer manufacturer would then communicate desired requirements to the chip manufacturer. A tipping point occurred when the computer manufacturers decided that the end customer did not require a faster processor and did not want to upgrade the processor on future models. The chip manufacturer wanted to continue to push their chipsets onto the market, however, so it developed a next generation desktop Reference Design to demonstrate the higher performing chipset configuration. The Reference Design consisted of a completed product, which included hardware, software, silicon mapping, testing equipment, component supplier selection, and build support for production runs.

When asked about this project, interviewees expressed that the primary goal of the desktop Reference Design was to demonstrate high quality, which was required to win business contracts with large computer manufacturers. The success in quality was attributed to the technical expertise and experience of personnel working for the chip manufacturer (Table 3.2). One interviewee identified primary factors to the success of the desktop Reference Design projects as time-to-market, supply chain management, and achieving high quality. It was also mentioned that high quality led to quicker market acceptance and higher profits (Figure 3.2). Interviewees also showed a consensus on “strong management leadership” as a reason for the success of the desktop Reference Design.

When asked what they would have done to improve upon the Reference Design process for desktop projects, three of six interviewees had a difficult time offering an answer. Most interviewees concluded that cost reduction needed to be addressed to increase profits. Table 3.5 summarizes and describes the success measures, as established in Section 3.2, for the desktop Reference Design process.

Table 3.5: Success measures for Desktop Reference Design Process as Described by Interviewees

Success measures	**Interviewee Comments**
Budget	High internal technical skills already within the company made for a low cost transition into the creation of Reference Designs.
Time-to-Market	Strong management leadership and direction kept projects from side-tracking, delivering projects on time.
Profit	Marketing proficiency and customers confidence in the brand increased customer demand for the product.
Quality	Technical focus of the chip manufacturer on desktop projects created products with a high level of quality.
Market Acceptance	Technical achievement and skills led to a high opinion of products designed by the chip manufacturer. A steady market with no competitors made for easy market acceptance of the chip manufacturer's design.
Market Share	Competitors were seen to have lower quality and to be lower performing. This led to the chip manufacturer achieving market dominance in desktop designs.

3.4.2.2 Technology 2: Laptops

In the desktop market, the chip manufacturer was able to create industry standards, e.g., board size and placement of critical components. Interviewees posited that standards allowed for a shortened time-to-market by reducing the required development time. With the introduction of laptops, however, the standards developed for desktops could not be transferred to laptops.

Each computer manufacturer had a unique industrial design for their laptops, making the development and implementation of standards difficult. The user experience started to become more important to the computer manufacturers and, as one interviewee stated, this drove the size and shape of the laptop design. To keep the time advantage that standards had given the desktop projects, the chip manufacturer adopted a non-form-factor Reference Design process.

In a non-form-factor Reference Design process, the chip manufacturer would develop a circuit board that would function inside the average-sized laptop. To demonstrate the functionality of the chipset, the populated circuit board was then connected to a desktop monitor and power source. This demonstrated the functionality of the chipset, although not in the form of a laptop. Thus, the term non-form-factor laptop Reference Design emerged.

Table 3.6 summarizes the success measures, as established in Section 3.2, for the laptop Reference Design process.

Table 3.6: Success measures of Laptop Reference Design Process as Described by Interviewees

Success measures	**Interviewee Comments**
Budget	Economic investment from desktop product lines was able to transfer both equipment and personnel to laptop projects with little need for additional budget.
Time-to-Market	Maintaining and acquiring personnel with strong technical backgrounds encouraged quick project completion times.
Profit	Marketing made use of the successful desktop marketing campaigns and applied them to laptops, leading to steady sales.
Quality	The steady supply chain established for desktops was able to be adapted to laptops because similar components were used for desktop and laptop designs.
Market Acceptance	The computer manufacturers that produced desktops also produced laptops. By keeping these relationships, the chip manufacturer was able to move into the laptop market with little difficulty.
Market Share	Customers that demanded the chip manufacturer’s desktop product also demanded the laptop product. This demand led to a high market share in laptops for the chip manufacturer.

Interviewees explained that the large desktop market presence allowed for a smooth transition into the laptop market. The technical know-how for working with chipsets was already in-house, and interviewees stated the clear management direction allowed for projects to have focus (Table 3.2). These advantages contributed to a reduction in time-to-market, higher quality products, and lower project budgets. Interviewees indicated that enforcing standards in laptops also could reduce development time. One interviewee stated that trying to enforce standards in laptops was not received well by computer manufacturers; there was concern that standards would stifle innovation and alienate customers.

3.4.2.3 Technology 3: Smartphones and Tablets

For the desktop and laptop markets, the chip manufacturer had been a lead innovator, pushing chipsets into the market. Interviewees who had experience with smartphone and tablet Reference Design projects identified slow movement into the emerging market as a primary reason for the current market share (about 1% worldwide). The interviewees identified contributing factors to the market entrant delay of smartphone and tablet Reference Designs as a lack of management clarity on projects and goals, supplier problems, and the unpredictable nature of the handheld market (Table 3.2).

The initial strategy of approaching smartphone manufacturers with a non-form-factor design did not lead to market acceptance. Laptop manufacturers had accepted non-form-factor designs because they trusted the performance and quality of the chip manufacturer’s product. The smartphone and tablet manufacturers were not the same as the desktop and laptop manufacturers, however, and new relationships had to be developed. When dealing with the smaller components contained in a smartphone, there are interaction factors that are not present in a laptop space. This was not initially apparent to the chip manufacturer.

To compensate for its lack of technical knowledge, the company hired new personnel. Several interviewees stressed that the chip manufacturer had a fully functioning smartphone form-factor Reference Design project completed within six months after smartphone manufacturers rejected a non-form-factor Reference Design. Since other supply relationships are established, the chip manufacturer must have a more competitive product than existing suppliers for smartphone and tablet manufacturers to invest in their Reference Design [46]. Table 3.7 summarizes the success measures, as established in Section 3.2, for the smartphone and tablet Reference Design process.

Table 3.7: Success measures of the Smartphone and Tablet Reference Designs as Described by Interviewees

Success measures	**Interviewee Comments**
Budget	The chip manufacturer required an entirely new supply chain, along with a new set of technical skills not available within the company to transition to smartphone and tablet markets. These factors increased the cost of the projects.
Time-to-Market	When trying to enter into the already established smartphone and tablet market, upper management gave vague directions to the design teams resulting in project delays and lack of project prioritization.
Profit	Chip manufacturer customers from desktop to laptops did not change, however, smartphones and tablets are driven by different manufacturers. The chip manufacturer had a product to sell but no one to sell it to.
Quality	Lack of clear direction from the chip manufacturer's management and an influx of new personnel led to conflicting decisions impacting supplier selection. New suppliers needed to be obtained because of the different components needed for a smartphone. Forcing suppliers to produce small quantities of parts resulted in the chip manufacturer relying upon suppliers with minimal manufacturing experience.
Market Acceptance	The chip manufacturer was known for having high power consuming chipsets. It is undesirable in the smartphone and tablet market to have a high power consuming device. Industry had doubts about the capabilities of the chip manufacturer's design to reduce power use.
Market Share	The smartphone and tablet manufacturers had established relationships with competitors and had no motivation to change suppliers. This barrier resulted in very low (1% worldwide) market share.

3.4.3 Compiled Results

The risk and success measures taken from the literature were used to create Table 3.8. In the table, a binomial approach was taken to show the differences in the technologies. An “X” represents good standing or a risk factor that the company handled well for a project, whereas a “–” represents a risk factor that was not adequately planned for or executed according to the interviewees. The desktop Reference Design projects were set as the benchmark, therefore the variation from the desktop technology (~90% market share) to the laptop technology (~80% market share) was only changed based on the non-form-factor model used. This shows that the chip manufacturer had been successful in implementing both non-form-factor and form-factor Reference Designs.

The past success of implementing a Reference Design process suggests that the apparent failure in the smartphone and tablet technology (<1% market share) was due to influences beyond a characteristic Reference Design process. The chip manufacturer successfully harnessed previous infrastructure in the transition from desktops to laptops, but was unable to sufficiently harness previous knowledge and skills to the smartphone and tablet markets. This supports the premise that the nature of the product, the dynamic market, and stiff competition play a role in Reference Design project success.

Table 3.8: Reference Design Project's Accountability of Risk Factors

	Desktops	Laptops	Smartphones & Tablets	
Risk Factor	Form-Factor Reference Design	Non-Form-Factor Reference Design	Non-Form-Factor Reference Design	Form-Factor Reference Design
Customer Demand	X	X	-	-
Economic Investment	X	X	-	X
External Political Issues	X	X	-	-
Internal Political Issues	X	X	-	-
Management Authority	X	X	-	-
Management Delays	X	X	-	-
Market Structure Change	X	X	-	-
Marketing	X	X	-	-
Personnel Resources	X	X	-	X
Project Clarity	X	X	-	X
Project Scheduling	X	X	-	X
Supplier Selection	X	X	-	X
Technical Focus	X	X	X	X
Technical Lifetime	X	X	-	X
Technical Skills	X	X	-	X
Value Chain Integrity	X	X	-	-

From the table, it can be seen that the non-form-factor smartphone and tablet Reference Design had the most risk factors identified as not being accounted for. Only one risk factor was adequately accounted for. According to the interviewees, this was primarily due to tardiness to the market, personnel with inadequate technical proficiency, and an unstable market created by shortened design cycle times established by competitors. The interviewees expressed a change of industry's view of the chip manufacturer to being competitive and growth potential of their products with the use of a form-factor Reference Design.

Several levels of technology were observed that made use of a Reference Design process to bring a product to market. When evaluated with respect to the discussed risk factors, the technologies that achieved success were found to account for more of the risk factors in their planning and managerial processes under a Reference Design process, as was found to be true from prior research on NPD [2], [10], [62]. Further examination of the results will be discussed in the next section.

3.5 Discussion

The recognition that the Reference Design process, while used in industry, had been excluded from literature drove the research studies. Defining and clarifying the Reference Design process was the goal of the first study. After defining Reference Design as a New Product Development process, the second research goal was established to determine if a traditional NPD process and a Reference Design process are driven by the same risk factors. This finding could enable the future development of the Reference Design process based on fundamental NPD process research. Thus, the success and risk factors in NPD established from prior research were then used to evaluate three different technologies that have implemented various forms of the Reference Design process. NPD projects are more successful when a high number of risk factors are accounted for[10], [61].

Given the success of the Reference Design process for desktops and laptops, it is easy to question why implementing the process for smartphones and tablets resulted in failure. Interviewees identified a change in the customer-supplier dynamic, influx of personnel, an increased industry desire to deliver a unique computing experience to the end customer, and the competitive handheld market as reasons for the projects failing. These influences will be discussed in the following sections.

3.5.1 Supplier-Customer Dynamic

The silicon chip manufacturer presented industry partners with desktop and laptop Reference Designs, and would work with partners to tailor the design for desired specifications. With the smartphone and tablet market, this cycle was not established between the chip manufacturer and industry partners. The current cycle for smartphones and tablets starts with the industry partner suggesting design specifications and requirements to the chip manufacturer. This external job-shop approach forces the chip manufacturer to design without standards and without the ability to produce designs that fully utilize the power of their standard chipset. This causes longer design times and higher project budgets to produce a product that is used in a lower quality configuration, creating an inefficient product.

3.5.2 Personnel Recruitment

To become competitive in the handheld device market, the chip manufacturer recruited talent from a number of other companies. The chip manufacturer had a culture of "providing chips to the industry," and the incoming recruits came from a culture of "creating the newest and greatest device." This created internal tension among employees, while unclear directions from management about the priority of projects contributed to the unproductive environment (Table 3.2).

As seen in Table 3.8, smartphones and tablets struggled to account for the majority of the identified risk factors. With time, the chip manufacturer has been able to resolve many of the risk factors. This personnel transition process follows Tuckman's model: storming, forming, and norming [78]. The model suggests that a team first goes through a period of distrust and chaos before coming to an understanding of expectations, resulting in a well-functioning team working to achieve a common goal. The design teams are transitioning into the norming phase of the model and therefore are achieving a productive status with projects completing on time and at budget.

3.5.3 Unique Computing Experience

Device manufacturers use the creation of unique shapes and features to make a product desirable to the customer and to differentiate themselves from the competition (Table 3.2). While this variety is advantageous for the end customer, it generates design difficulties on the chip manufacturer's ability to create a Reference Design that could be easily adopted by multiple device manufacturers. Design resources are expended on creating Reference Designs that are not used in full, when an industry partner consumes only the internals of a design (e.g., chipset) and not the form of the device. As the end user environment and high tech NPD projects become closer aligned, the risk of not giving customers what they want decreases, which increases the likelihood for success for a new product [46]. Customer satisfaction creates an increased product demand and, therefore, increases the potential profits a company can receive.

3.5.4 Competitive Market

The smartphone and tablet market is a dynamic environment. Two companies, Apple and Samsung, currently control about 50% of the market share, with the remaining market distributed across a large number of companies [79]. The time and resources required to develop a Reference Design that is acceptable for companies that implement an industrial design (e.g., Apple products have a certain look, whereas Samsung devices have a distinctly different look) is less than that required for a company that does not (Table 3.2).

Interviewees indicated that obtaining one of the top two companies as an industry partner is desirable, however, the unstable market has caused the top two companies to change frequently (about every 9 to 16 months). While competition also existed in the desktop and laptop markets, the profits and market shares were more evenly distributed, making it easier for the chip manufacturer to partner with a small number of companies and collect high profits.

3.6 Conclusion

Through the use of exploratory studies, a Reference Design process has been documented and three levels of technology evaluated for success in implementation. The Reference Design process was compared to the traditional design process, and found a unique aspect to be the involvement of two industrial partners in a synergistic relationship to develop and launch a product. In addition, risk factors and measures of success for the Reference Design process were evaluated based on those reported in literature for NPD processes. Results from the exploratory study appear to confirm that Reference Design projects that accounted for higher risk factors were more successful than those that did not account for risk completely.

While this study investigated a silicon chip manufacturer, future work could identify other potential industries where a Reference Design process could be successfully implemented. A Reference Design process is a method for introducing a new product to market and could be effective and efficient for the development of larger complex systems. Future work could evaluate the relative success of Reference Design projects in comparison traditional NPD project to further understand the drivers of risk and success, as well as its potential for broader application.

A Reference Design process focuses the efforts of one company on design engineering development and allows for another company to devote resources to the development of expertise and capability in manufacturing. While the two companies are synergistically connected and design for manufacturability is a common issue, this division of specialization allows for the joint effort to produce higher quality products and distribute risk.

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CHAPTER 4: CONCLUSIONS

Within this chapter, a summary and conclusion of the research is presented. An explanation of contributions to the field of New Product Development is also offered, concluding with suggestions for future work.

4.1 Research Summary and Conclusion

New Product Development (NPD) is required for a company to remain competitive in the global market. To understand the challenges corresponding to the traditional NPD process prior research has been examined in Chapter 2. The formation of a formal definition of NPD placed bounds on the topic to be investigated. The collected NPD processes validated the ambiguity of the research area. Another definition of the NPD process was presented to support the procedure difference between a traditional NPD and the Reference Design process.

Next, the measures of success in NPD projects were presented, along with the risk factors that impact the achievement of bring to market a new product. Table 3.2 recorded the risk factors that impact the success measures in the NPD process. An exploratory study was then executed with an industry partner to take advantage of available subject matter experts on the topic of the Reference Design process, since the process was not documented in literature. Eight interviewees provided insight into the use of a Reference Design process performed in three high-tech markets; desktops, laptops and smartphones and tablets. The interviews provided information that supported the notion of increased project success when more and higher risk factors are accounted for in an NPD process [10], [62].

4.2 Contributions

Prior research in the field of New Product Development failed to document the Reference Design process. There was also no accounting of the relevant risk factors and measures of success within the Reference Design process. The research here presents the Reference Design process applied to three levels of technology (desktops, laptops, and smartphones and tablets) to elucidate the process and compare it to the NPD process. By documenting the Reference Design process it is possible to offer an alternative to the traditional NPD process across industries. However, there are limits to how the Reference Design process can be applied in other industries that will need to be addressed by producing additional research.

4.3 Opportunities for Future Work

By concluding that Reference Design and New Product Development processes are driven by the same risk factors, the next question to investigate would be whether the Reference Design process is less risky, overall, than a traditional NPD process. This is an important question, because less risky NPD processes have the potential to significantly impact the success of new product development, leading to greater success in commercialization of innovative and complex products and systems. An approach that could be taken to evaluate this question could be the formulation of laboratory or industrial simulations to simulate the process of development and production of a similar product using both methods.

Second, research could investigate what industries the Reference Design process could be applied within. While partnership competency is a driving force for success in the semiconductor industry, this does not hold in other industries [80]. The assumption that a Reference Design process can only be applied to complex products would need to be appraised. With those findings, a plan could be formulated to indicate which industries could make use of a Reference Design process.

The chip manufacturer is currently working on Reference Design projects that involve end customer integration. Thus, as another opportunity for future work, it would be interesting to observe if this integration increases project success [81]–[83]. It has been observed that involving the customer in product design within an NPD process increases the success of the final product [81]. Thus, it could be hypothesized that increased involvement of business customers in the Reference Design process would lead to a more successful NPD project and, ultimately, a more successful product. This investigative work would have to be completed over several years to account for the development time for a new products within the semiconductor industry.

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Appendix A – Interview Outline

The outline presented here was created to support the interview process as described in Chapter 3. This outline was approved by the Oregon State University Institutional Review Board. The interviewer asked the same questions to all interviewees for the different levels of technology with a focus of failures and risks to a project. Information was also collected into how success was measured for the projects. Interviews lasted in length from 34 minutes up to 54 minutes. The interviews were all conducted within one month of each other.

1. At start of interview (Interviewer Name) will give a brief intro on what and why you are here for interview:
    a. Problem statement
    b. Looking for: a comparison between the development of desktop and mobile products
2. Interview
    a. Date
    b. Name
    c. What is your job title? Primary functions?
    d. How long have you worked with (Company Name)?
        i. How long have you worked in a desktop role- Goal is to develop what reference design was composed of in “Desktop years”
            - Reference vs product
                - Difficulties in designing a reference design
            - How was it successful?-how was this measured?
            - Failures?
            - Risks?
            - Improvements?

- What part did the supply chain and external partners who contribute to these processes make you successful (failure?)

ii. How long have you worked in a mobile role- Goal is to determine if desktop reference= mobile, if not what are the differences and why

- Reference vs product
  - Difficulties in designing a reference design
- How was it successful?-how was this measured?
- Failures?
- Risks?
- Improvements?
- What part did the supply chain and external partners who contribute to these processes make you successful (failure?)

e. Is there relevant experience you have at other companies that you will draw on or compare?

i. If so, please be clear below when you are referring to current company vs other company experience

ii. How does Intel conduct new product design different than any other company?

f. Could you describe the reference design process as a series of steps/ a process?

Appendix B – Interview Results

Interviewee responses were digitally recorded (.mp3 format). The digital recordings were then transcribed by the interviewer into a text document (MS Word format). To facilitate common themes and ideas, the quotes from the documents were then put into a tabular form. To further help with understanding, another table was constructed based on main ideas and common phrases.

Table B.1 displays the experience level of each interviewee, along with a definition of what a Reference Design is.

Tables B.2-B.4 display the interview results for the Desktop Technology.

Tables B.5-B.6 display the interview results for the Laptop (Mobile) Technology.

Tables B.7-B.9 display the interview results for the Smartphone and Tablet (Ultra-mobile) Technology.

Note: Cells within the tables have been greyed out if the interviewee had no information on subject, i.e., not all interviewees were familiar with all topics or technology levels.

Table B.1: Definition of Reference Design According to the Interviewees

Interviewee	Years at Current Company	Definition of Reference Design
1	12 years	*Push chips to market *Has evolved from a plug and play board to a completed device *Enable customer *Hardware and software
2	26.5 years	*Enable customer *Non-Form-Factor = circuitry development *Form-Factor = builds customer's confidence in product
3	16 years	*Method to demonstrate platform capabilities *Rule set and validation
4	16 years	*Design that can be consumed = customer development *Hardware and Software
5	17 years	*Centered around silicon *Repeatable→anyone can manufacture it *Recipe *Enable customer *Demonstrate what is possible *Also used for software development
6	19 years	*Physical layer *Software layer *How to physically instantiate the company's silicon products at the system level such that a customer can rapidly accept, incorporate it as a design aid or tool into their own process *Validation tool
7	18 years	*Proof *Implementing a platform (group of chips) and an OS to demonstrate functionality to industry *Hardware *Software *Internal Validation
8	19 years	*Hardware and software

Table B.2: Interview Results - Desktops (1 of 3)

	Desktop			
Interviewee	General	Risks/Failures	Improvements	Success
1	*Able to customize *RD came about because ODMs said that customers did not need more, Intel pushed the market→ made standard so that any ODM/OEM could market RD→ easy to drive volume	*Standardization did limit innovation		
2	*Test silicon *Enable customers *Standard rule sets *ODMs leverage RD to create a cost efficient design		*Hard to second guess *Since we were the leader, felt we had to do everything→ spent a lot of money that we didn't need to	*Enabling customers *Processor
3	*Design Rules *Sell chipset *Firmware-Software-Hardware	*RD best design possible→very expensive→ not useful for industry *Rambus memory *New components=hard to root cause problems *Simulation + Electrical Validation ≠ All possible use cases	*Rules become cost prohibitive *Rules take too long to establish	*Internal validation *Customer Adaptation
4	*Start with RD then cost reduce to get commercial product			

Table B.3: Interview Results - Desktops (2 of 3)

Desktop				
Interviewee	General	Risks/Failures	Improvements	Success
5	*Processor *Halo/Classic/Entry =different levels of designs *Hero Account *ORS (ODM reference system)	*Rule sets have to be strict but still allow for leeway *Scheduling-customer needs enough time to adopt design and take to market (TTM) *Cost→ not driving volume sells of desktop anymore → component cost really high *Creating a product that ODM/OEMs can use most of *Flawless→gold standard→cannot introduce false failures into the industry *Need to be flexible to ODM desired changes *Rambus *Changing components mid-design/power-up *Suppliers	*Cost of desktop→ investments made up front should be cost sensitive	*Adapted in industry within the right period of time *Enable customers *Catches silicon bugs *Tool to stabilize *Used to measure based on how much ODM/OEMs took from the RD
6				

Table B.4: Interview Results - Desktops (3 of 3)

Desktop				
Interviewee	General	Risks/Failures	Improvements	Success
7	*RVB(reference validation board)→ bring up and debug silicon→ very large boards	*Routing not being representative of what industry were actually doing *Rambus *Customers cut corners→ problem develops→ difficult to debug *Conservative to be stable→ masks problems when implemented in cost reduced mass volume	*Started doing this→ Targeted collateral→ tailor the collateral and the reference layout for different market segments	*Giving customers a starting point (before cost reducing)
8	*Standard hole location *Define hardware	*Schedule *Time to Market *Thermals within desktop computers	*Hard to second guess→ held up over time	*Volume *Sales

Table B.5: Interview Results - Laptops (1 of 2)

Mobile (laptops)					
Interviewee	General	Risks/ Failures	Improvements	Success Measured	Customers
1					
2	*Able to do non-form-factor because leader at the time, in desktop form factor with a smaller board *Enable *Moving to do more form factor designs now→ small volume				
3					
4	*No standard board size *Mostly Windows				

Table B.6: Interview Results - Laptops (2 of 2)

Mobile (laptops)					
Interviewee	General	Risks/ Failures	Improvements	Success Measured	Customers
5	*Different from Desktop RD: standards (no mobile standards), system design, batteries (no such thing as an off-the-self battery, may use off-the-self manufacturing)		*Eliminate cost up stream *Drive standards→but industry doesn't like standards *Strategic partnerships → don't need to develop everything internally *Working closely with ODM/OEMs		
6					
7					
8	*All OEMs have different form factors *Branding *Evolved differently than Desktop *Package + User-experience *Brand recognition *Outside-in design: how thin	*Thermal→limits on power consumption → boundaries on the CPU *Market entry *Getting a lot of sales and volumes off of one reference design challenging	*Pushed onto the market *Coming out at the start with a RD *Spending more time on the architecture and direction	*Market share *Sales *Volume	*Each ODM/OEM has own secrete sauce of what it wants in their user experience

Table B.7: Interview Results - Smartphones and Tablets (1 of 3)

	Ultra Mobile (smartphones/tablets)				
Interviewee	General	Risks/Failures	Improvements	Success Measured	Customers
1	*Not able to customize because everything is soldered on the board *Whole system approach	*Time to market *New technology hitting the market *New market entrant→finding a willing partner *Taking Desktop mentality into mobile			*Customers care about price, performance, battery, power consumption
2	*Had to do form-factor due to industry's lack of confidence in product→power consumption *Non-form-factor is for internal testing of silicon *Form-factor RD real proof to a customer	*Didn't move into market fast enough *Lost leader advantages (software and development around it)→not the innovator *too late with company computer architecture, everyone using ARM→how to get people to switch→can't be just equal, have to have reason to change *Went after Mobile like Desktop approach *Very competitive: other chip companies, if you don't have one of the top 2 driving volume to multiple customers is very difficult *Apple designs their own chips	*Attack the Mobile business as a separate business	*Not performance like desktop; it's what people can see and touch	
3					

Table B.8: Interview Results - Smartphones and Tablets (2 of 3)

	Ultra Mobile (smartphones/tablets)				
Interviewee	General	Risks/Failures	Improvements	Success Measured	Customers
4	*Enable customer- details on how to do that creates internal struggles *Mobile computing is evolving→app ecosystem	*Locating issues in SOC *Multiple Operating Systems *Multiple Form Factors *No Standards→need generic product to appeal to many different customers *Priorities→ on designs (software development, debug, modem certification…) →Balancing requirements *Mobile entry *Organizational changes *Late to market→ARM →liked Wintel (Windows + Intel)	*Need multiple devices for different requirements, one device cannot do it all *One for High Tier, focus on internal development and performance, would only contain chipset components/support *Second for low tier- prioritize features	*When starting, actually creating a functioning device *z-height *Stable platform	*High tier- have very good internal development, require little in RD *Lower tier- have little engineering, need entire device from RD
5					

Table B.9: Interview Results - Smartphones and Tablets (3 of 3)

Ultra Mobile (smartphones/tablets)					
Interviewee	General	Risks/Failures	Improvements	Success Measured	Customers
6	*Vertical strategy to force footprint *Horizontal enabling strategy utilizing a form factor→non form factor mask problems that can only be seen in form factor *Enable higher quality and faster time to market for silicon products	*Dislodge ARM→burden of proof *Late Market entrant *Shoes of customer (ODM/OEM) *Finite Budgets and Resources→want to get most mileage out of a RD *Internal validation vs. product *Cost relevant *Creating a RD that looks like a mass produced product→don't have the required volume for supply chain	*Management aligned on objectives→minimize the number of conflicting design goals	*Visually demonstrate how the tool enables new features *Enabled customer should see an increase in sales and volume over time	
7					
8					

Appendix C – Literature Review (Additional Support)

The following offers additional literature review material not included in Chapter 2.

To show the influence of risk factors on success measures in NPD projects, a visual representation was created from the review of literature (Figure C.1). It should be noticed that risk factors appear under different success measures, to identify the risk factors, symbols have been put next to identical factors. The success measures are not independent as Figure C.1 appears, for example time-to-market is effected by budget, as seen in Figure 3.2. Figure C.1 is a visual representation of Table 3.2.

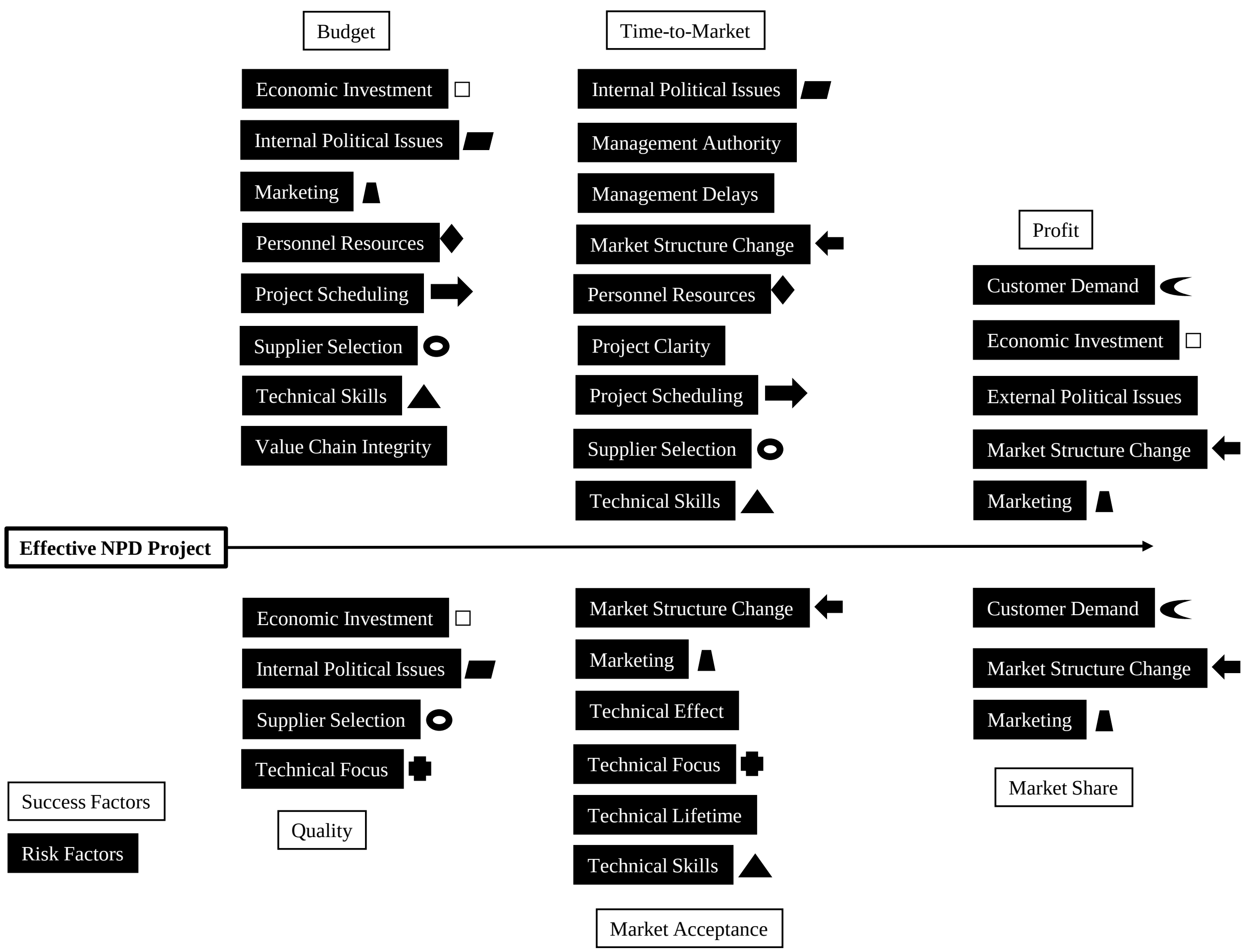

Figure C.1: Factors of Risk and Success in NPD Projects

Gosnik executed a study on 80 NPD projects to determine the uncertainties experienced during the project execution [62]. As a result, the primary factors effecting the time delay of a project were determined to be the following: project objectives not being clear, unrealistic time plan of the project, and limited authority of the project manager. To direct the focus of improvement needed in NPD projects, the study suggested the areas of project objectives, organization, human resources, and the NPD process as areas where improvement could best effect the overall outcome of the project [62].

Appendix D – Methodology Additional Support

Comparing the findings from searching the database Web of Science for "New Product Development" and "Reference Design" offers differences in numbers found and in what research fields support the different topics, as shown in Tables D.1 and D.2. *New Product Development* includes areas of management and business and the term is usually used to describe a process. *Reference Design* includes areas of electrical engineering and the term is usually used to describe a tool. The database search revealed these and similar uses of the terms, but did not include coverage of the Reference Design process as a New Product Development process. This lack of information supported the need to pursue an exploratory study with an industry partner employing the process. In this way, it could be defined and documented.

Table D.1: Keyword Search (Web of Science) New Product Development

Keyword	Number of Results	Top Topic Areas New Product Development
New Product Development (Topic)	28,844	Management, Business, Pharmacology Pharmacy, Engineering Industrial
“New Product Development” (Topic)	2,609	Management, Business, Engineering Industrial, Operations Research Management Science
New Product Development (Title)	1,435	Management, Business, Engineering Industrial, Operations Research Management Science
“New Product Development” (Title)	1,036	Management, Business, Engineering Industrial, Operations Research Management Science

Table D.2: Keyword Search (Web of Science) Reference Design

Keyword	Number of Results	Top Topic Areas Reference Design
Reference Design (Topic)	52,045	Electrical Engineering Electronic, Medicine General Internal, Automation Control
“Reference Design ” (Topic)	408	Nuclear Science Technology, Physics, Engineering
Reference Design (Title)	631	Electrical Engineering Electronic, Automation Control Systems, Nuclear Science Technology
“Reference Design” (Title)	52	Electrical Engineering Electronic, Nuclear Science Technology, Computer Science Interdisciplinary Applications

Appendix E – Narrative on Success Measures Distilled from the Interviews

This appendix offers additional results from the interviews regarding the success measures for the three levels of technology evaluated: desktops, laptops, and smartphones and tablets. The narrative that follows was created based on the eight interviews with industry experts with experience with Reference Design projects.

E1 Desktops

In the 1970s, computer manufacturers created their own circuit board layout, this also included component selection. The computer manufacturers would then communicate to the chip manufacturer what requirements they desired. A tipping point occurred in the early 1990s, when the computer manufacturer decided that the end customer did not require a faster processor and therefore the computer manufacturer did not want to upgrade the processor.

E1.1 Budget

When computer manufacturers resisted upgrading their processors, thinking that the end customer couldn't use the extra speed or be willing to pay for it, the chip manufacturer already had a strong board design group internally. Having the technical knowledge to create an entire design made it simple for a budget to be created and maintained, to start on new projects with minimal lapses in scheduling.

E1.2 Time-to-Market

The chip manufacturer was already using Reference Designs internally for chipset validation. The move to enabling the computer manufacturer with this design evolved over time. Identifying the use and marketability of a current project was what made the chip manufacturer able to offer the quality board design service first.

E1.3 Profit

The chip manufacturer was profitable when the computer manufacturer was purchasing the chipsets. As soon as this did not happen with the most current chipset, the chip manufacturer took strategic moves to ensure that the industry would continue to move forward. By making a Reference Design available to computer manufacturers, the chip manufacturer was able to continue seeing quarterly profits.

E.1.4 Quality

The Reference Design for the chip manufacturer was composed of the highest quality components and used the most up-to-date manufacturing processes. The cost associated with creating the physical product became a concern when passing the Reference Design on to the computer manufacturer; high quality parts and updating a manufacturing facility are expensive endeavors. The Reference Design for a new product is very expensive to produce. Eventually, the chip manufacturer created an internal group that would “dumb down” a design so that it could be competitive on the market from a cost standpoint.

E1.5 Market Acceptance

The rigor that the chip manufacturer invested to produce high quality board designs made it very easy for the industry to accept the designs. Industry also knew that if there were a problem with the design, the chip manufacturer would take the necessary steps to guarantee that the computer manufacturers would be satisfied with the continued technical support until a resolution was made.

E1.6 Market Share

Already being a dominant force for chipset manufacturing, leveraging Reference Designs to ensure that companies would continue to purchase upgraded chipsets increased and maintained the chip manufacturer’s market share for desktops. The overwhelming dominance allowed for the chip manufacturer to set industry standards for board design, and this standardization increased the success of the chip manufacturer’s ability to introduce new designs to its customers.

E2 Laptops

As desktop manufacturers transitioned to producing laptops, the chip manufacturer changed their Reference Design focus to laptop design.

E2.1 Budget

The chip manufacturer recognized that designing a laptop in its entirety was very expensive. Desktops had been standardized internally, whereas each computer manufacturer had a slightly different industrial design for laptops that affected the size of the computer and limited the size of the components. To offset this increased design cost, the chip manufacturer was able to create a board that was of an average laptop size, plug it into a desktop frame, and demonstrate the functionalities of the board and chipset. This non-form-factor Reference Design allowed for design projects to be more financially friendly.

E2.2 Time-to-Market

The migration from desktop to laptop board designing was not too difficult for the chip manufacturer. The technical knowhow existed and the relationships with the computer manufacturers were well-developed. This allowed board designs to be quickly presented to computer manufacturers.

E2.3 Profit

As with the desktop market, in the laptop market the chip manufacturer continued to see high sales of its chipsets. The return on investment on a single Reference Design project was high, due to the ability for one design to be easily altered to fit the needs of multiple computer manufacturers.

E2.4 Quality

The quality from desktop design transferred into quality in laptop design due to strong component supplier relations. As the computer market continued to grow, the lower-end component suppliers focused on creating components of a higher performance level while retaining a low manufacturing cost to stay competitive. As a result, laptops of a similar price point sold a year apart would notice the newer laptop having higher performance.

E2.5 Market Acceptance

The chip manufacturer had control of the desktop market and, by identifying that industry was moving to laptops and presenting computer manufacturers with a solution early on, the industry accepted the non-form-factor Reference Design. A non-form-factor Reference Design used a circuit board close to the required size to demonstrate the functionality of the chipset, while being used on a desktop platform.

E2.6 Market Share

The dominance in the desktop market transferred into laptop market for the chip manufacturer. Although the chip manufacturer did not retain the same percentage of market share. The rise of the technology ecosystem in China made way for a lot of smaller companies to start up and create niche markets. While the vast majority of chipsets where sold by the chip manufacturer, there was an emergence of others (e.g., Samsung and Qualcomm).

E3 Smartphones and Tablets

When smartphones and tablets where introduced to market, the chip manufacturer assumed it was a fad, partly because none of the computer manufacturers showed interest in producing smartphones or tablets. Lack of demand for the chip manufacturer to turn attention to handheld solutions led to a late entry into the market for the computer manufacturers and the chip manufacturer as well.

E3.1 Budget

When trying to enter into a market that already contained chipset suppliers (e.g., Apple and Qualcomm), the chip manufacturer had to increase their budget to obtain personnel with handheld device design experience, purchase new manufacturing equipment, and invest in new component supplier relationships.

E3.2 Time-to-Market

The chip manufacturer first viewed the mobile phone as a fad and therefore did not see a need to compete in the market. The computer manufacturers did not move into the phone space, therefore there was no demand from them for chipset solutions for phones. After realizing the mobile phone industry was not going away the chip manufacturer was late to the market and look more than a year to offer industry a useful product.

E3.3 Profit

The chip manufacturer incurred a significant amount of expenses on smartphone and tablet project but, to date, did not achieve substantial revenue for their efforts. This is due to the industry currently being supplied a chipset by a competitor. Thus, profits are low. However, several interviewees speculated that within the next few years handheld devices are going to require an increase in chipset performance, and this has been a strength of the chip manufacturer dating back to desktop technology. Thus, there is an opportunity for future profits from this market.

E3.4 Quality

While the chipset the chip manufacturer is offering industry is of high quality, the components being used in the Reference Designs are not produced to the same standards. The component suppliers for smartphones and tablets make their money by running full shifts and large batch sizes. The chip manufacturer has struggled to find partners that are willing to produce in the small batches required for the low volumes needed for Reference Designs. The chip manufacturer places high quality requirements on the component supplier, which causes tension in the supplier relationships.

E3.5 Market Acceptance

The first Reference Design the chip manufacturer showed to a potential industry partner was a non-form-factor design. The smartphone market had been strong for about five years at the time, so the industry partner felt the chip manufacturer really needed to prove that they could offer a competitive product, and they failed on the first attempt. The industry was supplied by a low power consuming chipset from a competitor. While the chip manufacturer was known for its performance, it was also known for its power consumption. This led the industry to doubt the chip manufacturer’s ability to create a competitive device, and presenting them with a non-form-factor Reference Design did little to sway that notion. Within six months, however, the chip manufacturer was able to present industry with a form-factor Reference Design fully functional smartphone. This gained some market acceptance, with devices sold in India, Europe, and Africa.

E3.6 Market Share

The combination of a late market entry and low market acceptance left the chip manufacturer having very little market share. With end customers demanding more of their handheld devices, chipset performance is becoming more important. The chipset manufacturer has been able to work with a large device manufacturer, Samsung, which may lead to eventually larger market share.

Appendix F: Industry Relationships (Additional Support)

For desktops and laptops, the chip manufacturer created a Reference Design and presented the design solution to computer manufacturers. After using the chipset and software in their product, the computer manufacturer would provide feedback to the chip manufacturer about future products. This process was termed an inside-out design by the chip manufacturer due to the internal component configuration being completed before concerns for the externals (Figure F.1). Inside-out design allowed for the chip manufacturer to push standards on to the market, to reduce project development time and decrease the time required to train manufacturing personnel.

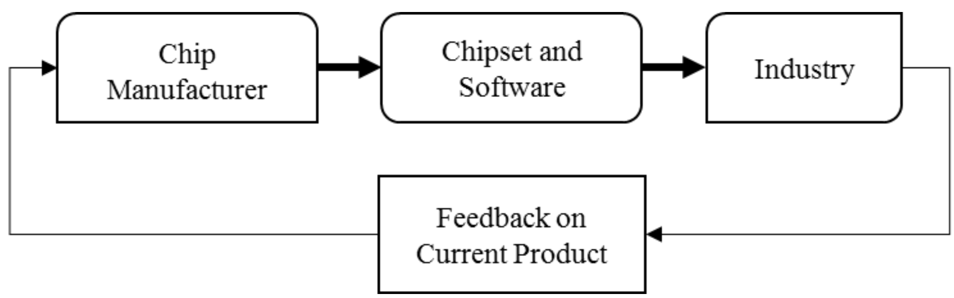

Figure F.1: Inside-Out Design

When the chip manufacturer moved into the smartphone and tablet market, there was a different model being used by the market, termed by the chip manufacturer as an outside-in design (Figure F.2). This market structure change was difficult for the chip manufacturer to adapt to since they were familiar with developing designs internally and then passing them off to computer manufacturers (Table 3.2). The handheld device manufacturer’s desire to create a unique computing experience (Section 3.5.3) forced industrial designs to conform to desired form requirements. An example given by one of the interviewees was the thickness of a device, or “z-height,” which, in turn, affects the thickness of all the components inside of the device. These form requirements are then passed on to the chip manufacturer to conform to in their chipset design. Thus, the chip manufacturer then develops a Reference Device around these requirements.

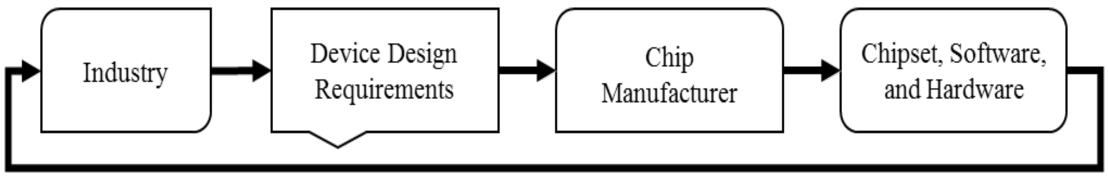

Figure F.2: Outside-In Design

Desktop manufacturers did not rapidly move into the smartphone and tablet markets. This led to no early demand from existing customers for products to support handheld devices, which hindered the chip manufacturer in entering the emerging market. Early detection of new technology is an important company strategy [65], and in this case the chip manufacturers observed the new market opportunity, but did not act on it. New customer relationships later had to be forged in a juvenile market undergoing rapid evolution.

Appendix G: Results (Additional Support)

As discussed in Chapter 3, a Reference Design process is driven by the same factors as New Product Development process. The results from Table 3.8 have been sorted into the success measures effected (Table G.1 and G.2) to create Figure G.1. This visual representation shows the desktop and laptop technologies not always performing the best. Also seen is the improvement the chip manufacturer has seen in smartphones and tablets in moving from a non-form-factor to a form-factor design.

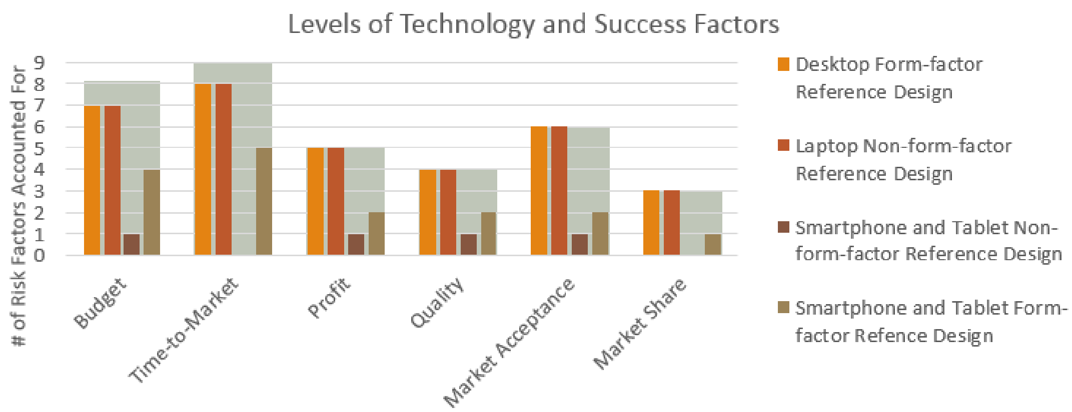

Figure G.1: Comparison of Technologies

The continual push to create new technologies for the chip manufacturer generates an environment where it is difficult to distinguish between a product fad or a legitimate leap in technology.

Table G.1: Reference Design Success Measures (1 of 2)

	Desktop	Laptop	Smartphone and Tablets	
	Form-Factor Reference Design	Non-Form-Factor Reference Design	Non-Form-Factor Reference Design	Form-Factor Reference Design
Budget	6	6	-6	0
Economic Investment	1	1	1	1
Internal Political Issues	1	1	-1	-1
Marketing	1	1	-1	1
Personnel Resources	1	1	-1	1
Project Scheduling	-1	-1	-1	-1
Supplier Selection	1	1	-1	-1
Technical Skills	1	1	-1	1
Value Chain Integrity	1	1	-1	-1
Time-to-Market	7	7	-9	1
Internal Political Issues	1	1	-1	-1
Management Authority	1	1	-1	1
Management Delays	1	1	-1	1
Market Structure Change	1	1	-1	-1
Personnel Resources	1	1	-1	1
Project Clarity	1	1	-1	1
Project Scheduling	-1	-1	-1	-1
Supplier Selection	1	1	-1	-1
Technical Skills	1	1	-1	1
Profit	5	5	-3	-1
Customer Demand	1	1	-1	-1
Economic Investment	1	1	1	1
External Political Issues	1	1	-1	-1
Market Structure Change	1	1	-1	-1
Marketing	1	1	-1	1

Table G.2: Reference Design Success Measures (2 of 2)

	Desktop	Laptop	Smartphone and Tablets	
	Form-Factor Reference Design	Non-Form-Factor Reference Design	Non-Form-Factor Reference Design	Form-Factor Reference Design
Quality	4	4	-2	0
Economic Investment	1	1	1	1
Internal Political Issues	1	1	-1	-1
Supplier Selection	1	1	-1	-1
Technical Focus	1	1	-1	1
Market Acceptance	6	6	-4	4
Market Structure Change	1	1	-1	-1
Marketing	1	1	-1	1
Technical Effect	1	1	1	1
Technical Focus	1	1	-1	1
Technical Lifetime	1	1	-1	1
Technical Skills	1	1	-1	1
Market Share	3	3	-3	-1
Customer Demand	1	1	-1	-1
Market Structure Change	1	1	-1	-1
Marketing	1	1	-1	1