PRODUCT MIX DETERMINATION UNDER UNCERTAINTY WITHIN A FRAMEWORK PROPOSED FOR EFFECTIVE PRODUCT MANAGEMENT

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A B S T R A C T

PRODUCT MIX DETERMINATION UNDER UNCERTAINTY WITHIN A FRAMEWORK PROPOSED FOR EFFECTIVE PRODUCT MANAGEMENT

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In many real life problems, uncertainty is a major complexity for decision makers. A typical example to such a case is product mix problem. In this study, we develop a methodology to aid the decision makers in product mix determination at the strategic level of product management under uncertainty. The methodology is based on a simulation optimization approach by which scenarios are generated using a statistical design of experiment approach. To the best of our knowledge, this methodology developed to aid the decision maker in product mix determination is a novel and original approach.

Our product mix model determines "how many" to produce from each product for each market where it will be sold. The decision maker questions the financial performance (profit) of the company by the results of the model. The product level is considered as product line and/or family since the product mix problem is handled at the strategic level of the product management framework. Depending on the best product mix and expected financial performance (profit) brought by the mix, the decision makers may choose to change their candidate product set and re-use our approach to find a new optimal product mix and its expected profit. In that sense the method developed in this study aids the decision maker by answering several "*what-if*" questions such as *what* profit level is obtained *if* the set of candidate products is changed, *what* happens to the profit level *if* a new market entrance is considered with the existing products, or *if* market conditions are volatile, *what* is the effect of these conditions to the level of profit, and so on. The model can also be used for budgeting purposes considering product breakdown and market disaggregation if and when necessary. The variants of the model are presented to serve these purposes. This information can be used as an input for aggregate production planning (APP) in which deterministic forecasts of demand for the aggregate products are used traditionally. In that sense, our method improves the traditional production management information system in APP. Further research directions involving extensions of the model and the solution approach are provided.

Key words: product-mix, uncertainty, product management, simulation optimization

Ö Z

ETKİN ÜRÜN YÖNETİMİ İÇİN ÖNERİLEN BİR ÇERÇEVEDE BELİRSİZLİK ALTINDA ÜRÜN KARMASI SAPTANMASI

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Pek çok gerçek hayat probleminde, karar vericiler için başlıca güçlük belirsizliktir. Ürün karması problemi böylesi bir durum için tipik bir örnektir. Bu çalışmada, ürün yönetiminin stratejik seviyesinde ele alınan belirsizlikte ürün karması saptanmasında karar vericiye yardımcı bir yöntembilim geliştirilmiştir. Bu yöntembilim, istatistiksel deney tasarımı kullanılarak senaryoların türetildiği benzetim eniyileme yaklaşımına dayanmaktadır. Bildiğimiz kadarı ile karar vericiye yardımcı olarak geliştirilen bu yöntembilim, ürün karması saptanmasında yeni ve özgün bir yaklaşımdır.

Ürün karması modelimiz, satıldığı her pazarda, her üründen "ne kadar" üretileceğini saptar. Karar verici, modelin sonuçları ile firmanın mali performansını (kârını) sorgular. Ürün karması problemi ürün yönetiminin stratejik düzeyinde ele alındığı için, ürün seviyesi ürün hattı ve/veya ürün ailesi olarak göz önüne alınmıştır. En iyi ürün karması ve onun getirisi olan beklenen mali performansa (kâra) dayalı olarak, karar vericiler aday ürünler kümesini değiştirebilirler ve yeni en iyi ürün karması ve onun beklenen kârını bulmak için yaklaşımımızı tekrar kullanabilirler. Bu bağlamda, bu çalışmada geliştirilen yöntembilim, *eğer* aday ürünler kümesi değişirse, kâr düzeyi *ne* olur, ya da *eğer* mevcut ürünlerle yeni bir pazara girilirse, kâr düzeyi *ne* olur, veya *eğer* pazar koşulları hızlı değişkenlik gösteriyorsa, bu koşulların kâr üzerindeki etkisi *ne* olur gibi "*ne-eğer*" türü çeşitli sorulara yanıt vererek karar vericiye yardımcı olur. Model, gerektiğinde ürün kırılımı ve pazar ayrıştırması göz önüne alınarak bütçelendirme amacı için de kullanılabilir. Modelimizin bu amaca yönelik olarak çeşitlemeleri sunulmuştur. Bu bilgi, geleneksel olarak bütünleşik ürünlerin gerekirci tahminlerini girdi olarak kullanan bütünleşik üretim planlamasında girdi olarak kullanılabilir. Bu bağlamda, modelimiz bütünleşik üretim planlamasında geleneksel üretim yönetimi bilişim sistemini iyileştirici olarak görülebilir. Modelin uzantıları ve çözüm yaklaşımına ilişkin yapılabilecek gelecekteki araştırmalar için yön gösterilmiştir.

Anahtar kelimeler: ürün-karması, belirsizlik, ürün yönetimi, benzetim eniyileme

To the loving memory of my parents,

A.Galip FEŞEL
and
M.Ülker FEŞEL

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CHAPTER 1

INTRODUCTION

In today's business world, companies face an increasingly competitive environment and thus strong pressure to perform in such an environment. Each company is challenged to offer the right products to satisfy its customers with a profitable product mix that can be efficiently manufactured. This requires a higher level of sophistication and effectiveness in their product management. The ultimate goal in effective product management is defined as the planning and shaping the optimum product mix. Therefore, among the several responsibilities of a firm's top management, the determination of the mix of the products to be marketed is very important regarding the survival and success of the company. So, the strategic implementation of product mix aims at identifying products which assure a profitable future for the company. In order to achieve this, the decision maker needs to get the necessary, fast and accurate information. In this study, we develop a methodology to aid such decision makers in product mix determination at the strategic level of product management under uncertainty.

As in many real life problems, uncertainty is a major complexity for decision makers in product management. The product mix problem within the product management context, which is finding the best amounts of products to be produced for different markets in a given planning horizon, is a typical example for such a decision making situation. Key parameters of the product mix problem are typically unknown to the decision maker at the time the decision has to be made. The product prices, costs of production and demands for products change depending on market dynamics such as behaviors of the customers, prices of suppliers and competitors, and new regulations imposed by the government. Therefore, product managers can neither be certain about future realizations of financial performance of the company caused by a specific product mix decision of them nor decide on the best product mix easily.

Our *primary goal* in the modeling of the problem is *to present an approach of dealing with uncertainty and a methodology developed for this purpose*. Therefore, the product mix optimization model is kept as simple as possible in order to highlight the importance of the methodological approach. To the best of our knowledge, our methodology developed to aid the decision maker in product mix determination is a novel and original approach implemented in product mix problem under uncertainty. Therefore, it represents the major contribution of this study.

The methodology is based on a simulation optimization approach where scenarios are generated using a statistical design of experiment approach. Major parameters of the product mix problem are taken as factors in the experimental design. Two levels for these factors are chosen using systematic sampling from assumed continuous probability distributions of the factors. As a result, a two-level full factorial design of experiments obtained each experimental trial of which corresponding to a scenario. The optimal product mix solution for each of these scenarios is obtained and is tested under all of the other scenarios. The best of the optimal solutions is selected using certain performance measures such as net profit after regret.

Our product mix model under a given scenario is constructed assuming that there is a given set of candidate products to produce for the next planning horizon, outsourcing decisions are already made, and a new investment for capacity building or expansion is out of the question. In short, our model determines "how many" to produce from each product for each market where it will be sold. The decision maker questions the financial performance (profit) of the company by the results of the model. In this study, the product level is considered as product line and/or family since the product mix problem is handled at the strategic level of the product management framework. Depending on the best product mix and expected financial performance (profit) brought by the mix, the decision makers may choose to change their candidate product set and re-use our approach to find a new optimal product mix and its expected profit. In that sense the method developed in this study aids the decision maker by answering several "*what-if*" questions such as *what* profit level is obtained *if* the set of candidate products is changed, *what* happens to the profit level *if* a new market entrance is considered with the existing products, or *if* market conditions are volatile, *what* is the effect of these volatile market conditions to the level of profit, and so on. The model can also be used for budgeting purposes considering product breakdown and market disaggregation if and when necessary. The variants of the model are presented to serve these purposes. This information can be used as an input for aggregate production planning (APP) in which deterministic forecasts of demand for the aggregate products are used traditionally. In that sense, our method improves the traditional production management information system in APP.

Analysis of the results and the statistical inferences show that our methodology of probabilistic approach provides better results in terms of net profit after regret when it is compared with the deterministic solutions. So, it is proven that the best solution to the product mix problem obtained by the developed methodology represents the most consistent results in an uncertain environment. While the model developed in this study is mainly geared towards the product mix problem, the decision aid method developed here is general and can be used in many decision making problems involving uncertainty, such as investment planning, financial portfolio planning, capacity planning, etc.

Of course, understanding the product management decision framework is essential to study the product mix problem in this context. In order to achieve this, both literature and field surveys were conducted in an integrative way. During this study, it has been realized that there is no comprehensive study dealing with the decision framework of product management from a holistic perspective. Therefore it has been intended to make an attempt to provide the major decisions in the product management framework by using the holistic perspective and system approach. As a result, a product management system was proposed, and based on this proposal; some efforts have been made to integrate the existing literature which only covers the development subsystem of the whole product management system. The major decisions are extracted, clarified and then presented in a structured and comprehensive way. We believe that all these efforts also represent a contribution to the existing literature of product management. The proposed decision framework of product management can be viewed as an initial attempt to fill the gap in the existing literature, so that this work can be improved further for the forthcoming studies in this area.

The structure of the dissertation is as follows: Chapter 2 presents the literature survey and background information in two sections. Background information of product management and related literature are presented in the section 2.1. Section 2.2 presents the literature survey of product mix problem.

The proposed product management system and the integrative decision framework of product management are presented in Chapter 3. The proposed product mix decision support system, including the developed methodology and the models, are explained in Chapter 4. Numerical results obtained by using the methodology are provided in Chapter 5. Chapter 6 presents conclusive remarks and offers the topics for the future studies.

The glossary which shows the terminology used in the study is provided in Appendix A. The questionnaire used in the field study is presented in Appendix B. The flow model developed for the decision framework of product management is given in Appendix C. Appendix D presents the computer coding by MATLAB developed to obtain the numerical results. Finally, an example output of MATLAB is given in Appendix E.

CHAPTER 2

LITERATURE SURVEY AND BACKGROUND

In this chapter, the related literature is presented in two main parts. In the first part, the general framework of the product management problem is described concerning the definition and origin of product management, the historical background, the general areas of interest in the literature, the major themes in the general context of product management, the sources of complexity, and the tools and techniques frequently used. It should be noted that this section does not attempt an exhaustive review of product management literature. Rather it focuses on the themes which are related to, have an impact on, and/or provide a background to our research problem. In the second part, the literature survey on the product mix problem is presented in detail.

2.1 PRODUCT MANAGEMENT PROBLEM

Product management (PM), as a profession, has its origin some 80 years or so ago. Haines (2009) calls product management as an "accidental profession" because, although there are many product managers in business life, no one has the degree in product management; but instead product managers may have backed into product management from another field or business discipline. Indeed, the literature supports Haines's statement, since there are relatively few books on the subject. Below, the general framework of product management is described through the related literature.

2.1.1 Definition and Historical Background

Product management begun as a management style in leading consumer product companies. Procter & Gamble has been credited with the creation of the product management concept. In 1931, the sales of Camay soap were diminishing, while the performance of Ivory soap was increasing. A Procter & Gamble executive suggested the assignment of an individual manager to be responsible for Camay, in order to pit the brands against each other. Thus, the brand management system has been created, and it was so successful so that it has been copied by most fast moving consumer goods (FMCG) companies (Dominguez, 1971; Gorchel, 2006).

Despite this early beginning, many years passed before any spreading influence was seen. Then, subsequent development was recognized in the chemical and the detergent industries. All these firms were successful in their initial efforts of applying the philosophy of product management to their operations. After a while, most industrial and consumer goods firms adopted product management on a wide scale (Dominguez, 1971).

During the 1950s and early 1960s, which was a period of rapid economic growth, many FMCG companies faced with some opportunities, because high consumer income have driven competition which resulted in an explosion of new product and brand offering. Thus, the modern product management system emerged (Wood and Tandon, 1994).

During the 1970s and 1980s, product management mainly focused on quality aspects of the products and production cost minimization efforts within long product life-cycles. During the 1980s, variations in product management structures, systems and styles of management emerged (Handscombe, 1989). Market dynamics, however, have been changing dramatically in the sense that popular strategies of the 1980s, such as cost saving and quality improvement, are no longer sufficient. Market conditions in the 1990s pushed the companies in competitive battles, and the winners were the companies which could create and dominate new markets by developing new products. (Handscombe,1989;Wood and Tandon, 1994). So, new product development management (NPD) gained an utmost importance in those years in the product management context.

Dominguez (1971) states that "product management has evolved from the need to centralize all data relative to individual products or product lines in one area in order to optimize operations and profits of the company". Since the beginning, product management has been viewed as an organizational response to market opportunities. It was a new approach which harmonized many aspects considering multiple products and brands of the companies in their business.

According to Gorchels (2006), product management has been viewed as an effective organizational form for multiproduct firms. Gorchels (2006) also states that considerable evolution was seen over the past few decades. Evolution in product management has been achieved by emphasizing customer management and value chain analysis, which put the product management in a more holistic position. Thus, "the overall responsibility of a product manager is to integrate the various segments of a business into a strategically focused whole in order to maximize the value of a product by coordinating the production of a product offer with an understanding of market needs" (p. 305). So, product management deals with not only products themselves, but also the product projects and development processes.

Product management is a matrix organizational structure in which a product manager is charged with the success of a product or product line, but has no direct authority over the individuals producing and selling the product. Much of the work of a product manager is through various departments and cross functional teams. The use of such cross functional product management teams to make product related decisions has grown recently. The widespread use of teams started in 1980s, with the growth of quality circles used in primarily in the auto and steel industries to combat Japanese competition (Gorchels, 2006).

Today, product management as an organizational form has moved into a variety of business-to-business firms, as well as into service organizations. Although traditional product management was successful, companies have increasingly modified their product management approach incorporating a focus on the customer. So the customer is the king of the market in the competitive environment which has an important impact on the manufacturing capabilities of the companies. The capabilities of manufacturing in addition to the expectations of customers have led to increased pressure for both speed of production and hence time-to-market and variety of products. Today, customers demand more tailoring in the products and want them faster than ever. This is derived partly the shortened product life cycles and partly from the demand of more customized products (Vollman et al., 2005).

Another major change in today's business world is globalization. Today many companies have manufacturing facilities in different countries other than their home country. In some cases this is a complex network of facilities which includes manufacturing and marketing subsidiaries. Besides internationalization, some companies, namely virtual companies are focusing on their core competencies and outsourcing their products. Partly as a consequence of globalization and partly as a response to outsourcing, interconnectedness of manufacturing firms has increased substantially in today's business world. This implies that companies are integrated as customers of their suppliers which results in very sophisticated supply chains or networks (Vollman et al., 2005). So, today's product management requires the management of these complex supply chains so that they may have to compete with customers and suppliers, but at the same time they may have to establish mutually beneficial relationships for their product mix.

Shortly, from the historical standpoint, the principles of product management remain the same mostly. However, the importance of product management and the recognition of this importance have been changed in both academic and business life.

Now, several definitions of product management to reflect different perspectives are presented. Then, an integrated definition of product management is provided from a broader point of view.

Dominguez (1971) defines product management as follows: "(product management) represents any given product in a hypothetical company as it is fed through the structure from conception to sale" (p.7). It can be noted that it is not a clear definition; however, it implies a holistic view. Later on, Dominguez attempts to expand this definition defining what product manager does. Dominguez (1971) defines the "Product Management Hexagram" considering the following principal areas: product, market, profit, forecasting, coordination, and planning. It is stated that these six key words provide the nucleus of the product management concept theoretically and functionally. These six entities are directly interrelated and have continuity. These also reflect the major responsibility areas of the product manager (Dominguez, 1971).

Baker and Hart (1989) state that their book has a distinguishing feature which it takes a *holistic* approach. Thus, they point out that, while many authors and texts see commercialization as the final step in the New Product Development (NPD) process, they regard it as the first step of a management process which only ends when the product is eliminated from the firm's product mix. However, under the title of "Product Management", the following subjects are examined:

- Commercialization: test marketing and launching the new product
- Managing growth
- Managing the mature product

This description simply reflects the marketing view, which we also see in Rainey's definition (2005): "Product management is the approach used for managing existing products and services" (p. 9).

Handscombe (1989) provides the following definition: "Product management is defined as the dedicated management of a specific product or service to increase its profit contribution from current and potential markets, in both the long and short term, above that which would otherwise be achieved by means of traditional approaches to the management of territorial sales activity, marketing and product development" (p.1). This definition reflects organizational perspective. In our opinion, it is ambiguous and not comprehensive although great effort is seen to include many things. Later, Handscombe (1989) provides the definition of an "effective" product management which is clearer in terms of the activities of product management which is as follows: "Effective product management is a practical, purposeful and positive approach to improve company results through the efforts of a competent and committed team coordinating and progressing the development, manufacturing, marketing, sales and sales support of a strategically important group of products" (p.1).

Gorchels (2003) presents a general definition of product management: "product management is the entrepreneuiral management of a piece of business (product, product line, service, brand, segment, etc.) as a "virtual" company, with a goal of long-term customer satisfaction and competitive advantage" (p. 2). Gorchels, in another book (2006), gives the following definition: "Product management deals with managing and marketing the existing products and developing new products for a given product line, brand, or service" (p. xii). It is also stated that "product management is the holistic job of product managers, including planning, forecasting, and marketing products or services (p. xii). So, Gorchels indicates three main activities in product management which are planning, forecasting and marketing. Note that "forecasting" can be accepted as a "planning" tool. Therefore, it may not be considered as one of the major activities. Later on, the scope of product management is viewed as follows:

1. Preparing strategic foundations.
2. Product planning and implementation.
3. Managing existing and mature products.

Note that "product planning and implementation" includes the new product planning and its phases till the commercialization of the product. The major objective of product management is denoted as "*to achieve profit through superior customer satisfaction with their products"* (Gorchels, 2006).

Haines (2009) defines product management simply as follows: "Product Management is the *holistic business management of the product* from the time it is conceived as an idea to the time it is discontinued and withdrawn from the market" (p. 5). He continues by stating that product management is business management at the product, product line, or product portfolio level. Note that "product portfolio" and "product mix" are used interchangeably in most of the texts, to describe the entire set of the products of the company. It is also stated that "product management transforms good ideas into successful products", which actually defines simply the new product development part of the product management. Haines (2009) proposes to use "Product Management Life Cycle Model" in which three areas of works are defined. These three areas are;

1. New product planning,
2. New product introduction,
3. Post-launch product management

The hierarchical management levels are considered in this model, as "Strategic" and "Tactical". Note that post-launch product management represents the management of existing products of the company which is also considered as "day-to-day business". It should be pointed out that, even at that area, only strategic and tactical management levels are considered in Haines' model. In our opinion, this work area should include the activities of all levels, i.e., strategic, tactical and operational.

Finally, Steinhardt (2010) defines product management "as an occupational domain that is based on general management techniques that are focused on product planning and product marketing activities" (p. xi).

Considering all these definitions, the following *integrative definition of product management* can be proposed from holistic point of view:

Product management is *a function which mainly deals with the development of new products/technology and markets, and/or improve existing products/technologies and extending product lines in order to create profitable portfolio (mix) of products satisfying the customers.*

Rainey (2005), in his book on the subject of innovation, states that the assessment of product portfolio is very important for determining new product choices. He adds the following:

> *"The portfolio of existing products typically has a powerful influence on the choices for new products and the criteria used in the selection process. Existing product lines normally fit into a well-defined business or industry structure, providing the means to identify how products and services are related to the organization's mission, objectives and strategies"* (p. 79).

Thus, product portfolio assessment includes an evaluation of existing products and a determination of the types of products. Later, we will call this problem area as the "determination of the candidate product set" for the selection of the strategic product mix of the company.

So, it can be concluded that *the scope of product management concerns the complete set of products of the company, so-called* ***Product Mix.*** *The ultimate* ***goal*** *in effective product management is defined as the planning and shaping the optimum product mix.*

2.1.2 Domains of Literature

Loch and Kavadias (2008) deal with a challenging issue in the NPD area of PM; *"What is the theory of NPD?"* It is stated that there is no *"body of theory"* of NPD. Loch and Kavadias (2008) explain this as follows: "The problems associated with NPD are so different (short- and long-term, individual and group, deterministic and uncertain, technology dependent, etc.) that we need different theories for different decision challenges related to NPD rather than a *theory of NPD*" (p.xv). This question has important implications for both product managers in real business life, and for the academic research community. Loch and Kavadias ask “If there is no theory of NPD, does an academic field of NPD even exist?” (Loch and Kavadias, 2008; p.xv). The answer is “Yes”; however, they realized that there has not been a lot of activity in book-length studies of NPD in recent years although NPD has made significant progress. This is consistent with what Haines (2009) states about the PM as a profession as mentioned above. Loch and Kavadias (2008) state that the idea of their book has come out through this triggering disscussion. Indeed, there is a vast and complex body of literature relating to the various elements of NPD. However, Product Management (PM) in a holistic view is not as lucky as NPD, because there are relatively few books on PM literature. Accepting NPD is an important part of the holistic PM, it can be stated that PM problem has a challenging nature and it pursues to exercise the minds of researchers across various academic disciplines. From economics to engineering, manufacturing to marketing sciences, organizational behavior to strategy, operations management to operations research, a large number of studies cover many issues within the PM context, reflecting their own perspective and using their own terminology.

Krishnan and Ulrich (2001) present a review paper, which is highly cited, on product design and development. Their review is a broad and an encompassing work in the academic fields of

- Marketing,
- Operations Management,
- Engineering Design, and
- Organization.

They point out that there are significant differences among papers within each of the perspectives, not only in the methodology used and assumptions made, but also in the conceptualization of how product development is executed (Krishnan and Ulrich, 2001). Let us consider the definition of “Product” in these academic fields from their perspectives:

- Marketing: “A *product* is a bundle of attributes”.
- Organizations: “A *product* is an artifact resulting from an organizational process”.
- Engineering Design: “A *product* is a complex assembly of interacting components”.
- Operations Management: “A *product* is a sequence of development and/or production process steps” (Krishnan and Ulrich, 2001; p.3).

However, a generalization has been made that while *how* products are developed differs, *what* is being decided is fairly consistent at a certain level of abstraction. This study will be examined in detail when the decision framework of product management is discussed in Chapter 3.

In sum, the product management problem shows a *multidisciplinary nature* covering mostly the following disciplines:

- Organizational Behavior
- Marketing Sciences
- Economics
- Engineering
- Strategy
- Management Sciences/Operations Research

This domain of literature gives an idea about the range of the research in product management. So, the research in this area requires interdisciplinary research due to the multidisciplinary nature of the problem. Since it is a large body of knowledge, it is necessary to choose a focus. Therefore, concerning the goal of the product management problem presented in the previous section, we choose to center this research study in strategic product mix problem within the product management context.

2.1.3 Major Themes in Product Management

This section briefly offers the major themes in product management. The "product management" subject is very broad, therefore only the ones that play important role in establishing a baseline for the "Proposed Product Management System-PMS (see Chapter 3) are emphasized. For a moment, let us consider the breakdown of the word "Product Management"; so that the themes for the "product" and its "management", and finally external context of product management related themes are considered. Thus, the themes are grouped as follows:

1) "Product" Related Themes
2) "Management" Related Themes
3) Contextual Themes

1) <u>Product Related Themes:</u>

Let us consider the definition of *product*: "A term used to describe all goods, services, and knowledge sold" or Webster's online dictionary says "A product is something that is produced" (Haines, 2009; p.6). In a product management context, these definitions are not sufficient to establish a base for the discussion. Therefore, we consider some key concepts related to the term "product" below.

a) <u>Product Life Cycle (PLC):</u>

"Product Life Cycle" (PLC) is simply the whole life span of the product. A traditional PLC model is illustrated in Figure 2.1 in which cash flow (or sales revenues) is plotted against time. The PLC model in Figure 2.1 reflects purely the marketing view which considers the product after the commercialization and entrance into the market. The holistic product management view, as shown in Figure 2.2, considers the PLC starting from the "idea" phase till the end of its life, i.e., disposal of the product.

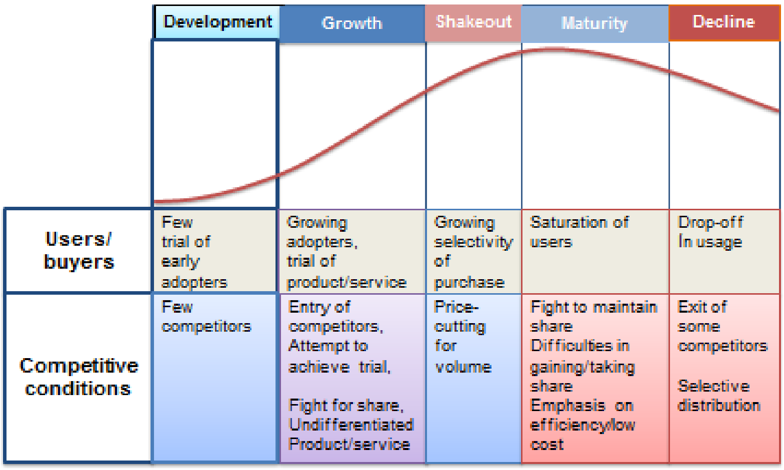

Figure 2.1: Traditional Product Life Cycle (PLC) (Source: Johnson, Scholes and Whittington, 2005; p. 86)

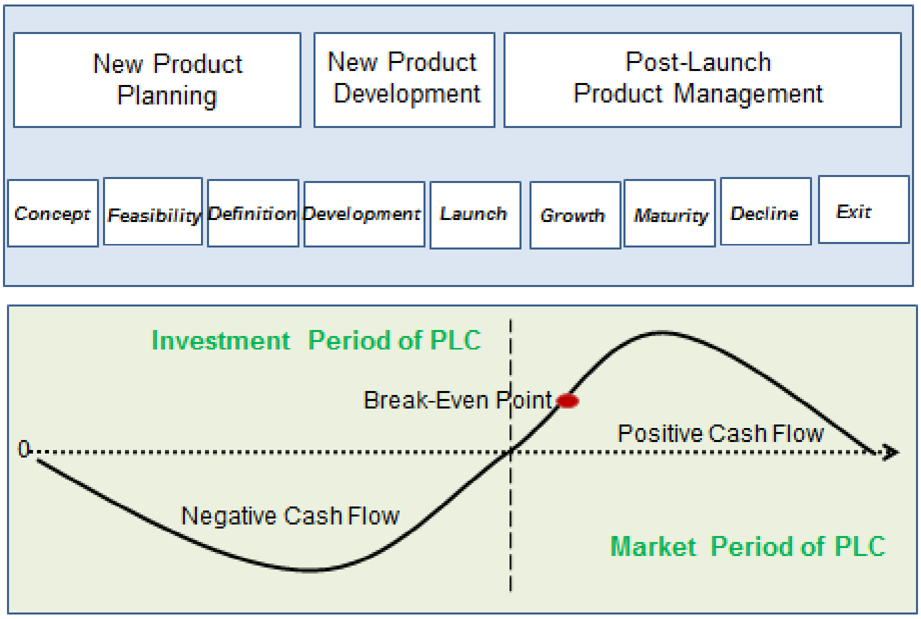

Figure 2.2: Holistic View of Product Life Cycle (Source: Haines, 2009; p. 531)

As shown in Figure 2.2, during the investment period, the company makes investments to develop new products and/or improve the existing ones. Therefore, the cash flow is negative throughout this period. Then, a typical product enters the market after the commercialization and follows the periods of growth, maturity, and decline of cash (revenue) generation before it reaches its end of life.

During the market period, there are several marketing strategies to extend the successful product's life in the market. Usually, components of the strategic marketing mix (4 P: Product, Price, Promotion, Place) are used as the tools for this purpose. Additionally, spending efforts through a series of continuous improvement projects (CIP) is another effective strategy to extend the market life of a successful product. The decline of product revenue occurs in the period following the maturity phase. This is often averted by using a CIP strategy which extends the product's life (Rafinejad, 2007).

b) Product Hierarchy:

A product may not be just a single entity. A product may be a part of other products, a part of a product line, or included in a product mix. "Alternatively, products can be broken down into product elements, modules or terms. Products may be built upon product platforms or product architectures" (Haines, 2009; p.6). The hierarchy of products is illustrated in Figure 2.3.

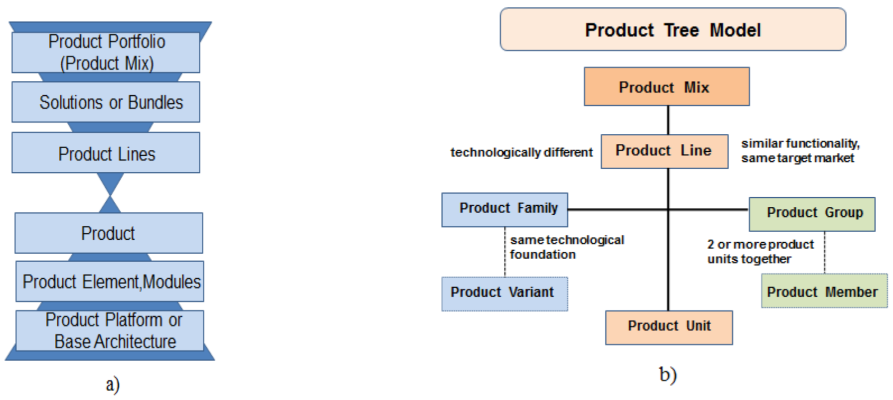

Figure 2.3: Typical Hierarchy of Products (Sources: a) Haines (2009); p.7; b) Steinhardt (2010), p.109)

c) Product Manufacturing:

Planning activities in product management involve evaluating manufacturing environment and capabilities to make sure the planned product can be produced. "A manufacturing system is an objective-oriented network of processes through which entities flow" (Hopp and Spearman, 2000; p.190). So, a manufacturing system has an objective, and contains processes. We emphasize the word "entities" in this definition. Entities include not only the parts being manufactured, but also the *information* that is used to control the system. The *flow* of the entities through the system describes how materials and information are processed. The processes in the flow of information can be matched to the purpose of the *demand management system* provided in Vollman et al. (2005); the demand management system provides information that helps to integrate the needs of customers with the manufacturing capabilities of the firm.

Depending on this property, the major characteristics of the different manufacturing environments are presented below (Vollman et al., 2005; pp.21-24):

Make-to-Stock (MTS) Environment:

- "Customers buy directly from available inventory" (p.21).
- "The essential issue in an MTS environment is to balance the level of inventory against the level of service to the customer". Therefore, "a trade-off between the costs of inventory and the level of customer service should be made" (p.21).
- Shifting the trade-off can be achieved by better forecasts of customer demand, by more fast transportation/distribution alternatives, "by speedier production, and by more flexible manufacturing" (p.22).
- To achieve higher service levels to the customers for a given inventory level, MTS firms consider investing in lean manufacturing programs.
- "Regardless of how the trade-off comes out, the focus of demand management in MTS environment is on providing (forecasts) of finished goods" (p.22).
- The company may know what customers can buy in an MTS environment, but it may not know if, when, or how many.

Assemble-to-Order (ATO) Environment:

- "The primary task of demand management is to define the customer's order in terms of alternative components and options" (p.22). Therefore, "the inventory that defines customer service is the inventory of components, not the inventory of finished product, because, the number of finished products is usually substantially greater than the number of components that are combined to produce the finished product" (p.22).
- One of the critical success factors of a company in ATO environment is engineering design that enables flexibility in combining components, options, and modules into finished products. Therefore, "it is also important to assure that they can be combined into a viable product in a process known as *configuration management"* (p.22).
- "An ATO environment illustrates the two-way nature of the communication between customers and demand management" (p.22). Customers need to be informed about the possible combinations, which should support the needs of the marketplace.
- In order to deliver the customers' orders quickly, some ATO companies have applied lean manufacturing principles to decrease the time required to assemble the finished goods.

Make-to-Order (MTO) or *Engineer-to-Order (ETO)* Environment:

- In MTO/ETO environment, the company is not sure what the customers are going to buy.
- The company needs, therefore, to get the product specifications from the customers and translate them into manufacturing.
- The task of demand management in an MTO environment is to coordinate information on customers' product needs with engineering.
- Engineering should determine what materials are required, what steps will be taken in manufacturing, and the costs involved in an MTO environment.

- Demand management's forecasting task includes determining how much engineering and production capacity will be required to meet future customer needs in an MTO/ETO environment.

2) Management Related Themes:

The decisions regarding acquisitions, mergers and establishing other business relationships, such as joint venture, strategic investments, licensing, etc., are in the domain of strategic aspects of executive management. This domain is directly related to the core vision of the corporate which also specifies the corporate goals. "Growth" is the dominant goal for a typical company. Growth opportunities are almost unlimited. Developing new products is one of the many ways for realizing the vision of the company. In the product management framework, new product development is a primary mechanism for improving or transforming a company's performance into a more productive and rewarding dimension in business life. Clearly, there are other means to realize business goals and objectives, including acquisitions and mergers, or strategic outsourcing. These strategic growth means in PM are described briefly below:

a) *Acquisitions/Mergers and Other Business Relationships*:

A company can go in several different directions to find opportunities to increase revenues. These opportunities are different, so are the risks and the levels of investment. Rapid growth companies regularly scan these opportunities then choose one or more. Many rapidly growing companies, like Unilever, have followed acquisition to grow. As a growth strategy, driving the acquisition can be powerful, but it must be integrated with the core vision (McGrath, 2001).

Acquisitions can be an integral part of product strategy. There are different strategic implications of acquisition types in the sense that each enables product strategy differently. When correctly handled, acquisitions and other business relationships such as mergers, joint ventures, partnerships, strategic investments can provide opportunities for growth. Through an acquisition, the company can easily access the desired technology that it needs to expand into a new market. Acquisitions can also be used to strengthen a competitive position in the marketplace. Some acquisitions are made to improve operational efficiency through increased economies of scale in production and consolidation of activities (McGrath, 2001).

In a *joint venture*, "two companies come together to form a third business owned jointly" (McGrath, 2001; p. 299). The joint venture typically develops a new platform for a new market but related to both companies. "A joint venture needs to combine sufficient market and channel capabilities with the necessary technology and technical skills from the two companies" (McGrath, 2001).

With a *strategic investment*, one company makes an investment in another in order to get an access to that company's market or technology. The main idea is that the company making the investment gets the same return as other investors, but also gets other advantages. In order to get these advantages company must make larger investments, frequently at more than the market price (McGrath, 2001).

b) *Outsourcing (Make versus Buy)*:

During the product development phase, as the definition of the product evolves the management decides where the product will be built. This decision is simply called as "sourcing" or the "make versus buy" decision. Outsourcing is defined as follows: "Outsourcing is the word used when a function that may normally be carried out by the company in-house is actually carried out elsewhere by another party" (Haines, 2009; p. 337).

Outsourcing is usually accepted as a tactical level decision. In addition to this view, outsourcing is defined as one of the important manufacturing and operations strategies (Rainey, 2005). Rainey (2005) states that "an efficient and appropriate production system for a given product can be a strategic weapon and competitive advantage". He also considers outsourcing as an issue in the supply-network design of the company. Supply chain management (SCM) describes the aspect of operations management that deals with converting raw materials into final products, and the delivery of those final products to customers. For many companies, SCM refers to maintaining and operating a network of suppliers, manufacturing and distribution facilities not only in the home country but also around the world.

Rainey (2005) also states "An important strategic issue in production is "make versus buy" dilemma" (p. 413). Outsourcing frequently offers a cost competitive alternative to performing the required activities in–house. The impact of this decision is stated as follows: "The decision whether or not to produce an item internally can influence short-term market share, as well as long-term competitiveness and corporate survival" (Rainey, 2005; p.413). In recent years, outsourcing has been suggested for many activities, except the activities by which the company can provide unique value to its customers and/or those which the company may have strategic need. The popularity of outsourcing depends on several reasons:

1. The company is downsizing (possibility of using fewer employees).
2. The outsourcing of an activity is often less costly.
3. Outsourcing has become a part of the companies' philosophy and strategy.

In today's business world, extreme applications of outsourcing can be seen among the companies; outsourcing the entire product and maintain no in-house manufacturing capability is a popular manufacturing strategy. This is the so-called "virtual company" approach (Rainey, 2005). Nike is a well-known example of this type of company.

Outsourcing can accelerate product development projects and shorten time-to-market by leveraging the suppliers' resources, technology and manufacturing capabilities. "The outsourcing strategy should be regularly reviewed and updated to reflect the realities of the marketplace, including changes in the bases of competitive advantage, technological maturity, competitive landscape, and evolution of the firm's core and context. Some companies form a *strategic outsourcing council* that regularly reviews the firm's core and context and updates the outsourcing strategy and decision process" (Rafinejad, 2007; p. 284).

3) Contextual Themes in PM:

a) *Environmental Sustainability:*

Environmental sustainability has become a crucial requirement in product development in the twenty-first century. "*Environment* refers to air, water, soil, and all other natural resources of the earth (including raw material) that are endowed for the well-being of living species (people, animals, and plants) locally, globally, at present, and in the future. *Environmental sustainability* refers to being in harmony with the ecological system of the earth, ensuring that manufacturing resource utilization and effluents do not harm the ecosystem equilibrium" (Rafinejad, 2007; p. 218).

The "green-house theory" and "global warming" are both environmental concerns which have strong effects in the design and manufacturing activities of the companies in many industries. Therefore, environmentally friendly design is encouraged by the recognition that sustainable economic growth can occur without consuming the earth's resources. Customers are also affected by this trend and thus manufacturers make an evaluation of how the environment should be considered in the design of their products. "Design for Environment" (DFE) (or "Design for Environmental Sustainability (DFES)) addresses environmental concerns as well as postproduction activities, such as transport, consumption, maintenance, and repair. "The aim is to minimize environmental impact, including strategic level of policy decision making and design development. Since the introduction of DFE, one can view the environment as a customer. Therefore the definition of defective design should encompass the designs that negatively impact the environment. As such, DFE usually comes with added initial cost, causing an increment of total life cost" (Yang and El-Halik, 2009; p. 378).

In product design and development of a manufacturing process, the major goal is to achieve meeting the environmental laws and standards, global protocols. Designing for maximum efficiency and for minimal waste means "the usage of process consumables, manufacturing material, and packing sustainable product does not include hazardous material or material that cannot be recycled" (Rafinejad, 2007; p. 218). To meet all these requirements DFES is used in product design phase of the development process. In this approach, the product design must start with a life cycle analysis that assesses the environmental impact of the product throughout its life cycle which starts with raw material extraction and goes on with manufacturing, use, and end-of-life disposal. Shortly, DFES minimizes the environmental impact throughout the cycle (Rafinejad, 2007).

b) Globalization:

In today's business world, many companies operate in a global marketplace. Customers, competitors, employees, suppliers, contractors and partners are located worldwide. Global strategy in product management requires providing products by applying both domestic and international standards into products. Therefore, designing and manufacturing of products should meet world standards. So, global manufacturing brings both opportunities and some complexities to the companies. Today, globalization has strategic value for business growth across the board.

If the company is based in the country where its business resides and sells to its customers from the home office, product management in this case is called "domestically based global PM" (Gorchels, 2006). On the other hand, if the company is located in the country or region where its sales take place, the product management function is a "locationally based global PM". Domestically based global PM typically employs "upstream" product development efforts. Locationally based global PM can fall along a continuum from downstream activities to full-stream. In full-stream PM, unique product offerings are created for the global markets from design through sale. Note that full stream activities contain both strategic and tactical activities. In this case, profit and loss (P&L) responsibility belongs to the global management. For example, Unilever has a similar structure, except that P&L responsibility resides with the regional presidents rather than the global category organization,that controls marketing, product mixes, and strategy (Gorchels, 2006).

As a result, today's global manufacturers' goal is to achieve accelerating time-to-market and process cycle times, reducing product development costs, maximizing productivity, improving product quality, driving innovation and optimizing operational efficiency, by leveraging global networks of employees, partners and suppliers across the manufacturing starting the design phase (PTC.com).

Regardless of whether a company has multinational locations, long-term product strategies on a global basis are developed and similarities of the customer needs across different world markets are searched if standardizing is possible and customizing is necessary. Through this, companies have opportunities to expand their future foreign sales and also develop competitive strategies against global competitors. In global PM, "many planning principles are common across all these situations although the implementation of the principles might vary" (Gorchels, 2006).

2.1.4 Complexity of the Product Management Problem

Kavadias and Chao (2008) discuss the difficulties and complexity of the NPD portfolio management problem in their study. As it was mentioned before, NPD is an important sub-system of the product management system (PMS) from a holistic point of view. Therefore, the complexity in the context of NPD is also valid in the PMS even with additional dimensions of complexity. Kavadias and Chao (2008; pp.138) raise the following considerations:

- "*Strategic alignment*: The NPD portfolio problem entails a large ambiguity and complexity, since the firm's success factors and their interactions are rarely known. Therefore, strategic alignment should be considered effectively to communicate the firm strategy and cascade it down to an implementable NPD program level".

At the product management level, this strategic alignment is considered with the corporate strategic plan.

- "*Resource scarcity*: Scarce resources critically constrain the NPD portfolio problem". In order to achieve broader product lines the resource allocation decision is a critical success factor.

At the product management level, the *earmarking of the resources* is considered in the strategic context. Through such an earmarking activity, NPD program budgets are determined. The allocation of budgeted (constrained) resources among the projects is still a challenging problem in of decision making at the NPD level.

- *Project interactions*: In a multi-project environment, synergies and incompatibilities in technical aspects are important in investment decision making. "Interactions between success determinants play a critical role in the resource allocation decision".

At the product management decision level, *product interactions* are one of the sources of complexity.

- *"Outcome uncertainty*: NPD projects are characterized by a lack of precise knowledge regarding their outcomes. Therefore, management (decision makers) face the uncertainty of the potential market value and technical output of any given project".

In addition to technical uncertainty, market uncertainty is considered as the major source of complexity in product management decision level.

- *"Dynamic nature of the problem*: Decision makers must allocate resources and NPD programs evolve over time" (pp.139).

In short, strategic alignment with the corporate goals, resource scarcity in general, product interactions, market uncertainty and other environmental uncertainty issues in addition to the technical outcome uncertainty, and dynamic and cyclical nature of the problem are the major complexity sources in the PM problem.

2.1.5 Tools and Techniques Used in Product Management

It is evident that the product management problem is a large scale and complex problem. Hundreds of decisions are made in several decision making areas, concerning different objectives, at different levels of management, and at different phases of the PLC of the products. Below, the major tools and techniques which are commonly used as the solution approaches considering the specific goals of different problem areas of product management are presented in two tables. Table 2.1-a presents the techniques and tools in accordance with the stages in PLC. In Table 2.1-b, they are presented according to the management levels in product management. We focus on some of the strategic PM tools which are directly related to our study.

Table 2.1-a: Tools and Techniques with respect to PLC Stages

Product Development Phase (Investment Period)	**Tools/Techniques/Methods (Development/Engineering Tools)**
Discovering market opportunities (Ideation)	Market research methods (e.g. Surveys, Focus groups, Benchmarks, Conjoint Analysis) Kano model
Customer needs/requirements study	Quality function deployment (QFD)
Concept development and Product design	CAE, CAD, CAM, CAD-CAM,TRIZ Axiomatic design DOE
Manufacturing process/Product launch and Production	DOE Taguchi method, Forecasting

Table 2.1-a: Tools and Techniques with respect to PLC stages (Cont'd)

Market Phase (Market Period)	**Post-Launch Product Management Tools**
Product consumption (Selling period) Product withdrawal Disposal	All "Decision Tools" in Table 2.1-b

Table 2.1-b: Tools and Techniques with respect to Management Levels

Management Level	**Tools/Techniques/Methods (Decision Tools)**
Strategic Level	SWOT Strategic Bucket Scenario Planning/Analysis Strategic Roadmapping AHP/ANP MS/OR Tools (Product Portfolio/Mix Selection Models)
Tactical Level	PRM and TRM MS/OR Tools (Project Portfolio Evaluation Methods) Forecasting AHP/ANP
Operational Level	Market Research Methods MS/OR Tools

Popular Decision Tools at the Strategic Level of Product Management:

Decision makers make strategic choices facing a high level of uncertainty in the strategic area of product management. In order to scan and evaluate the environmental and internal factors effectively in their decision making processes several tools can be used. Some of them are presented below.

a) Strategic Buckets:

Strategic bucket is a decision support tool which addresses the NPD portfolio management. NPD portfolio management deals with the selection of NPD projects under the constraints of limited financial resources. NPD portfolio management is a challenging problem area in product management because resources must be allocated among innovation programs and each program may be in conflict in terms of corporate strategy. The successful solution depends on the consideration of a fundamental trade-off between short-term benefits and long-term benefits of the company. Short-term benefits are obtained usually through incremental innovation efforts which are generally the improvement of existing products. On the other hand, the long-term benefits are achieved through radical innovation projects which are the new-to-market or new-to-world products (Chao and Kavadias, 2008). There are several methods which support the managerial decisions when allocating resources across NPD programs. Among them, the strategic buckets method is a strategic approach which aims to increase the effectiveness of decision of earmarking resources for radical NPD programs. So, "*a strategic bucket is a collection of NPD programs which are strategically aligned with an innovation strategy determined at the* *corporate level"* (Chao and Kavadias, 2008). Typically, NPD programs in a strategic bucket include

- improvements and modifications of existing products,
- cost reductions programs,
- basic advanced technological research in Research and Development (R&D), and
- next-generation new products.

Figure 2.4 depicts an example of four strategic buckets. Management at the strategic level makes forced splits of money across various dimensions (e.g by product line, by market, or by project, etc.). From these splits four buckets (or more) are created. Then, projects are sorted into buckets, and rank-ordered within the buckets until the spending limit is reached for each bucket. Ranking can be made with a financial index or a scoring model.

Cooper et al. (2001) present a significant research that specifically addresses the practice of strategic buckets as an NPD portfolio management tool. It can be stated that this research provides descriptive evidence of the use and popularity of strategic buckets with the result that 65% of the companies prefer using it.

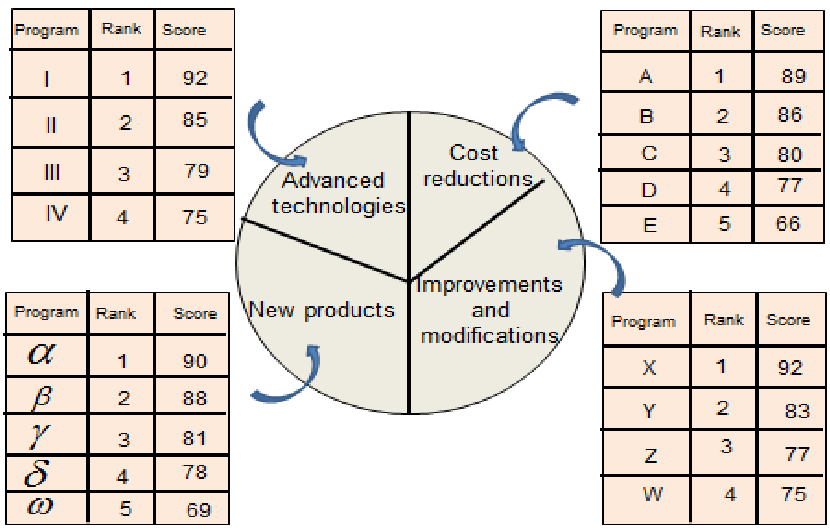

Figure 2.4: An Example of the Strategic Buckets Tool (Source: Chao and Kavadias, 2008; p.908)

b) *Scenario Analysis*:

Our research study proposes a scenario-based scheme as the solution approach to the strategic product mix problem. Therefore a special emphasis was spent to this tool. A literature survey was conducted considering the most important studies in this area (Johnson et al., 2005; Ozer, 1999; Schoemaker, 1991; Schoemaker, 1993; Bunn and Salo, 1993; Zetner et al.,1982; Wright and Goodwin, 2009). For brevity, we refrain from discussing all these studies in detail here, and refer the interested reader to the above mentioned articles.

First, let us consider the definition of "scenario". "Scenarios are detailed and plausible views of how the business environment of an organization might develop in the future based on groupings of key environmental influences and drivers of change about which there is a high level of uncertainty" (Johnson et al., 2005). The purpose of scenario analysis is not to forecast precisely the environmental or uncertainty issues, but it is valuable to have different views or illustrations of possible futures. The most important benefit of these scenarios is the improvement of the learning capability of the organization, because scenarios make more perceptive about the forces in the business environment and what is really important. Managers are able to evaluate and able to develop strategies for each scenario.

Stating that many firms incorporate scenario planning into their strategic decision making as a response to increased uncertainty, interdependence and complexity, Schoemaker (1993) examines the multiple scenario approach in his study. The purpose of the study is to explain how scenario planning differs from other traditional planning approaches. Schoemaker (1993) criticizes these prior descriptions stating that none of them is its full organizational essence although each of them captures important aspects of the method. Then, the multiple scenario analysis is presented as an important tool to examine major uncertainties and expand managers' thinking. In this paper, scenarios are defined as "*focused descriptions of fundamentally different futures presented in coherent script-like or narrative fashion"* (Schoemaker, 1993; p.195). It is also noted that "scenarios are not the states of nature or statistical predictions. The focus is not on single-line forecasting nor on fully estimating probability distributions, but rather on bounding and better understanding future uncertainties" (p.196). Thus, multiple scenarios are used to characterize the range within which the future is likely to evolve in corporate strategic planning. In other words, scenarios are used to bind the zone of possibilities by highlighting dynamic interactions and reflecting a variety of viewpoints so as to cover a range of future possibilities.

The main ingredients for scenario construction are trend analysis and the identification of key uncertainties with their correlations among them. It is stated that the outcomes can be clustered around high versus low continuity, or high versus low surprise. Approaches to planning are compared in Figure 2.5. In this comparison, the followings are highlighted:

- Uncertainty concerns the extent to which the causal structure of a strategically relevant variable is unknown.
- The complexity dimension captures the extent to which the causal structure is unique to that variable, i.e., independent of the causal structures of the other strategic variables.

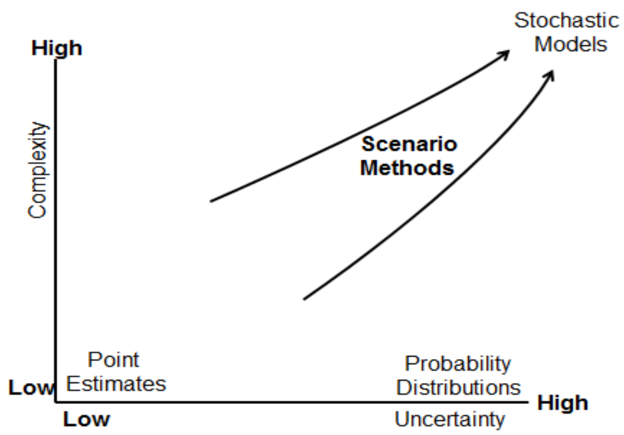

Figure 2.5: Approaches to Planning (Source: Schoemaker, 1993; p.198)

As it is shown in Figure 2.5, when uncertainty is high best estimates become relatively less important and measures of dispersion more relevant. It is stated that "a common approach is to accord each point estimate an upper and lower bound, so that one is highly confident the actual outcome will fall within that range. One intended benefit of scenarios is to instill greater realism; deeper understanding and consequently better calibration in subjective confidence ranges are provided" (p.198). When both uncertainty and complexity are high, stochastic models are frequently employed in which some variables are treated as being random. However, Schoemaker (1993) makes a comment that stochastic models do not work well in practice in the field of strategy. It is concluded that the "scenario method is a compromise between a completely stochastic approach at all levels, and the common tendency to have no systematic incorporation of deep uncertainty in the firm's strategies at all" (p.199).

In contrast to Schoemaker (1991, 1993) Bunn and Salo (1993) argue that scenario development converges with forecasting. To support this argument an analysis is presented. The paper also offers some practical guidelines and an integrative perspective on using scenarios to support strategic planning. A scenario is defined as "a route through a decision tree, supported by a narrative catalogue of the events and opportunities" (Bunn and Salo, 1993; p. 292). Bunn and Salo (1993) point out that when scenarios are successful when used as a basis for strategic planning. In those cases, they help the managers to acquire more insight into risk, robustness and flexibility of various decisions. As a conclusive remark, it is stated that the main point is to use scenarios under different objectives and protocols by establishing the plurality of their uses in forecasting rather than in distinguishing them as a separate forecasting methodology.

Zetner et al. (1982) discuss scenarios and their use in strategic corporate planning. The difference between forecasting and scenario analysis is underlined stating that forecasting deals with to the extent required distinguishing between forecasting methods and the methods used to develop scenarios.

c) Product Roadmap/Technolgy Roadmap (PRM/TRM):

Road-mapping is a verb that describes the process of roadmap development. Thus, it can be said that "the *roadmap* is simply the outcome of *road-mapping*" (Kostoff and Schaller, 2001). It can be stated that the road-mapping is proposed as a tool/technique which can help companies to survive in turbulent environments by providing a focus for scanning the environment and a means of tracking the performance and individual technologies.

It has been indicated in the related literature that the concept of roadmap has been developed and used by Motorola in the late 1970s (Kostoff and Schaller, 2001; Phaal et al., 2003; Ma et al., 2007; Gindy et al., 2006). Starting from early the 1980s, the Motorola approach has been more widely recognized and practiced in Philips, Lucent Technologies, etc. (Ma et al., 2007). Therefore, it can be stated that Motorola is the original creator and user of roadmaps. Although its original field is strategic planning for technology and product development at the enterprise level, it is also used in industry, in science to support sector-level research and decision making in both national and international context (Kostoff and Schaller, 2001; Phaal et al., 2003; Ma et al., 2007; Gindy et al., 2006).

As in the case of ordinary highway maps, a "Technology Roadmap" (TRM) can be viewed as consisting of nodes and links. These roadmap nodes and links have quantitative and qualitative attributes. Kostoff and Schaller (2001) give the following simple example to clarify the idea behind TRM. For example, in a highway map, a link (road) has a direction, a length, and sometimes an effective width (two lanes etc.). These are essentially quantitative attributes. However, sometimes a highway map will show a dotted line next to a road, denoting that road as scenic. This is a qualitative attribute (Kostoff and Schaller, 2001). Thus, the following classification, which represents independent roadmap application areas, has been introduced:

1. Science and Technology (S&T) roadmaps
2. Industry technology roadmaps (TRM)
3. Corporate or product-technology roadmaps (PRM)
4. Product-portfolio management roadmaps (Strategic roadmapping)

There are many definitions which are given considering the application areas, the formats of presentation, the objectives of the driver, etc.. The common point that we can note is that *TRM is a tool/technique which link or integrates the business planning to technology planning.* Or, a more comprehensive definition can be as follows: *Technology road-mapping is a strategic/tactical management tool to help organizations in effectively identifying potential products or services for the future, determining proper technology alternatives and mapping them with resource allocation plans.* A strategic TRM definition is provided as follows: "*A TRM specifies the technological requirements that a firm needs to enable its aggregate strategy, irrespective of how the firm will access the technology*" (Rafinejad, 2007; p.36).

The purpose of a PRM is to define how existing products will evolve and what new products will be developed and when they are commercialized over the planned period. In case of a new technology, the PRM should reflect the diffusion of technology and should identify the evolution on the basis of competition and marketing mix components. "The PRM consolidates the business, market, and technology strategies into a product and market development vision and guides the firm's product commercialization and marketing programs" (Rafinejad, 2007; p.92).

Recently, research on TRM as a theoretical methodology has started to appear, providing road-mapping guidelines and linking TRM to other management tools such as QFD, Scenario mapping, AHP, TRIZ, etc. QFD offers a reliable starting point for road-mapping and building the required cross-functional cooperation. The outcome of the QFD process corresponds with the roadmap planning phase, which is completed by determining the corresponding technologies (Rafinejad, 2007; Gerdsri and Kocaoğlu, 2007).

d) *<u>Management Science and Operations Research Tools (MS/OR Tools)</u>*:

Below project evaluation/product selection models are presented briefly. There are four main approaches to project portfolio evaluation:

- Benefit measurement models,
- Economic models,
- Portfolio selection models, and
- Market research models

"Benefit measurement models rely on subjective assessment of strategic variables, such as strategic alignment (fit) with corporate objectives, competitive advantage and market attractiveness" (Cooper, 1993; p.170). *Checklists* and their extensions and *scoring models* are the ones in this category which are frequently used in business life. Project interdependency is not considered on the overall resource allocation question.

Economic models treat project evaluation as a traditional investment decision. Computation approaches, such as payback period, break-even analysis, return on investment, and discounted cash flow (capital budgeting methods) are used. To handle the uncertainty, probability-based techniques, such as decision tree analysis and Monte Carlo risk assessment are proposed. They require reliable data, but such data usually are not available. These models are generally considered most relevant for "known" projects (incremental projects, improvements and modifications). Project independency is assumed in the models of this category.

Mathematical programming models and techniques such as linear, dynamic and integer programming are employed in *(Product/Project) Portfolio Selection models.* The objective is to develop a portfolio of new and existing projects (products) to maximize the objective function (expected profits) subject to a set of resource constraints.

Market research approaches are usually used for simple consumer goods. Market research techniques, when used as a decision tool, assume that there exists market acceptance of the new product. The assumption here is that strategic, technological and production issues are not relevant. "Given a strictly market based screening decision, it makes sense to use a variety of market research based techniques ranging from consumer panels and focus groups to perceptual and preference mapping" (Cooper, 1993; p.171).

e) *<u>Combination of Several Tools</u>*:

In the product management context, an appropriate combination of these tools can be used according to the decision making problem under consideration. In Hou and Su's study (2007), they present "an approach for efficiently analyzing customers' preferences and the capabilities of a manufacturer and its competitors, in order to provide appropriate solutions based on the information gained from each particular PLC stage”. The issues such as market intelligence, core competence, organizational strength, market attractiveness, product strategy and product position are analyzed in each stage of the PLC. To achieve this, a model named “Customer-Manufacturer-Competitor (CMC) orientation analysis for PLC” is developed. To effectively analyze information and to provide solutions, QHD, TRIZ and AHP/ANP have been applied to implement the model.

In another study, a modeling framework for product development decision making is proposed which incorporates knowledge-based and decision support systems with MS methods for project evaluation (Liberatore and Stylianou, 1995). At the core of the framework, the methods and techniques are used to acquire and process the expert knowledge. These methods include scoring models, logic tables, AHP, discriminant analysis and rule-based systems. Through a series of case studies the framework is applied and the results are presented.

2.1.6 Gaps and Weaknesses in the Product Management Literature

In most marketing texts, the product is regarded as only one of the components of the marketing mix (“4P”) and major emphasis is given to the selling and promotion activities in the product management framework. Since the marketing view deals with the market period of PLC of a product, the product development phase is largely ignored.

On the other hand, the studies dealing with NPD focus on the development process and neglect all other aspects (Baker and Hart, 1999). However, NPD represents only one aspect of the firm’s business and is highly dependent on the successful management of existing products for its funding.

Even in books which deal with product strategy and management, the emphasis is given largely on the process of new product development with little attention given to any other aspects. “In the real world, product management is the day-to-day management of the product through its life cycle which is the primary concern of an organization” (Baker and Hart, 1999).

Haines (2009), as an old product management practitioner and a new academician, makes an important observation which we totally agree with. “Product Management has no well-defined framework and is often treated as a transient discipline in many companies” (p. xxviii). Emphasizing knowledge available to a practitioner in product management, Haines (2009) also states “Individuals and companies struggle with Product Management because there has not yet been a codified body of knowledge available to the Product Management practitioner”, and he adds; “Absent from the curriculum, however, is an overall framework or “anatomical structure” to look at Product Management holistically and there is no holistic framework within which to manage and grow your career” (p. xxix).

Firstly, this comment must be true, because our literature survey on the subject supports it in the sense that there is no a well-defined, structured and comprehensive study regarding the framework of product management from a holistic point of view. Realizing this gap in the product management literature after an extensive literature survey, it is intended to make an attempt to fill this gap in the literature. Chapter 3 presents this effort.

Secondly, it is realized that an important weakness exists in the literature regarding the selection of products at the strategic level of product management. Kavadias and Chao (2008), related to NPD portfolio selection, state that "quantitative research efforts have been restrained at the *tactical* level of analysis and they have not been widely adopted in practice because of the complexity associated with the decision". Within this context, they offer a comprehensive literature review, and highlight several of the previous research findings, and some of the lessons drawn for researchers and practitioners. As a *conclusive remark*, we consider the following: The NPD portfolio selection problem remains largely an open problem especially at the top management decision making level (Kavadias and Chao, 2008). Note that NPD portfolio determines minor improvements, new product introductions, or radical developments associated with the product mix of a company. This issue partly represents the determination of set of candidate products of the product mix of a company. Including the candidate existing products which are to be kept to the NPD portfolio will result the complete set of candidate products which is a major input of the strategic product mix problem.

Finally, to determine the mix of products at the strategic level of PM describes our research problem. It was seen that this problem is usually handled in *production management* framework in the literature. So, it is decided to develop and propose a product mix Decision Support System (DSS) to aid the strategic level of management, which is based on quantitative methods and aims to be implemented practically and effectively. The proposed DSS is presented in Chapter 4. In the subsequent section, a detailed literature survey on the product mix problem is presented.

2.2 PRODUCT MIX PROBLEM

For many firms, the most important decisions relating to production are those that determine the product mix for a given period of time. The following features characterize a product mix problem:

1. Maximization of contribution to financial performance.
2. Constraints resulting from resource limitations.
3. Bound constraints on planned production.

The product mix problem is modeled as a mathematical programming problem (Johnson and Montgomery, 1974). It is a classic example of the direct application of Linear Programming (LP) approach (Ravindran, 2008), and this kind of product mix problems are called as "deterministic product mix problems".

Normally any manufacturing company makes a variety of products using raw materials, machinery, labor force, and other available resources. Traditionally, the problem of deciding how much of each product to manufacture in a period, to maximize the total profit of the company, subject to the availability of required resources is defined as the **product mix problem**, which is a common problem area in many industries (Ravindran, 2008). The problem is defined as the quantity determination of a given set of products subject to resource constraints in order to maximize profit, which can be seen as the "*traditional production planning problem*". The same kind of problem related with the product selection decision is defined as "*strategic production planning problem*" in the study Alonso-Ayuso et al., (2005).

It is stated that "explicit consideration of uncertainty about the demand for a product is difficult in constrained problems, such as product mix determination" (Johnson and Montgomery, 1974). These kinds of problems are called as "stochastic (or probabilistic) product mix problems". Direct treatment of uncertainty about demand involves making probability statements about the desired relationships between production and demand and then translating these probability statements into linear inequality constraints. This approach is called *chance constrained programming* (Johnson and Montgomery, 1974). Secondly, the probability distributions of demand are used in formulating a model for the expected total contribution to profit and overhead during the period, and then optimized subject to a single resource constraint (probabilistic model with a single resource constraint). In the case of discrete demand, the "knapsack problem", can be considered (Johnson and Montgomery, 1974).

There is a vast amount of literature regarding the product mix problem. We present a review of this literature in following sections, based on the modeling approaches of product mix problem in the literature.

2.2.1 Modeling Approaches of Product Mix Problem

The modeling approaches of the product mix problem are presented in two groups according to the treatment of the contextual variables considered in the problem. These are:

1) The models of the deterministic product mix problem.
2) The models of the stochastic or probabilistic product mix problem (in which uncertainty is considered).

Various examples are given for the first group of studies concerning the modeling approaches of optimization and some other methods such as AHP and ANP. Similarly, the product mix problem under uncertainty was searched in the literature under the optimization approaches in which uncertainty is considered and also a few examples are provided which handle uncertainty through different optimization methods.

2.2.1.1 Deterministic Product Mix Problem

The studies presented in this group represent the extended examples of the traditional product mix problem. Most of them are the examples of the optimization modeling approach.

Product Line Decision Making:

Product Line Decision/Design (PLD) problems constitute a domain of literature related to product mix problems. Most articles on product line optimization are based on the max-surplus-choice models, a deterministic rule under which each customer chooses the available product that provides him the highest surplus (Kraus and Yano, 2003). The typical objective is either to maximize the seller's profit or to maximize some measure of welfare (total benefit to seller and customers). We have several examples presented below.

Kraus and Yano (2003) indicate that Zufryden (1982) is the first to formulate the problem as an integer program. His objective is to maximize the weighted sum of consumers choosing a product line under the max-utility choice rule. They state that a solution procedure is not provided.

Green and Krieger's (1985) model differs from Zufryden's model in the sense that it considers a set of products whose composite utilities have been obtained by presenting these product profiles to consumers for evaluation. The objective is to maximize either seller value or buyer welfare by deciding which products to offer under the max-utility choice. This model does not explicitly incorporate prices or costs, and fixes the number of offered products.

McBride and Zufryden (1988) formulate Green and Krieger's problem as an integer program and develop optimization-based heuristic procedures to solve the simpler welfare maximization problem and the more difficult seller value maximization problem. They report the optimal solutions for small cases of both problems.

As indicated by both Kraus & Yano (2003) and Morgan et al. (2001), Dobson and Kalish extend Green and Krieger's model to allow price setting and choice of the number of products, as well as per product fixed costs. The goal is to maximize welfare or profit under the max-surplus choice rule. They show that the welfare maximization problem is equivalent to the uncapacitated plant location problem. They also propose and test several heuristic methods for the profit maximization problem.

Recent product line design models allow for more complex cost structures. Raman and Chhajed (1995) consider a scenario in which, in addition to choosing which products to produce, one must also choose the process by which these products are manufactured. Ramdas and Sawhney (2001) consider situations where the fixed cost of a component is shared by two products. Kraus and Yano (2003) state that Dobson and Yano allow for a wider range of complex interactions by admitting per-product fixed costs, resources that can be shared by multiple products, as well as technology choices for each.

Chen and Hausman (2000) present a model in which only a limited number of candidate products will be offered and that prices can take only a set of discrete values. The objective is to maximize profits by deciding product selection and pricing simultaneously. The special structure of the problem allows them to relax the integrality constraints for the discrete price choices and use standard non-linear programming software to find optimal solutions for problems of realistic sizes.

Product Mix Problem and Product Variety Management (Family Line Decisions):

Product variety management is another domain of literature related to the product mix problem. Ramdas (2003) provides an excellent integrative review in his study introducing a framework for managerial decisions about product variety. It is pointed out that managing product variety requires decision making at different organizational levels, over different time horizons, before and after product launch. In his framework, the following common set of decision themes is considered:

a) *variety-creation*; includes four decision themes which are
    - dimensions of variety,
    - product architecture,
    - degree of customization, and
    - timing.
b) *variety-implementation*; includes three decision themes which are
    - process and organizational capabilities,
    - points of *variegation* (or decoupling),
    - day-to-day decisions.

Note that *variegation* is defined as describing "how a firm's products are perceived as distinct from one another" (Ramdas, 2003). Product line decisions and specifically product mix decisions are seen in the major decision theme of *dimensions of variety* in the common set of *variety-creation* theme, which involves deciding

- *what* and *how many* products to offer,
- the target markets, and
- introduction timing of each product.

There are several research studies which focus on family line decisions (Tucker and Kim, 2008; Tucker and Kim, 2009; Jiao et al., 2007; Hopp and Xu, 2005; Kokkolaras et al., 2002). Tucker and Kim (2008) address two fundamental areas in product family design in their study:

1. Incorporation of market demand
2. Product architecture reconfiguration

In order to incorporate market demand into the formulation of a family line, they use a data mining approach where customer preference data are translated into performance design targets. Product architecture reconfiguration is modeled as a dynamic optimization design entity, that is, the initial stage of product design is not kept as fixed, and instead it evolves with fluctuations in customer performance preferences. So, they use a multilevel optimization model to link product design and product planning, which maximizes company profit. In their subsequent study (Tucker and Kim, 2009), the set of product concepts are generated through a decision tree data mining technique, and subsequently validated in the engineering design using again multilevel optimization technique. It is stated that the incorporation of decision tree data mining technique into the model leads to a tremendous savings in time and resources in product portfolio design and selection process.

Product Mix Problem and Technology Decision Making:

Additional contributions are included in the studies of Morgan and Daniels (2001) and Morgan et al. (2001). Morgan and Daniels (2001) present a technology adoption decision model that integrates product mix and technology adoption decisions for the automobile industry, recognizing that product mix and volume are important variables in determining the cost effectiveness of new technologies. Customer demand projections reflecting market trends are also included in their model. They state that "a key element that differentiates this framework from traditional technology adoption decision models is explicit consideration of the interrelationships between the *product line decisions* that ultimately dictate the portfolio of products offered by the firm, and the *technology decisions* that drive both functionality and manufacturability of the firm's product mix". A multi-period integer programming approach is used in the modeling. The objective is to identify a mix of products to offer and to assign a technology for each selected product such that total profits are maximized over a time horizon.

Product Mix Problem and Manufacturing Process Selection:

Morgan et al. (2001) present a model which can be seen in the area of the models that integrate product and process selection which are given above. However, they extend the literature by explicitly considering *manufacturing cost interactions among candidate products.* By using binary decision variables, the model is constructed to select the subset of products that maximizes the objective function. The objective function represents the total contribution to profits from the products included in the product line by subtracting the associated variable costs, holding costs, and individual product and manufacturing class set-up costs from the total revenue earned satisfying demands from the targeted customer segments. This model is used to examine how the optimal product mix is affected by a firm's cost structure, and to study product line characteristics including profitability, breadth, and diversity of manufacturing requirements associated with the selected mix and market share captured. Although it is stated that demand uncertainty is considered as an extension to their basic model, an explicit form does not exist. It is only stated that the basic model can be modified to incorporate uncertainty with respect to each customer segment.

Product Mix Problem and Product Interactions:

Although the decision model is not a product mix model, one can note Urban (1969) as one of the pioneering studies dealing with product interactions in the context of a marketing mix model, considering the following criteria:

1. decision relevance, i.e., the model should encompass the major factors and market phenomena affecting the best marketing mix for a product line, and
2. simplicity of the model whenever possible.

So, the following factors are identified as decision relevance:

1. aggregate product class marketing mix effects,
2. product class interdependencies, and
3. intragroup relative competitive brand effects.

First, a linear log function is established to capture marketing mix effects which allow nonlinearity in response to the marketing variable. Secondly, two basic kinds of interdependencies are considered, namely *complementarity* and *substitutability*, and another equation is formed by using cross elasticities as parameters which are the measures of product interdependency. Then, the group marketing mix and intergroup product interdependencies are combined to specify the total sales of one product class. Next, the market share expression is formed using the same format in the first step. These are called sub-models in the study. These sub-models are combined into one equation to describe the sales of the firm's brand in a product class, which also represents the demand for one product of a firm's product line. Finally an objective function is formed as the total profit of the firm. It is stated that "assuming the firm's problem in the short run is to maximize the total profit subject to existing technical, managerial, financial, and production constraints, the output of the model should be the best marketing mix for each brand in the firm's product line. This requires the optimization of the model which is difficult since the model is not amenable to mathematical programming or other analytical techniques. However, it may be solved by an iterative search routine".

Since Urban's study, the product interaction issue has received attention from researchers to incorporate into their models. Another study which considers product interactions is introduced by Monroe et al. (1976). In this article, an integer programming approach to the product mix problem is used by considering *pairwise revenue interactions among products*, as opposed to Morgan (2001), in which the product interaction effect is considered in the cost structure for substitutable products only. In Monroe et al. (1976), the interaction effects between revenues earned by the various products are explicitly considered. Product introduction and deletion decisions are simultaneously determined to maximize the firm's objective function over the planning horizon subject to specific resource constraints.

Product Mix Problem and Production Bottlenecks:

Many researchers have discussed the product mix problems and their solutions through Theory of Constraints (TOC), introduced by Goldratt and Cox (Lea and Fredendall, 2002; Sing et al., 2006; Linhares, 2009; Lee and Plenert, 1996; Perkins et al., 2002; Tsai et al., 2008; Souren et al., 2005). The TOC approach focuses on the bottleneck constraint in production processes and proposes a set of principles and concepts to manage the constraints. The concept of TOC is based on three operational measures: throughput, inventory and operating expense. The TOC approach consists of five steps to identify and manage the system constraints:

1. Identify system constraint(s),
2. Decide how to exploit system constraint(s),
3. Subordinate everything else to the above decision,
4. Elevate system constraints, and
5. Go back to step (1) and do not allow inertia to be constraint.

Thus, identifying and exploiting the resource constraint to adjust the capacity of that resource, it is possible to increase the production and profit of the company (Köksal, 2004; Nikumbh et al., 2009). As a tool for product mix decisions, the TOC-based approach is often used alternatively (or parallel) to optimization tools, such as the contribution margin per constraint unit method or LP approaches (Souren et al., 2005). Souren et al. (2005) discuss some premises to generate optimal product-mix decisions using a TOC-based approach, and show the reasons for the non-optimality of the TOC-based approach. Lee and Plenert (1996) examine the case of the introduction of a new product.

Lea and Fredendal (2002) examine how three types of management accounting systems and two methods to determine product mix interactions in both the short term and the long term affecting the manufacturing performance. Lea and Fredendal's (2002) study provides insights into the product mix decision considering fluctuations caused by environmental uncertainty, using an integrated information system which integrates a manufacturing system and a management accounting system.

Variations of Goldratt's product mix problem are proposed by several researchers (Onwubolu and Muting, 2001; Köksal, 2004). Köksal (2004) provides a comprehensive literature survey on TOC and questions the power of the TOC-based approach in focusing quality improvement for bottom line results, and thereafter develops an LP model which aims to maximize throughput and minimize quality loss to find the product mix for a specific period under known or predicted levels of quality of processes. Hence, Köksal (2004) proposes an improvement of a TOC-based algorithm.

Product Mix Problem and Sourcing Decision:

Although the sourcing decision (i.e., make or buy decision) has an important impact on the product mix decision, few studies take place in the optimization research area in the literature (Küttner, 2004; Arya et al., 2008). Küttner (2004) considers aggregate production planning with and without outsourcing, which are formulated as LP models in his study. The model to solve the problem of optimal product mix is demonstrated explicitly, and then the conditions are determined under which outsourcing is profitable for a firm. In other words, the model needed to consider outsourcing is not given in an explicit form, but instead it is stated that "the model based on aggregate production planning (APP) is needed to determine the decision of what fraction of components to produce in-house and what fraction to outsource" (Küttner, 2004).

Product Mix Problem and Environmental Sustainability:

Nowadays, several recent developments in environmental awareness and control have contributed to increased environmental concern. In addition, new governmental regulations may obligate companies to consider taking back and recycling their products. Additionally, environmentally friendly products and processes also contribute to stakeholders' satisfaction since environmental attributes of products are becoming increasingly relevant for consumers' demand preferences. Today, many firms are environmentally aware and they start to deal with these issues systematically, because these developments have negative impacts on their cost structures and competitiveness. In short, a firm's strategic, tactical and operational decisions are affected by the impact of environmental considerations. We review a few studies which address this important concern of the firms below.

Letmathe and Balakrishnan (2005) addressing this issue, present a study to illustrate how environmental concerns affect the product mix and profitability of the firm. It is stated that the environmental impact of a firm's products, processes, and resource usage are typically measured by the amount of emissions of waste water and other industrial wastes and pollutants. They present two mathematical models to determine the optimal product mix and production quantities in the presence of several different types of environmental constraints, in addition to typical production constraints. The first model assumes that each product has just one operating procedure, which is formulated as an LP problem. The second model, which assumes that the firm has the option of producing each product using more than one operating procedure, is a mixed integer linear programming (MILP) model. The solutions of both models identify the products that the firm should produce along with their production quantities. It is concluded that these models can be used by firms to quickly analyze several "what-if" scenarios such as the impact of changes in emission threshold values, emission taxes, trading allowances, and trading transaction costs.

Stuart et al. (1999) point out that a few quantitative approaches for the selection of manufacturing processes with environmental considerations have been presented in the literature. They also state that "in general, these quantitative models for business-focused decisions that include environmental considerations are limited to either assembly or disassembly decisions". So, in their study they propose a comprehensive product and process mix model, which extends the existing product and process mix approaches to include environmental costs, variables, and constraints. It is stated that their study is the first attempt which handles the complexities of life cycle product design by incorporating varying recycling market prices and limits, legislated limits, and product take-back rates over the product life cycle, i.e., the time horizon for the problem is over the product life cycle. The model is able to compare the profitability and environmental impacts of designs for product life extension to designs for shorter product lives, which is also stated as a unique approach in the paper which links product design and take-back decisions. In other words, their innovative take-back approach considers both the date of manufacture and date of take-back.

In their problem statement, the following questions are asked which are translated into a type of decision variable in their model:

1. Which feasible product and process design combinations should be selected for production during each time period? (This question characterizes a strategic long term issue.)
2. What manufacturing configuration (number of workstations) should be used? (This question links the strategic and operational issues.)
3. In what quantities should the selected product and process design combinations be produced each time period?
4. What assembly, repair, and reclamation inventories result from these production strategies?
5. By what quantities will process wastes and packaging wastes exceed recycling capacities?

They construct a MIP model with the objective of maximizing net revenues of the company.

<u>Product Mix Problem Under Different Approaches from Optimization</u>:

Product mix decision problems have been examined by using approaches different from an optimization approach (Wind; 1974; Chen et al., 2006; Taylor et al., 1994; Chung et al., 2005; Nikumbh et al., 2009).

Chung et al. (2005) propose an application of the analytic network process (ANP) for the selection of product mix for efficient manufacturing in a semiconductor fabricator. In order to evaluate different product mixes, a hierarchical network model based on various factors and the interactions of factors is presented. By incorporating experts' opinion, a priority index is calculated for each product mix studied, and a performance ranking of product mixes is generated.

Miscellaneous Examples of the Product Mix Problem:

There are several studies of product mix problems which address specific industrial issues, like product mix of an insurance company, product mix decision in a mixed-yield wafer fabrication, product mix in the TFT-LCD industry, product mix planning in semiconductor manufacturing, product mix in plywood manufacturing, and tool planning in multiple product mix for wafer foundries (Kahane, 1977; Wu et al., 2006; Wang et al. 2007; Chou, 2000; Roy et al., 1982; Hsiung et al., 2006).

In a recent study of Wang et al. (2007), the traditional product mix problem has been studied considering a number of unique characteristics of the TFT-LCD industry (i.e., in the consumer durables sector), such as the supply of key components, the process yield, the committed orders, and the efficiency of resource utilization. It is stated that the primary interest of decision makers in this industry is not only to improve production performance but also to effectively make product mix changes using flexible production and business operation. Therefore, determining the optimum product mix and analyzing its implications is an essential part of the design process for the achievement of a robust and flexible production system. A company's product mix is defined as the percentage of total throughput devoted to each product. Product mix analysis focuses on determining the optimum product mix and highlights the implications of varying the percentage of each product on different production activities. The problem encountered here is to determine product demand allocations that are suitable for production factories. A MILP is used to determine the optimal product mix for all available resources for a monthly production plan in order to maximize the net profit subject to constraints imposed by resource limitations, fulfill orders, and inventory costs. They extend the model for multiple production planning periods.

It can be concluded that there are many rich models for the product mix decision problem. However, the main issue of uncertainty remains the same. In other words, product mix planning using deterministic models has the disadvantage that the uncertainties are not considered. Hence the decisions will not be optimal, and there is no guarantee that the decision makers of the firm will not run into very unfavorable situations because of the discrepancies between the assumed and the real evolution of the critical parameters of product mix decision (Cui and Engel, 2010).

2.2.1.2 Product Mix Problem under Uncertainty

In general, research on optimization that considers uncertainty can be categorized according to the four primary approaches:

1) Stochastic programming approach,
2) Fuzzy programming approach,
3) Robust optimization approach,
4) Simulation optimization approach

In the stochastic programming approach, some parameters are regarded as random variables with known probability distributions (Ravindran, 2008). It should be noted that the stochastic programming approach focuses on optimizing the expected performance (e.g. profit) over a range of possible scenarios for the random parameters. In this optimization approach, stochastic problems are divided into two-stage and multi-stage problems. In the first sub-class of this category, the initial decisions are taken first, which are followed by a random event. Next, the recourse decisions, which are based on this random event, are taken. As the second sub-class of this category, the stochastic dynamic programming approach includes applications of random variables in dynamic programming which can be found essentially in all areas of multi-stage decision making. It is assumed that a system evolves over a set of stages, between which a stochastic event occurs; a corrective control action (or a recourse action) can be taken in the next stage. This kind of an approach is also called as multi-stage stochastic programming (Zima, 2009). In this case, decisions are made at each stage.

The fuzzy programming approach seeks the solution considering some variables as fuzzy numbers.

Robust optimization approach represents uncertainty through setting up different scenarios which demonstrate realizations of uncertain parameters. The aim of this approach is to find a robust solution which ensures that all specified scenarios are "close" to the optimum in response to changing input data (Mirzapour Al-e-hashem et al., 2011). In contrast to stochastic programming, in which data uncertainty is modeled in stochastic nature, robust optimization does not assume the stochastic nature of the uncertain data (Ben-Tal and Hertog, 2011). In the robust optimization approach, an uncertainty region is defined on constraints while keeping the objective as certain.

Due to the similarity of our problem formulation approach, we will give a special emphasis to the *simulation optimization approach*. Better et al. (2008) present some new approaches of the simulation optimization for managing risk. The advantages and disadvantages of traditional optimization approaches are discussed in the study, and they illustrate the advantages of simulation optimization through two practical example problems. It is stated that traditional scenario-based approaches, like scenario optimization and robust optimization consider only a small subset of possible scenarios, and therefore the size and complexity of the models handled by these approaches are very limited. The scenario optimization approach is summarized as follows:

1) Compute the optimal solution to each deterministic scenario sub-problem.
2) Solve a tracking model to find a single, feasible decision for all scenarios.

The key aspect of scenario optimization is the tracking model in step 2, which has the purpose of finding a feasible solution under all scenarios by penalizing the solutions that differ greatly from the optimal solution. Note that we use step 1 above in our formulation approach. It is pointed out that robust optimization may be used when the parameters of the optimization problem are known within a finite set of values, and hence, it has been concluded that "most traditional optimization techniques that attempt to deal with uncertainty, is their inability to handle a large number of possible scenarios" (Better et al., 2008). The authors argue that some recent innovative approaches in simulation optimization can overcome the limitations stated above by providing a practical and flexible framework for decision making under uncertainty.

In the simulation optimization approach, the optimization problem is defined outside the complex system. Therefore the simulation model can change and evolve to incorporate additional elements of the complex system, while the optimization procedures remain the same. Better et al. (2008), providing a general form of an optimization problem, state that simulation optimization tools are designed to solve the type of optimization problems in which the vector of decision variables includes both integer values and variables that range over continuous values.

The optimization procedure in the simulation optimization approach uses the outputs from the system evaluator, which measures and evaluates the merit of inputs. Better et al. (2008) illustrate the optimization procedure as in Figure 2.6.

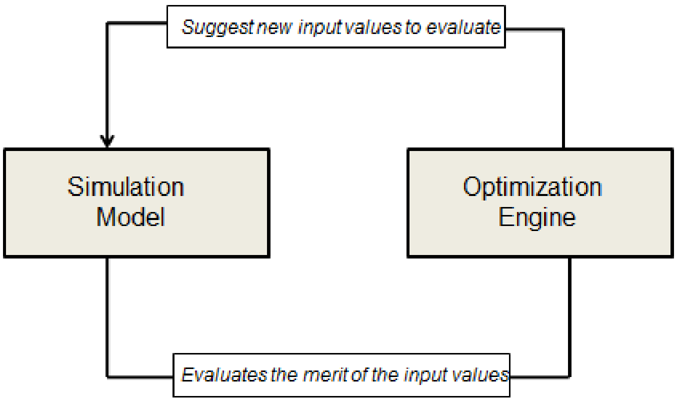

Figure 2.6: Simulation Optimization Procedure (Source: Better et al., 2008)

The process depicted in figure 2.6 continues until an appropriate termination criterion is satisfied. It is stated that this criterion is usually based on the analyst's preference for the amount of time devoted to the search.

Finally, Better et al. (2008) point out an important remark about the solution space of the problem. It is stated that the uncertainties and complexities modeled by the simulation are often such that the analyst has no idea about the shape of the response surface, i.e., the solution space. Since there is no closed-form mathematical expression to represent the space, there is no way to gauge whether the region being searched is smooth, discontinuous, etc. In short, this study views the simulation optimization approach as more efficient, flexible and practical than the traditional optimization approaches under uncertainty, stating the following:

> "*While this is enough to make most traditional optimization algorithms fail, meta-heuristic optimization approaches, such as tabu search and scatter search, overcome this challenge by making use of adaptive memory techniques and population sampling methods that allow the search to be conducted on a wide area of the solution space, without getting stuck in local optima*" (Better et al., 2008).

Below we review some specific research studies as the application examples of the general approaches described briefly above.

Cui and Engel (2010) deal with the medium-term planning of a polymer production plant, considering demand, plant capacity and yield uncertainties. They consider the following approaches as the treatment of uncertainty caused by demand, capacities, revenues, etc.:

- event-driven or periodic re-planning,
- reactive re-planning,
- robust planning,
- multi-stage or two-stage stochastic planning.

They state that robust planning and multi-stage planning are variants of stochastic optimization, in which models take uncertainty explicitly into account. Moreover, it is stated that stochastic models with recourse consider the corrective measures that can be taken after the realization of some uncertain parameters while in robust planning and this option is not included. They have also a criticism about the multi-stage stochastic approach regarding the solution algorithm of this kind of decision problems which leads to a complex nested structure, because at each stage, the reaction of the algorithm to the information obtained at later stages must be taken into account. It is pointed out that this is the main reason of multi-stage problems approximations into two-stage problems. After the discussion of this kind of issues, they propose a stochastic dynamic MILP formulation with two-stage. They consider a moving horizon strategy in their model which is stated that it represents a contribution to this area of the literature.

Mirzapour-Al-e-hashem et al. (2011) present a multi-objective APP model to solve the multi-period multi-product multi-site APP problem for a medium-term planning horizon based on existing conflict between the total losses of supply chain and customer satisfaction level over the planning horizon under different scenarios using the robust optimization approach. The main features of the proposed model are as follows:

1) It considers the majority of supply chain cost parameters such as transportation cost, inventory holding cost, shortage cost, production cost and human related cost;
2) It considers employment, dismissal and workers' productivity;
3) It considers the working levels and possibility of staff training and upgrading;
4) It considers lead time between suppliers and sites and between sites and customers' zones;
5) Cost parameters and demand fluctuations are subject to uncertainty.

This problem is formulated as a multi-objective mixed integer nonlinear programming problem and then transformed into a linear one and reformulated as a robust counterpart as multi-objective linear programming in which the risk of solution is measured through the absolute deviation method instead of sum of square error to maintain model linearity. Finally this robust multi-objective model is solved by applying the LP-metrics method. They apply the model to a company in order to demonstrate its practical use.

Alonso-Ayuso et al. (2005) deal with the problem of determining what products to produce and market, and with the plant selection and production capacity dimensioning. They call the problem *strategic* production planning under uncertainty. They consider the product price, demand and production cost as the uncertain parameters in their two-stage stochastic optimization model. The uncertainty is represented by a set of scenarios. It is stated that most stochastic approaches to production planning only consider tactical decisions. In order to include the strategic level of decision making to their problem, they present a mixed 0-1 deterministic equivalent model for the two-stage stochastic optimization problem, in which the first stage variables are *strategic 0-1 variables to determine product selection* and plant dimension. Then, the second stage variables are tactical continuous variables to determine the production, stock and market shipment of the products for each period throughout the time horizon under each scenario. Due to the combinatorial nature of the problem and large number of scenarios, getting the optimal solution is impossible and even not realistic. Therefore, they present a Branch-and-Fix-Coordination (BFC) scheme to exploit the structure of the problem in a stochastic environment, specifically the structure of the non-anticipativity constraints for the 0-1 variables. It is stated that the proposed BFC scheme provides the optimal solution with less computational effort.

Cristobal et al. (2009) outlines the stochastic dynamic programming approach in their study and present an application for modeling using this approach. They use the scenario tree in a back-to-front scheme. In other words, they consider the multi-period stochastic mixed 0-1 sub-problems related to the sub-trees whose nodes are the starting nodes (i.e., scenario groups) in each state along the time horizon. Each sub-problem considers the effect of stochasticity of uncertain parameters from the given stage by using the curves that give the expected future value (EFV) of the objective function. Each sub-problem is solved for a representative set of reference levels of the linking variables between the previous stages and a given one. They use a pilot case which is a classical tactical production planning problem, consisting of deciding how much production, and where applicable, how much loss in product demand can be expected at each period along a time horizon.

Hasuike and Ishii (2009) consider a product mix problem both maximizing the total future profit and minimizing excessive inventories under uncertainty with respect to future profits and customers' demands. The proposed product mix problem is formulated as a multi-criteria programming problem considering maximizing all aspiration levels, regarding the goal of the decision maker of the total future profit and each inventory levels, assumed to be fuzzy goals. They assume a single period case in this study. Hasuike and Ishii (2009) extend their former model in their study by considering a multi-period and multi-criteria product mix problem minimizing the total cost, maximizing the total profit and minimizing the inventory levels under various random and ambiguous conditions. In order to reflect the real problem situation, a standard product mix problem is integrated with manufacturing and distribution planning decisions in the supply chain. To do this, they formulate a random/fuzzy model which contains a mixture of both random and fuzzy parameters. It is stated that the problem is not a well-defined problem due to the inclusion of these random variables and fuzzy numbers and it is hard to solve it directly. In order to overcome the computational inefficiency and complexity, they introduce chance constraints so that the main problem is transformed into a nonlinear programming problem. Consequently, using the stochastic programming approach and fuzzy programming approach, the problem is converted to a deterministic equivalent problem. Furthermore, to solve it more efficiently, the solution method using the mean absolute deviation is constructed.

In another research study, Hasuike and Ishii (2009) considers the product mix problem including randomness of future returns, ambiguity of coefficients and flexibility of upper value with respect to each constraint. The flexibility of the upper value of each constraint is taken into account by assuming that they are not fixed values but variable including a measure of range. Therefore, they introduce aspiration levels to each constraint and several models based on maximizing total future profits under a level of satisfaction to each fuzzy goal are proposed. Basically they propose three models under several randomness, fuzziness and flexibility:

1) Probability fractile optimization model to future profits; the case where decision makers plan to maximize the total future return as much as possible under holding more than the target probability.
2) Probability maximization model to total future profits; the case where decision makers want to earn more than target value in almost all situations.
3) Preference ranking model; the case where the decision maker has a preference ranking among all the fuzzy goals. So, this model is constructed considering the aspiration level of future returns is higher than the minimum aspiration levels of all constraints.

Similar to the studies mentioned above, all these models are basically nonlinear programming problems and are transformed into deterministic equivalent problems in order to make them solvable. Hasuike and Ishii (2009) extend their earlier studies mentioned above by using risk management methods used in the portfolio theory to product mix decision problems, indicating that “since product mix decision problems are considered part of resource allocation problems, product mix decision problems and portfolio selection problems are regarded as similar problems” (Hasuike and Ishii, 2009). They also state that “particularly in the supply chain management, the product mix is the most important problem, but as yet; only a few studies addressed product mix decision problems under uncertainty based on portfolio theory and supply chain flexibility”. However, in most approaches to product-mix decision problems through TOC, randomness and fuzziness are considered separately, but to represent real product-mix decision cases under the changes of future customers’ demands and a large amount of efficient and inefficient information in the real market, it may not be valid to consider future profits as fixed values, random variables, or fuzzy variables. Rather, they should be considered as product-mix decision problems that integrate randomness and fuzziness. Furthermore, in most previous studies, the main focus is not on the concept of flexibility in responding to many different future scenarios. It is important to introduce flexibilities such as considering several future scenarios and their levels of satisfaction, in terms of the target total profit and the upper values of constraints.

These are the main reasons why they address this specific issue of flexible product mix decision problem under uncertainty. This paper proposes, using stochastic and fuzzy modeling to address probabilistic and ambiguous factors, flexibility to deal with demand volatility and readiness to make various changes from the original product-mix decision, and TOC to identify bottlenecks and portfolio selection to deal with risk management. They propose two mathematical programming problems similar to the models (1) and (2) given above. Similarly, these models are called stochastic and fuzzy programming models, and are transformed into nonlinear programming problems by setting the target values and using chance constraints.

In the work of Vasant and Barsoum (2006), the product mix problem is considered in the production planning management where the decision maker plays an important role in making decision in an uncertain environment. So, the objective of this paper is to find optimal units of products with higher level of satisfaction with vagueness as a key factor. In other words, they try to find a good enough solution for the decision maker to make a final decision. An industrial application of fuzzy LP (FLP) through the S-curve membership function is investigated using a set of real life data collected from a chocolate manufacturing company.

In a more recent study, Bhattacharya et al. (2008) have studied a fuzzified approach using FLP with a logistic membership function (MF) to find fuzziness patterns at disparate levels of satisfaction for TOC-based product mix decision problems. The main objectives of the study are as follows:

- To find fuzziness patterns of product mix decisions with disparate levels of satisfaction of the decision maker.
- To provide a robust, quantified monitor of the level of satisfaction among decision makers and to calibrate these levels of satisfaction against decision maker expectations.

They call their approach “Human-machine intelligent” (HMI) approach which uses FLP. They conclude that the HMI-FLP approach is suitable for improving solutions obtained from TOC product mix decisions.

Under the headline of product line selection under uncertainty, we present first the study of Kraus and Yano (2003). They address the problem of selecting a set of products and their prices when customers select among the offered products according to a share-of-surplus choice model. They define the customer surplus as “the difference between his utility (willingness to pay) and the price of the product”. The share-of-surplus model considers the fraction of a customer segment that select a particular product, as the ratio of the segment’s surplus from this particular product to the segment’s total surplus across all offered products with positive surplus for that segment. A mixed integer optimization model is constructed and they develop a heuristic to get the solution. Next they develop a variant of their procedure to handle the uncertainty in customer utilities, which is so-called *probabilistic choice* behavior. Their reasons underlying the using of a share-to-surplus choice model are explained as follows:

- This model explicitly accounts for prices which they want to optimize for the offered products.

- As compared to the choice models in which customers purchase products even when their surplus is negative may lead to an undesirable situation for the manufacturer.
- It is stated that their aim is to optimize both binary product selection decisions and continuous pricing decisions, so they need a tractable representation of customer choice.

Indicating that there is only one study addressing simultaneous product offering and pricing for a large set of potential products under a probabilistic choice model, they view their work as an important initial step in the direction of solving the general problem in cases where the customer purchase only products for which their surplus is positive.

Schön (2010) proposes an alternative modeling structure to the probabilistic choice behavior mentioning the Kraus and Yano (2003) study. In the proposed model, a convenient structure is achieved by viewing demand rather than price as the decision variable. Instead of offering binary variables for product selection, the decisions about which products to offer are simultaneously controlled with continuous pricing decisions by determining the optimal price and demand level, respectively. In other words, "each pricing decision is simultaneously a decision about offering or not offering a product if there exists a so-called null price sufficiently high to exceed willingness-to-pay and thus to turn down demand for the product". Then not offering a product corresponds to turning down demand for it, or equivalently raising its price sufficiently high, i.e., to the null price.

Li and Azarm (2002), focusing on the design phase of product development, extend their previous study for design selection of a single product with multiple attributes. In their study they seek the answer to the following question: "How should we generate the design alternatives that are the best possible and devise from them a product line whose market potential is accounted for, given customers' preferences, market competitions, and uncertainties in several parameters?" Their purpose is to integrate the engineering design perspective, and the management and marketing perspective. They present an integrated approach for a product line design selection problem based upon the marketing potential of the candidate product lines. Their overall framework of the approach can be summarized as follows:

The product line design selection is divided into two stages:

1. *Design alternative generation stage*: In this stage, the best possible design alternatives for variants that form a candidate product line are generated. In order to take into account commonality among variants in a product line, different scenarios (i.e., with or without commonality) can be considered. The multi-objective optimization problem is formulated and solved to obtain Pareto design alternatives. They assume there are analysis (or simulation) models available that evaluate performance metrics of design alternatives from an engineering point of view. This optimization is repeated for every scenario.
2. *Product line design evaluation*: The goal in this stage is to select a set of variants to form the best product line. Candidate product lines are formed and evaluated in order to account for:
    - Achievement of business goals (NPV of profit and market share);

- Large variety of customers' preferences;
- Market competitions, represented by competitive products in the market;
- Product life cycle; and,
- Uncertainties in parameters such as cost, market size, discount rate etc.

Uncertainties exist in customer preference data, market size, product cost, yearly change in variable cost, yearly change in price, and discount rate, among others. To handle the uncertainties a Monte Carlo simulation is used. To estimate the designer's expected utility for a candidate product line, a large number of Monte Carlo trials are performed to obtain the probability distribution of business goals (NPV of profit and market share) and also that of the designer's utility. Based on the expected utility theorem, the designer's expected utility is found, which is used as the criterion to evaluate different candidate product lines. Note that there are some similarities in this approach to our approach of problem formulation despite the fact that the problems statements are totally different.

The product mix problem under uncertainty has also been examined using different approaches other than the optimization approaches mentioned above (Chen et al., 2006; Chen et al., 2007; Bayou, 2005). Chen et al. (2006) analyze the product mix decision problem in the framework of new products, by using the analytic hierarchy process (AHP) introducing fuzzy numbers. AHP is a popular multi-criteria decision making (MCDM) method. This model considers the vagueness and the uncertainty of experts' judgment. In their subsequent article (Chen et al., 2007), they propose fuzzy AHP using triangular fuzzy numbers, in order to determine NPD mix, by including a confidence level and a risk index to capture the effects of market risks, technological complexity, controllability and creditability of resources data.

Finally, it should be noted there are several product mix under uncertainty studies which are conducted for specific industrial manufacturing companies, like product mix capacity planning model for semiconductor industry (Stafford, 1997), product mix problem in a Dip Molding company (Nikumbh et al., 2009), and capacity planning in the face of product mix uncertainty for wafer fabrication facilities (Kotcher and Chance, 1999) where each considers the special properties of manufacturing in those industries for the formulation of the product mix problem.

2.2.2 Cost Structure and Costing Approaches in the Product Mix Problem

The cost structure and costing approaches are important relevant subjects in the context of the strategic product mix problem. As it is explained in Chapter 3, the proposed product mix DSS provides input to the aggregate production planning within the framework of the product management context. Below the choice of cost content and costing approaches in the literature is presented related to the product mix problem.

In the aggregate production planning context, the following specific costs are considered (Nahmias, 2001):

1. *Smoothing costs.* Smoothing costs are accrued as a result of changing the production levels from one period to the next. The most important source of the change is the changing the size of the work force.

2. *Holding costs.* These are the costs that accrue as a result of having capital tied up in inventory.
3. *Shortage costs.* Shortages are represented by a negative level of inventory. Shortages occur when demand exceeds the capacity of the production facility or when demands are higher than anticipated. In APP, it is generally assumed that demand is backlogged and filled in a future period. In a highly competitive environment, that excess demand is lost and the customer goes somewhere else. This case is known as lost sales.
4. *Regular time costs.* They are the costs of producing one unit of product during regular working hours. These costs include actual payroll costs of regular employees working on regular time, the direct and indirect costs of materials, and other manufacturing expenses. When all production is carried out on regular time, regular payroll costs become a "sunk cost" over a planning horizon of sufficiently long. If there is no overtime or worker idle time, regular payroll costs do not have to be included in the evaluation of different strategies.
5. *Overtime and subcontracting costs.* They are the costs of production of units not produced on regular time.
6. *Idle time costs.* "The complete formulation of the APP problem includes a cost for underutilization of the workforce, or idle time. In most contexts, the idle time cost is zero, as the direct costs of idle time would be taken into account in labor costs and lower production levels" (Nahmias, 2001; p.119).

Hence, we consider only "*regular time costs*" in our mathematical model depending on the single planning period, zero inventory, and stable workforce assumptions. The cost of producing one unit of product is one of the key inputs in product mix problem. The choice of cost content has been extensively studied in the product mix literature. We will concentrate on a few ones which are most relevant to us (Lea and Fredendall, 2002; Lee and Plenert, 1996; Sridharan et al., 2008; Souren et al., 2005; Köksal, 2004).

The content of the unit production cost depends on the types of management accounting systems. Therefore, we will briefly discuss the impact of management accounting systems on product mix decisions below.

Theory of Constraints (TOC), which was developed by Goldratt at the beginning of the 1980s as a new management philosophy, has received increasing attention from researchers. Souren et al. (2005) analyze the impact of the Theory of Constraints (TOC) and Throughput Accounting on product mix decisions. It is pointed out that many applications and management tools in different management fields have been developed based on the TOC philosophy. One of these applications is the Throughput Accounting (TA) approach. TA approach is focused on constraints and it is designed as a direct costing approach. Therefore, product mix decisions constitute a main application area of TA. The main aim of Souren et al.'s (2005) paper is to provide an "insight into the TOC-based approach by analyzing the main premises of product mix decisions" (p.362). As mentioned before, TOC approach has five major steps. Souren et al. (2005) indicate that only the first two steps of the TOC approach support short-term product mix decisions, while the other steps are aimed more towards the medium or long–term planning issues of the production system. In this study, throughput is simply defined as follows:

Throughput = Sales price – Material costs

Köksal (2004) considers the following definition of throughput: “the rate at which a system generates money through sales”, mathematically

Throughput = Sales revenues – Totally variable costs (TVC)

TVC include raw material inventory content of the sales and any other costs that increase directly because of an increased level of production. Inventory is “all the money that the system has invested in purchasing things that it intends to sell”, which includes items like raw materials, buildings, machinery and such under its heading. Operating expense is defined as “all the money the system spends in order to turn inventory into throughput”, which includes wages, overhead costs, maintenance and depreciation (Köksal, 2004; p. 5011).

Through several examples, Souren et al. (2005) analyze

1. the solution space in product mix decisions, influenced by the types and number of constraints, integer versus non-integer solutions, and
2. the objective function in product mix decisions, in view of decision centric allocation of costs to products, considering linear versus non-linear objective functions.

Souren et al. (2005) present the conclusions derived from their analyses in the form of a checklist, which is illustrated in Figure 2.7.

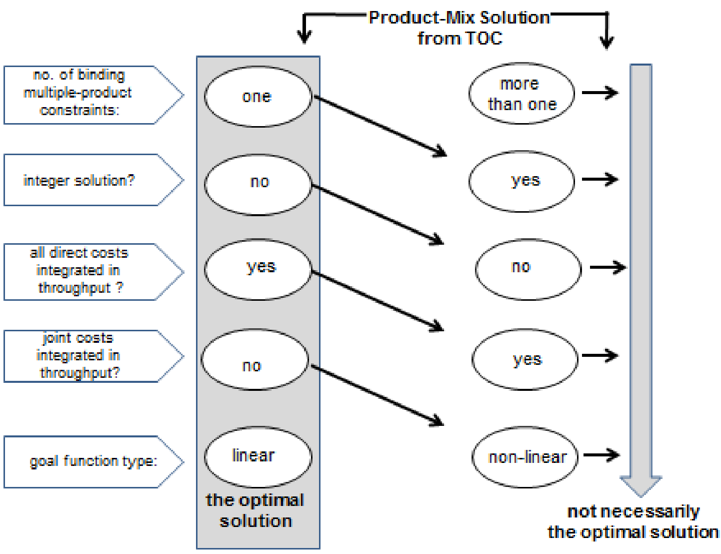

Figure 2.7: Checklist for the usage of the TOC-based approach (Source: Souren et. al., 2005; p.373)

Sridharan et al. (2008) examine TOC-based costing and Activity-Based Costing (ABC) in relation to the product mix decision concept in their study. Eloborating the contrasting features of both costing approaches, the selection problem of TOC and ABC in a product mix context is clarified, and they introduce an economic concept namely "asset specifity" as an alternate explanation to a firm's specific choice. It is stated that the major reason of constrasting these two costing system is the differences in the main purpose of the two systems:

- "TOC seeks to optimize production by managing the constraints and thus obtain higher throughput.
- ABC aims to increase the accuracy of product costs by a systematic allocation of costs to activities consumed by the products" (Sridharan et al., 2008; p.105).

Since TOC's focus is throughput, it aims to reduce the costs of inefficiency in constraining resources such as bottlenecks so as to increase the throughput. However, ABC aims to build the costs of most resources into the product costs regardless of resource bottlenecks.

Other than the differences in the purposes of the TOC-ABC costing systems, the following contrasting features of TOC-ABC and ABC-Traditional Costing are provided in Sridharan et al. (2008) considering the suggestions in the accounting literature:

In a TOC-based system, as long as the market price of a product covers the material and other out-of-pocket costs, the product can be accepted as profitable.

- ABC first traces costs to activities and then allocates the cost of activities to the products, which is in contrast to traditional costing where costs are traced to departments before getting allocated to the products regardless of whether the resource is actually consumed by the product or not. ABC charges the costs of only those activities that are demanded by the products. So ABC product cost can be considered to be more accurate than traditional costing.
- The constracting characteristics of TOC-ABC are grouped as follows:
    1. *Cost variability.* While TOC considers only material and related out-of-pocket costs as truly variable, ABC seeks to include most costs as variable with respect to multiple activity drivers.
    2. *Constraint location.* While TOC considers the existence of at least one constraint which may be either within the firm (e.g., manufacturing process) or outside of the firm (e.g., market demand), ABC does not generally recognize any constraint.

Considering the accounting literature, the following is suggested: TOC is a short term decision tool since most costs remain fixed in short run while ABC is more of a long term tool since most costs are variable in the long run (Sridharan et al., 2008).

One of the most relevant studies to us is Lea and Fredendal (2002) which "examines how three types of management accounting systems and two methods to determine product mix interact in both the short term and the long term to affect the manufacturing performance of two shops – one with flat and the other with a deep product structure" (p. 279). Stating that researchers have some disagreement about the best method of determining the product mix and the best management accounting system to use, it is aimed to analyze the interaction of the product mix decision not only with ABC and TA, but also with traditional cost accounting (Lea and Fredendal, 2002). We highlight the major points in the study below.

The management accounting system has an important effect on the product mix decision by calculating the product cost and the product's contribution margin. Without going into the details of these three costing systems, we prefer to present them in Table 2.2, which outlines a comparison of these accounting systems provided in Lea and Fredendal (2002).

An important feature of the study is the handling of uncertainty involved in the system such as demand variation, purchasing price fluctuation, and processing time variation to better represent the reality. Therefore, the authors state that, product costs determined by the accounting system are based on real time production data, then the updated product costs are input to the manufacturing system to make product mix decisions. A simulation environment for three multi-level products in seven work centers in a make-to-stock manufacturing environment for each shop is created. They perform a 3x2x2 factorial design with one repeat measure. The results are obtained from 6 replications.

Table 2.2: Comparison of management accounting systems (Source: Lea and Fredendal, 2002; p. 281)

	Traditional full costing	***Activity-based costing***	***Throughput accounting***
Time of introduction	1900s	1970s	Late 1980s
Type of production	Mass production that has volume related overhead	Any type of production	Production that has insignificant overhead and labor costs
Variety of products	Homogeneous and limited variety	Homogeneous and heterogeneous	Homogeneous and heterogeneous
Automation/technology usage	Low and limited	Low to high	Low
Overhead allocation	Usually volume related	Based on activity usage	None
Costs included in product cost computation (the difference between cost and selling price is the profit used product mix algorithm)	Direct material Direct labor Factory overhead (both variable and fixed)	Direct material Direct labor Factory overhead (both variable and fixed) Sales, general, and administration	Direct material

The major conclusions and suggestions are summarized below:

1. It is suggested that ABC is more sensitive to environmental uncertainty than traditional costing. However, traditional costing is not outdated and irrelevant as some researchers suggested.
2. It is also suggested that LP may be more sensitive to environmental uncertainty than TOC, which explains the reason that TOC is valuable tool in practice.

All three accounting systems are performed in both short-term and long-term decisions when the performance measure is profitability. So,

1. "A very important finding of this research is that management accounting systems which lead to higher short-term profits will generate higher long-term profit, contrary to findings by some researchers that suggest that short-term and long-term decision making may be in conflict" (p. 296).
2. Furthermore, the performance of product structures or product mix algorithms is not different in the short and long-term.
3. When TOC is used in combination with any accounting system, it reduces the bottleneck shiftiness for both the flat and deep product structures, which means that using TOC increases the shop manageability.

The details of the results are given in the form of a decision tree with respect to the decision factors, namely, management accounting system (3 levels), product mix algorithm (2 levels), and product structure (2 levels) (Lea and Fredendal, 2002).

Finally, we will consider the article of Lee and Plenert (1996) which compares LP-based and TOC-based methodologies for selecting the optimal product mix concerning the profitability. Our major interest in this study is the evaluation of introducing a *new product* alternative which is analyzed using the LP-based, TOC-based and traditional accounting methodologies. They simply conclude that the traditional costing methodology is inferior in evaluating the introduction of new products comparing to the other two methods, they are indifferent for the rest of the two methods, namely LP-based and TOC-based methodologies.

2.2.3 Models of Price-Demand Relations

Our main purpose is to search and understand the demand-price relations in order to determine an appropriate transfer function of these inputs of our product mix model which we use in our probabilistic approach. Therefore, our major focus is on the explicit forms of demand functions in the literature.

The relationships between demand and price are studied heavily in the context of pricing theory in the literature (Ferrer et al., 2010; Hamister and Suresh, 2008; Tang et al., 2011; Koenig and Meissner, 2010; Chen et al., 2010). Many applications of pricing theory has appeared to manage supply chains (Chen et al., 2010; Tang et al., 2011; Hamister and Suresh, 2008) and in revenue management (Koenig and Meissner, 2010; Shakya et al., 2012). There are also several articles directly adressing the demand models (Soon et al., 2009; Soon, 2011; Shakya et al., 2012). Among them, Soon (2011) presents an excellent review of pricing models in his recent study. Below we will highlight the main points of this literature which are most relevant to us.

Pricing is a significant tool used in the profit maximization of firms, which represents also an important problem area for those firms. Pricing, and particularly pricing strategies are used in day-to-day market operations of firms to manipulate demand, and to regulate the production and distribution of products.

Soon (2011) states that much of the research focuses on the pricing of single products because of the complexity of multi-product demand functions. Let us consider the following important remark existing in the study:

> "*As more firms enters the markets, and due to the heterogeneous tastes of consumers, it became necessary to incorporate product differentiation and competition into pricing models. In these competitive and multi-product pricing models, the demand – price relationships (or demand functions) of multiple products are among the core ingredients. As products are commonly substitutable for or complementary to one another, the demand for each product should depend on the prices of all products in the same market*" (Soon, 2011; p.8149).

According to him, his study is the first one discussing a review of pricing models with focus on explicit demand functions of prices. His main purpose is to provide his work to the use of researchers who require knowledge of the different aspects of *multi-product* pricing involving the *modelling of demand for products*. The study focuses on pricing strategies for *multiple products* that are necessary to consider in a *competitive market* with multiple sellers and product differentiation.

He first presents the common types of pricing models relevant to his focus in this work. Next, various-types of demand models are introduced (both deterministic and stochastic).

Various types of pricing models are summarized below:

1. Static-non-competitive pricing models
2. Dynamic non-competitive pricing models
3. Competitive pricing models

Static-non-competitive pricing models involve the simultaneous pricing of multiple products offered by a single seller, where a fixed price is set for each product. Different varieties of single product offered are considered with corresponding different prices set in different literature. In the paper, however, all these different varieties are considered as different products. In other words, the number of products corresponds to the number of price variables considered.

Dynamic non-competitive pricing models reflect the strategy where the pricing of products changes over time. In multiple-period or discrete-time models, the prices change from period to period, while remaining constant within each period. Such a pricing strategy considers the changes in demand over time.

In *competitive pricing models*, each seller's objective depends on his and other sellers' decisions. The demand function facing each seller is thus commonly a function of other sellers' choice variables as well. An example of one of the simplest model called Bertrand oligolpoly game, is as follows:

- Each seller i maximizes his profit, $\pi_i = (p_i - c_i)D_i(p_i, p_{-i})$ with p_i, c_i and D_i as the price, cost(constant) and a demand for product i, respectively, and p_{-i} as the price vector of all *other* products. Note that p_i is the only decision variable for seller i and there may be restrictions on it, like upper and lower bound constraints.

Several variants and extensions of the competitive pricing models are presented, for example,

- sellers offering multiple products each and multiple-period pricing scheme,
- limited capacity of firms and a two-firm model,
- revenue maximization problem of seller,
- retail pricing strategies under centralized and decentralized supply chain setting,
- simultaneous pricing policies of oligopolistic manufacturers and a common retailer,
- a model which combines the complexity of time-dependent demand and cost functions with that arising from dynamic lot sizing costs,
- a Stacelberg game where the price leader and the follower offers one brand each in the market. The objectives of the leader and follower are to set prices so as to minimize the deviations of sales in each period ,
- a bi-level transit fare equilibrium model for a deregulated transit system,
- a model in a homogeneous product market, i.e., the firms offer exactly the same product and the consumers usually purchase the product from the firm offering it at the lowest price.

Types of Demand Models:

Demand models are fundamental tools in pricing models. Soon (2011) states that there exist many formulations in the literature whether they are solely price-dependent or dependent on other attributes as well, either with deterministic or stochastic parameters. The most commonly considered demand model is the linear demand function (Soon et al., 2009; Soon, 2011; Shakya et al., 2012). Before going into the detail about the functional forms presented in Soon (2011), we present general linear demand system in matrix notation (Soon et al., 2009):

Linear demand system:

$d(p) = b - Ap$, where d and p are the demand and price vectors, respectively, b is a constant vector and A is a matrix of appropriate dimensions. By the law of demand, i.e. the demand d_i decreases in its own price p_i , the demand function d_i will be negative for a large value of p_i.

All the vectors are column vectors. Because the products are substitutable for each other or complementary to each other, demand depends on the prices of all products, thus it is a function of price.

$$b = \begin{pmatrix} b_1 \\ \vdots \\ b_N \end{pmatrix} \qquad A = \begin{pmatrix} a_{11} & \cdots & a_{1N} \\ \vdots & \ddots & \vdots \\ a_{N1} & \cdots & a_{NN} \end{pmatrix}$$

The diagonal entry a_{ij} of A is the *decrement* in demand for product j when the price p_j *increases* by one unit, and the (j,k) entry a_{jk} of A represents the change in the demand for product j as the p_k changes. When the price of product j increases, the demand d_j should decrease.

<u>*Deterministic Demand Models:*</u>

In deterministic demand models, it is assumed that the sellers have perfect knowledge of the demand processes, i.e., customer behavior is known throughout the time horizon considered. They are simple and can provide a good approximation for the more realistic stochastic models. We grouped the demand models as follows:

1. Linear demand functions
   a) Single Linear Demand Models
   b) Piece-wise Linear Demand Models
   c) Log-Linear Demand Models
2. Concave demand functions
3. Logit Models

We briefly explain them below.

Soon (2011) gives the typical explicit form of the *single demand function* as follows:

$d_i(p) = b_i - a_{ii}p_i + \sum_{j\neq i} a_{ij}p_j$,

where $d_i(p)$ is the demand for product i at the price vector p of all products, $a_{ii} > 0$ reflects the effect of its own price on its demand, and a_{ij} represents the *dependence* of its demand on other products' prices (if they exist). Note that the parameters $a_{ij} > 0$ (or $a_{ij} < 0$) imply that the product j is substitutable for (or complement to) product i. Soon (2011) notes that such a demand function can also be derived from the quadratic utility function of a representative consumer.

Piecewise linear demand functions are considered in the form of

$\max \{ b_i - a_{ii}p_i + \sum_{j\neq i} a_{ij}p_j, 0\}$,

where linear functions with different parameters over different price ranges , i.e., each piece corresponds to a different price range.

Shakya et al. (2012) mention *exponential demand functions* in their study which we group as the *log-linear demand model.* Shakya et al. (2012) consider the commonly used demand models for single product case in their article. So, for the sake of convenience, we adopted the model for single product case to the multiple product case using the same notation given in Soon's (2011) review article as follows:

$$d_i(p) = e^{a_{ii} + \sum_{j\neq i} a_{ij} p_j}$$

Here, a_{ii} and a_{ij} are the parameters similar to the linear model representing the impact of the price on the demand.

Another commonly used demand form is *concave demand functions* in which demand is a concave function of all products' prices and decreases in p_i's.

Apart from linear or concave demand models another type of frequently employed demand functions are the functions which satisfy the "increasing differences" (ID) or "logarithmic increasing differences" (LID) property (Soon, 2011). "A function $f(x_1,\ldots,x_n)$ is said to have (ID) in (x_i,x_j) if $f(x_1,\ldots,x_i',\ldots,x_n) - f(x_1,\ldots,x_i,\ldots,x_N)$ is nondecreasing in x_j for all $x_i < x_i'$. When *log f* satisfies (ID) property, *f* is said to possess the (LID) property" (Soon, 2011; p.8154). *Logit demand functions* are common examples of these types of functions. An example is provided for this type of function:

$$d_i(p) = \frac{k_i e^{-\lambda p_i}}{C_i + \Sigma_{j=1}^{N} k_j e^{-\lambda p_j}}, \quad \text{with } \lambda > 0,\ C_i > 0,\ k_i > 0 \text{ for all } i.$$

Shakya et al. (2012) indicate that logit model is one of the most popular demand model used in practice where it is possible to explicitly model the consumer's choice.

Stochastic Demand Models:

These models are more complicated as they are employed to handle the uncertainty of demand. Demand function is modeled based on a given probability distribution. We present the different formulations of stochastic demand models based on Soon's (2011) review paper. Soon (2011) considers two basic classes of price-demand relations:

1. Linear Demand – Price Relations
    - As mentioned before, linear demand is often used to represent the relation of demand and price. Randomness of demand is incorporated into these models that the *mean* of demand is a linear function of prices. Usually, demand follows a normal distribution.
2. Logarithmic Demand – Price Relations
    - Demand and prices of product *i* $(i=1,\ldots,n)$ have the logarithmic relationship;

$d_{i,t} = e^{\beta_{i,0}} \Pi_{j=1}^{n} p_{j,t}^{\beta_{ij}} e^{u_{i,t}}$, at time *t*, where β_{ij} $(j \neq i)$ represents the cross-elasticity between product *i* and others, and $u_{i,t}$ is the error term. In this model, instead of considering a normal demand distribution, the error term is assumed normally distributed (for each i and t). Correlation among the error terms of different products is also allowed.

Soon (2011) states that many studies consider varied forms of these two models of uncertain demand:

a) a multiplicative model

$d_t(p) = \beta_t\, \delta_t(p)$,

b) an additive model,

$d_t(p) = \delta_t(p) + \beta_t$

where $\delta_t(p)$ is the demand function and β_t is the uncertainty parameter at time t.

In our problem case, the linear demand system will be considered in modeling.

CHAPTER 3

PROPOSED PRODUCT MANAGEMENT FRAMEWORK

The research problem in this study can be stated simply as the strategic implementation of *product mix problem under uncertainty* in the *product management* (PM) context. To understand the importance and the position of the product mix problem within the product management context requires deep understanding of product management in its entirety, such as the scope of activities, its context, difficulties, major decisions, critical success factors, organizational characteristics, etc. One source of getting this knowledge is to investigate the related literature. Therefore, through an extensive literature review, a knowledge platform was established to understand and analyze the basic characteristics of product management. This knowledge platform is called the "*Literature - Based Perspective of Product Management"* in this study. The second source of this knowledge is, undoubtedly, the real business life itself. Management practitioners clearly recognize a field of expertise in product management. Those practising experts, i.e., managers, in the real business life have accumulated experiences and observations in this management field. Therefore, it is very important to see and understand the "*Managerial Perspective of Product Management*" in real life. So, to gain an insight of product management in real life and also to see if there is a gap between the literature-based perspective of PM, a field study has been conducted. It is also believed that such a field study contributes to realize the major difficulties and decision making problems ,and hence, the relative position of the strategic product mix problem among these major problems within the product management context. Additionally, the types of information or knowledge which may support the decision makers in developing the solutions for these problems have been detected. Thus, it can be stated that the field study findings are beneficial and helpful to determine the needs of the managers which in turn guide the development of the solution approach and the construction of the decision support system for the research problem under consideration.

In this chapter, first, the details of the field study and its results are presented. Next, based on both the literature and field study findings, a proposed product management framework is presented. Later, a Flow Model which is the pictorial description of the decision making process of PM is described in detail. Following this description, the major decisions in the PM framework are reviewed. Finally, the major contributions to the PM literature are outlined.

3.1 A SURVEY OF REAL LIFE PRACTICES: MANAGERIAL PERSPECTIVE OF PRODUCT MANAGEMENT

The *main objective of the field study* is to extract and gather information which enable us to define the product management problem, and to see the relative position of the product mix problem under uncertainty in this complex decision making framework. Contributing to this main aim, the *research objectives in the field study* are outlined as follows:

1. To investigate the perception of product management in the companies,
2. To understand the product management practices,
3. To identify the factors which are influencing the decision making process of product management,
4. To identify the major decisions in product management, and
5. To identify the critical success factors of effective product management.

The methodology of field study, the design of the research, survey procedure and selection approach of the case studies are presented in the next section.

3.1.1 Research Methodology of the Field Study

The design of the research requires determination of the method to be used in the study. For this purpose, the empirical research literature is overviewed focusing on the research objectives and the methodologies applied in the studies (Kaynak, 2003; Wayhan and Balderson, 2007; Tuominen et al., 1999). One methodology is to conduct a *cross-sectional mail survey* to test a proposed research model and hypotheses (Kaynak, 2003). For this purpose, the domain of constructs are identified based on a comprehensive literature review. Data are collected through a cross-sectional mail survey methodology, then the research questions posed in the study lend themselves to investigate the relationships between multiple variables. A large sample size is required to obtain reliable and valid results in this methodology. There are some proposals to conduct a robust empirical methodology standards in empirical research literature (Wayhan and Balderson, 2007). It is pointed out that self-reported data from management may be subject to bias.

Empirical research studies are extensively performed in NPD area of the literature. Among these studies, the study of Tuominen et.al (1999) reflects some similarities to our research objective and planned field work. It aims at analyzing the basic characteristics of the *product innovation systems* in organizations. For this purpose, the basic elements and their relations to the innovation management system have been extracted from the literature, and the basic model and items to be investigated are proposed. Investigations have been performed in three companies from electronics industry. According to the proposed model, the authors establish items and questions and conduct *structured interviews* in those companies in order to clarify the characteristics of their innovation management system.

As a result, an insight was obtained from the overview of this literature, although it covers a limited number of studies. Then, it was decided that it would be appropriate to conduct a *multi-case study approach* in our study. In addition, the general rules and principles of the survey methods are examined in empirical research tools in the statistical survey analysis literature in order to avoid the possible errors in research design (Rossi, Wright and Anderson, 1983; Fink, 1995; Alreck and Settle, 1995; Rea and Parker, 2005; Fowler, 2009).

Research Design:

Firstly, on the basis of previous studies in the literature, the *Elemental Product Management Model*, the basic structure of *Proposed Product Management System* and an Input-Output Model for PM were established, and based on these, the items to be investigated were extracted in our field study. The Elemental Product Management Model and Proposed Product Management System are described in section 3.2.

Secondly, the cases of field research were determined. The rationale for using case studies was to observe and describe product management decisions, activities, factors influencing decisions, difficulties, major decisions, successes, required information, management organization, planning tools, decision making tools, etc. within their real life settings.

Four companies were selected that would help to conceptualize and describe the product management in real life. The case study companies are referred to as Company A, Company B, Company C and Company D. The selection criteria of those companies are given below:

1. Be different industry segments of the manufacturing sector,
2. Have substantial experience in product management,
3. Be classified as producing at least relatively incremental innovations.

Survey Procedure:

It was decided to employ *structured interview* in our study, which is also known as a "*standardized interview*" or a "*researcher-administered survey*", realizing that it is commonly used in survey research studies (Rea and Parker,2005; Fowler, 2009). The aim of this approach is to ensure that each interview is presented with the same questions in the same order so the answers can be reliably aggregated. This is important for minimizing the impact of the *context effect* (Oppenheim, 2000). The interviews had two aims:

1. To overcome the limitations of self-administered questionnaire surveys, such as item nonresponse bias (Wayhan and Balderson, 2007) and inconsistency in understanding of questions.
2. To achieve a deeper understanding about product management practices.

In addition to the interviews, annual reports, company brochures and corporate websites were also analyzed to gather background information about the case companies. After completing the interviews, the summary reports were sent to the interviewees for their confirmation.

Questionnaire Construction:

The questionnaire was used to design structured interviews for each of the case organizations. With the help of the form, the same basic questions were asked to every interviewed person from every company. The senior managers and directors who are responsible for product management were interviewed and they completed the questionnaires.

While constructing the questionnaire, the *context analysis* and *content analysis* and also the general rules, like the format, the order of the questions, wording, etc., for the survey were considered (Frazer and Lawley, 2000; Fowler, 1995; Oppenheim, 2000; Gillham, 2007; Brace, 2004). Following the general principles, a cover letter was prepared explaining the purpose of the research, and an explanatory note was provided for the interviewed manager.

Based on the content analysis, the questionnaire was structured in three basic groups:

1. *Company profile questions*: The respondent has asked to describe its organization type and size.
2. *Direct product management questions*: Management practices are examined related with the major activities, decisions, internal and external decision factors, information used, analytical tools.
3. *Generalization questions*: The general perception and definition, critical success factors, expected results of product management are examined.

Except for a couple of questions, the questionnaire is composed of *closed questions*, to be answered through a Likert scale using the values 0-100. Table 3.1 shows an outline of the questions used in the interviews and the questions are presented in Appendix B.

Table 3.1: Outline of the Questions for the Interviews

Personal task and role, in how one is connected to product management.
Company profile information: type of products, sector, sales composition (domestic, international), mission statement, strategic goals, strategies etc.
The critical success factors of the company in performing the management of its products.
The general perception of product management in their practical management.
Goal setting for product management.
Measurement of R&D and selection of R&D projects.
The driving forces and factors that considered in product management.
Assessment of competitive situation.
The links of product management to strategic planning.
Assessment of customer needs in product management.
The analytical tools and techniques used in information generation and flowing of information in decision making process of product management.
The strengths and difficulties in product management of the company.
Assessment of environmental protection efforts of the company.

3.1.2 Field Study Results

Based on the questionnaire constructed, semi-structured interviews were conducted with five individuals from four companies. To ensure consistency, interviews were chosen on the basis of either representing the product management function, or direct involvement in the product management performance. All interviewees were high rank holders in their companies, and the questionnaire was completed by these senior managers. Interviews lasted 90-120 minutes at each company.

Below, the results of individual company interviews are provided emphasizing the decision making process of product management in those companies. Next, some general conclusive remarks are given to point out the common observations in the companies regarding the relevant issues with our research problem in an integrative way with the literature findings.

Company Interviews:

Below, the major findings obtained from the interviews are presented for each case focusing mainly on the decision making process in their product management. After the interviews, the product management experts are asked for replying the questionnaire. The answers of all companies are summarized comparatively in Table 3.2.

<u>CASE-1: Company A</u>

We conducted our interview with the Sales Manager and his deputy. The Company operates in the Consumer Durables Sector, and has a traditional family type of organizational structure.

The product management model of Company A can be described by the following diagram (Figure 3.1):

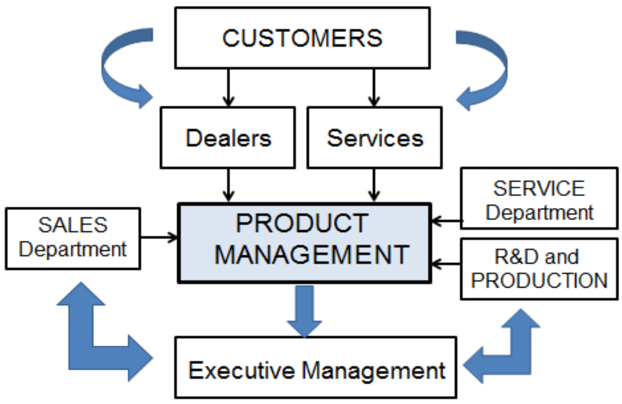

Figure 3.1: Product Management Model of Company A

Company A has a large set of products and it is pointed out that technological changes are not rapid in the market. Market share distribution over the players in the market is quite stable. Product strategy formulation is made based on:

- customer requirements,
- competitors' behavior in the market, and
- products in the market.

They use budgeting as the planning tool. The actual sales figures are impulses for the new products and/or improvement of existing products, and their NPD decisions are generally modifications and/or improvements on existing products. It is stated that "innovative" products in the market are actually "imitative" products.

CASE-2 : Company B

Our interviewee was the "Technology and R&D Group President" who was also a member of the Executive Committee, the decision making unit of new product development.

The company operates in Fast Moving Condumer Goods (FMCG) Sector and has a good and prestigious brand name. Altough it is a family type of organization, it has been managed by professional managers. The company has five plants and $ 1 Billion net sales has been generated, in which the international sales share is about 20%.

Product management activities include strategic product plan of 5 years, which is called as the "Master Plan". Sales and supply chain activities are described as the major activities, and these activities are supported by

- Marketing,
- Finance and IT,
- Human Resources,
- Product Development and Technology (PD).

26% of total sales is provided by the new products of the company. NPD is the combined activity of R&D and PD, where R&D is dealing with mainly fundamental research and experimental research. In PD, creativity stimulation activities take place. The background and culture of the organization has an important role in these activities. Brainstorming and benchmarking are the major tools in developing the ideas for the new products. The illustration of innovation process in NPD is presented in Figure 3.2.

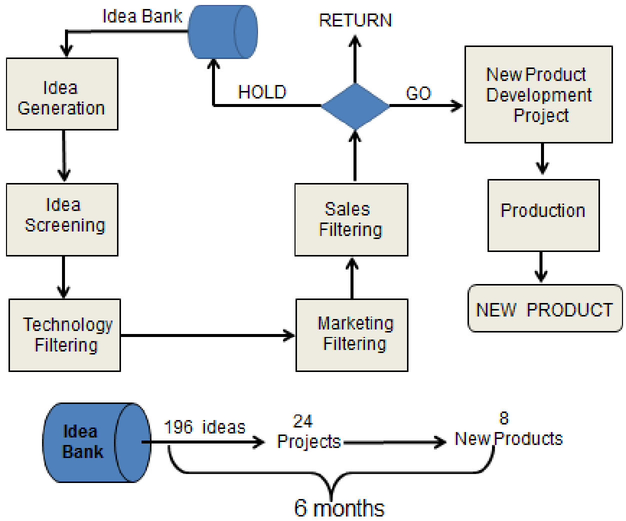

Figure 3.2: Innovation Process of Company B

Investment decisions are taken by the Executive Committee of New Products, whose members are the presidents of

- Marketing Group,
- Sales Group,
- Technology and R&D Group,
- Production.

Budgeting, product portfolio analysis, trend analysis (using the past three years) are the basic decision tools. Continuous systematic follow-up of sales are made on line for 200,000 sales points. The assessment of consumer needs is made through the consumer panels and using the focus groups. Product safety is considered in innovation efforts.

CASE-3: Company C

Company C operates in FMCG sector in Turkey since 1953. We conducted our interview with one of the most experienced category managers in Company C. There are two main groups of products and each product is called by its brand name, i.e., “product” and “brand” terms are used synonymously in the company.

The company is a part of a bigger corporation. Turkey is one of the countries in the “Asia, Africa and Central & Eastern Europe” region. So Company C calls itself as “Local” , and the mother company is called as “Global”. The mother corporation defines itself as a “multi-local multi-national” corporation. Turkey’s region is the most successful region among three regions of the Global corporation with respect to both sales volume and sales growth in 2008.

It will not be wrong to define the Global corporation as a “giant” in its sector over the world, with its 174,000 employees, 40.5 billion Euro turnover, around 100 countries in which they operate, 1 billion Euro R&D investment and 6000 researchers in one unified R&D center. The Local company has a very dynamic working environment, and the average age of management of 50 people is 34. The main activities can be described shortly as “producing and selling”, because strategic decisions and technology, innovation, NPD activities take place in the Global corporation. A two-way feedback process is working between the Local and the Global groups. The local company defines marketing as the "mother of the product". Indeed, the major business is marketing, and product launch decisions are their major concern.

The manufacturing phase of the product management is defined as "business case", in which cost structures and volumes are determined, based on a strategic product plan of five years, and locally

- Market potential,
- Consumer needs,
- Market expectations, and
- Inputs from R&D.

The main goal is the maximization of sales revenues. New product introduction, or simply product launch is managed as a typical project management case. A network management team of 40 people follow the projects. The team members are from

- R&D Department,
- Finance Department,
- Logistics (supply chain) Department.

The network team has regular monthly meetings. The company conducts concept and product tests to understand and evaluate consumer needs. When a new product becomes 6-months old in the market, the company performs a "post-launch evaluation". According to the marketing philosophy of the company, continuous systematic follow-up is important in order to be able to improve the products quickly and promote the whole development process. The category manager says that "We have 40-45 follow-up sentences, we observe the impact of these sentences on our customers". These are actually the "brand messages"- the things a company wants to communicate to consumers, the expectations that should be sent in the consumer's mind. "Companies seek to present a unified face to consumers, with consistent messages communicated through advertising, corporate policy, and, of course, their products" (Oppenheimer, 2005).

The highest level decision maker is the Executive Committee whose members are from both local and global companies. The new goal of the company is "Growth without innovation" which implies stronger marketing power strategy. Another implication is "merging & acquisition", which has been proven by examining the annual report of the Global corporation. In this report, it has been stated that the corporation has strengthened the product portfolio through the acquisition of a Russian food company, and another acquisition has been planned already.

Apart from the 5-year strategic product plan, the Global company has a 20-year TRM. Time-to-market decisions are taken together with the Local and Global companies, considering the projects in the pipeline of R&D and the readiness of the market.

CASE-4: Company D

We conducted our interview with the "Outsourcing manager", who was the developer of the strategic product planning system of the company. At the moment, this system is successfully implemented although they have some bottlenecks and difficulties.

The company represents a part of a bigger corporation in Turkey and operates in the Consumer Durables Sector. It provides products and services to consumers in more than 100 countries with its 12 production plants in 4 different countries, 12 sales and marketing companies and 10 brands. The CEO is from marketing branch of the company and he is the highest level decision maker of the product management.

First of all, it should be noted that the company has very well-defined and well-established strategic module of product management. The corporate goals, mission statements, vision, strategic targets and value chain (shared values) are clearly stated and exist as written documents. As an example, the vision statement is as follows:

"To possess one of the 10 most preferred global brands in our sector by the year 2010", and their slogan is *"TARGET 2010 – TOP 10".*

Our interview was supplemented by the written documents of the company. It can be easily stated that the product management system of Company D is parallel to what we have described in Section 3.2 based on the literature. The descriptive model of product management of the company is shown in Figure 3.3. This model was provided by the company itself. It was stated that there are strong interactions between the technical and marketing aspects of the product management. The company has some difficulty of having an integrated working mechanism in those broad areas of PM in harmony. It was realized that the company's perception of PM covers all the theoretical aspects in a broad sense, namely *product planning* and *product marketing*.

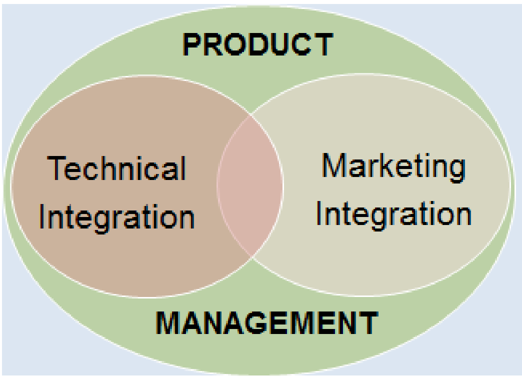

Figure 3.3: Product Management Model of Company D

In another diagram (Figure 3.4) provided by the company, the major activities of PM are shown. It was realized that the source of the diagram presented in Figure 3.4 belongs to the book of Steinhardt (2010) which is one of the recently published books in PM literature. It should be noted that these diagrams do not show the strategic considerations in PM. However, it can be stated that Company D has spent great efforts trying to get the benefits from the PM literature in order to establish an effective PM system in their organization. Another important observation is that the decision framework what we have proposed in section 3.2.2 totally covers the decisions of Company D.

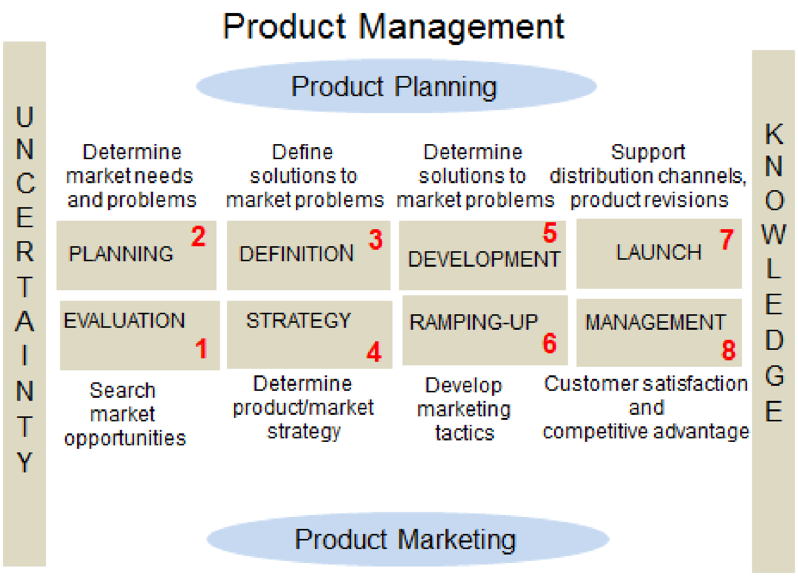

Figure 3.4: Product Management Activities of Company D (Source: Translation of the document provided by Company D)

In their product management, "make/buy"decisions take place depending on

- quantity,
- urgency, and
- productivity

considerations. So it was seen that the "outsourcing" decision is an important dimension in their decision space. Outsourcing decision may take place in different levels of decision making;

- Decision on product itself.
- Decision on product components.
- Decision on inputs of products.

In their product range, 30 % of "Heating, Ventillation and Air Conditioning" products as quantity are provided through outsourcing, which represent a 20 % share in turnover. In addition to outsourcing, the company has tried to enlarge its product range by taking merging & acquisition decision. As we have learnt, the negotiated company was an Italian company which was one of their competitors in the global market.

All these decisions represent the strategic level of decisions of the company. At this level, a cross-functional team contributes to the decisions of CEO at the highest level. The members of this team are from the departments of

- R&D,
- Marketing,
- Sales, and
- Production.

The company has a separate "Product Management Department" which is totaly responsible for planning, coordination and execution of the activities related with PM.

The company is the business leader in the domestic market with over 50% market share. Their products' major competitors are imported goods. This is the reason why company's main objective is to increase the market share in the global market.

Technology leadership, powerful sales force with approximately 4500 dealers, a service network with 600 after-sales service stations, and financial structure are their main major strengths in the national market. The company gives a special emphasis to service activities as an important factor to understand and assess the customer requirements. Home visits and questionnaires are other sources of information in evaluating the consumer needs. Although the company can be seen as "business-to-business"(B2B) type of company, its considerable efforts to have connections and contacts with the end-users show us the company's marketing view and the importance of achievement the goal of keeping the leading market position in theTurkish market.

Technology and innovation, as one competitive power, is the most important critical success factor in their PM. Another success factor is undoubtedly the capability of generating knowledge and using scientific tools. As mentioned before, the company has developed a strategic product plan for a 5-year planning horizon. In implementation, the regular revisions and updating is being done for the coming periods. In addition to this planning activity, a TRM has been developed in the R&D department, and NPD projects and processes are followed by means of these tools. The NPD process starts with the idea generation phase. The company is organizing "creativity triggering activities" and consumers are invited to those activities. Voice of customers (VOC) are deployed to the product design phase by QFD. Brainstorming and benchmarking are also used in product development. Financial restrictions are considered in project prioritization phase, and sometimes the project priority list is changed based on the availability of financial resources. The company uses nano technology to implement changes in micro scales. Modifications and improvements in existing products are made under the name of "updating".

The company is quite sensitive to environmental sustainability and this sensitivity has been reflected in their new innovative products.

Table 3.2 presents the summary of the interview results comparatively for all companies

Table 3.2: Summary of Interview Results

Feature	Company A	Company B	Company C	Company D
Type of Product	Consumer Durables	FMCG	FMCG	Consumer Durables
Turnover of Company	$ 100 Million	$ 100 Million	Euro 40.5 Billion – Global Euro 14.5 Billion Local's group	Euro 3.7 Billion
Number of employees	700	3000	174,000 Global 3,000 Local	Over 18,000
Share of International Sales	% 10	% 15 – 18	100 countries local-multinational business	% 50
Strengths & Core capabilities	Technical capabilities, large product portfolio, human resources	Organizational culture, skillful R&D and PD personnel, deep customer knowledge	Strong portfolio of products, global leader in R&D, technology superiority, patents	Market leadership, quick response to market requirements, technological capabilities and innovation, corporate culture
Success factors of PM	Market penetration, understanding of customers' needs	Understanding of customers' requirements, creativity & open minded-ness, continuous follow-up of market	Customer satisfaction, best products, value based management, continuous follow-up of market	Formal PM system, value based management, creativity triggering activities, understanding of customers' needs, wide product range, high quality products, after sales services network

Table 3.2: Summary of Interview Results (Cont'd)

Feature	Company A	Company B	Company C	Company D
Driving forces of PM	Customer satisfaction, founder's value	Customer satisfaction, profitable growth	Customers' requirements, market dynamics	Customer satisfaction, profitable growth in global market
Biggest problems in PM	Rapid adaptation to market manipulations, quality of human resources	Increasing costs, right product selection under uncertainty, talent acquisitions and retention, industrial espionage	Forecast vs. reality differences	Sales forecasting and pricing
Organization structure of PM	Teams	Teams – Executive Board of NPD	Network Team	Team – CEO Final decision maker
Goal setting approaches and tools	Budgeting	Budgeting, strategic plan, portfolio analysis	Budgeting, TRM, strategic plan	Budgeting, TRM, strategic plan
How to decide the amount to invest	Based on available fund	Based on long term market expectations	TRM, continuous R&D investments	Strategic targets and opportunities, TRM
Approaches for Customer needs assessment	Home visits, dealers discussion, services discussion	Customer panels, focus groups	Focus groups, concept and product testing	Home visits, questionnaire, dealers discussions, services discussions and reporting

Table 3.2: Summary of Interview Results (Cont'd)

Feature	Company A	Company B	Company C	Company D
Approaches for Competitive Analysis	Dealers and services discussions, no systematic tools	Benchmarking, systematic analysis for technology competitiveness	Strong, lasting relations with customers and suppliers, systematic analysis for technology competitiveness, new products in R&D pipeline	Systematic analysis for technology competitiveness in global market, technology leadership in domestic market, patent analysis
NPD Approach	PLC consideration observing sales figures, incremental	Innovative products, development projects on a continuous base, innovation concerning product safety	Incremental, mergers & acquisitions, "green" innovative products	Innovative products, environmental impact analyses for new investments, environment-friendly products, outsourcing, mergers & acquisition
R&D measurement & selection of project	Fixed amounts based on earlier years, predetermined projects	Business impact, sales opportunities	On a continuous base, 3% of net sales	Resource planning and prioritize the projects with financial resources management
Product proposal system	No formal proposal system	Formal proposal system, idea bank	Formal proposal system	Formal proposal system

3.1.3 General Conclusive Remarks

The common observations on the results of the field study, together with the literature knowledge, point out some important major findings which constitute the cornerstones of our proposed product management system presented in section 3.2. These conclusive findings are summarized below.

1. ***Product Management Approach***

In the literature, there are several approaches in product management regarding the major product strategy driving the company (Steinhardt, 2010; pp.5-6). These approaches are stated as follows:

- Technology-driven
- Sales-driven
- Market-driven

Technology-driven companies focus on providing better technology instead of "focusing on closely matching customer needs and abilities with that technology" (p.5), believing that they know what is best for the customer. A *sales-driven* company is focused on maximizing short-term return on investment. This product strategy is defined as the "conservative or lifesaver strategy and it is used as a survival mode tactic" (p.5). These types of companies use price as the primary marketing tool to differentiate their products from their competitors', which may put these companies in difficulty in the long-run. *Market-driven* approach requires a proactive product management, i.e., "they engage customers before the product is planned, defined, designed and developed" (p.6). Market-driven companies produce sustainable products which "help establish market leadership and revenue growth potential" (Steinhardt, 2010; p.6). This approach requires a formal work culture and an effective organizational structure.

In the field study conducted, it was observed that all companies define themselves as market-driven companies. As it was mentioned above, all companies are in the manufacturing industry. Two of them are operating in the "*Fast Moving Consumer Goods*" (FMCG) sector; the others are in the "*Consumer Durables*" (CD) sector. It has been observed that FMCG companies are more "market oriented" than CD companies, although they show innovative efforts in their product management. These are mostly incremental innovation in which existing technological platforms are used.

Although the companies define themselves as market-driven companies, it has been observed that Company A is a more sales-driven company because they have no formal product proposal system, they do not use TRM/PRM tools, their organizational structure is looser than the other companies, the product variants are heavily modified core products and they are a follower in the market.

It can be concluded that a successfully implemented market-driven approach with properly structured product management team produces successful products and hence an effective product management system. Thus, a well-defined product planning starts with listening the voices of customers in the market through the problem tellers of the PM system. Note that the *market-driven approach* to PM is the underlying approach of our proposed PMS presented in section 3.2.

2. Product Management Organization

Two companies are representing parts of bigger corporations; the others are family type organizations. So, it was worthwhile to observe the differences of organizational cultures and management philosophy. As expected, the companies which are a part of bigger companies have more formal and systematically described models of product management. Surprisingly, one family company (Company B) was really institutional in their product management.

In large enterprises, an "empowered cross-functional product team with a strong team leader" is accepted as one of the most important success factor of the company (Haines, 2009; Steinhardt, 2010). Haines (2009) states that

> "*The purpose of a cross-functional product team is to manage all the elements needed to achieve the financial, market, and strategic objectives of the product, as a business. The cross-functional product team is made up of delegated representatives from their respective business functions. This team is the primary mechanism through which an organization initiates product strategies and plans,… Finally, the product team is responsible for the profitability of the product in the marketplace*" (p.62).

According to Haines (2009), maintaining the cross-functional team across the product life cycle is the most effective approach. This approach was clearly observed in Company D in our field study; every product manager is responsible for 1000-1200 products and those products are followed-up through their product life cycles. A similar approach was used in Company B and Company C. These FMCG companies use the "Category Managers" title instead of "Product Managers" and they group certain products in their follow-up activities. Company A follows sales figures of the products and collects the customer complaints through the Sales department and Service department, respectively. In this company, product managers communicate with these departments mentioned above to monitor the products. Therefore, it can be said that product management department in Company A has no direct involvement in follow-up and monitoring the products in the market.

In the literature, there are three different levels of cross-functional product teams running the product management business: *strategic*, *tactical* and *operational*. Management communicates their strategic intent up and down the organization. It is stated that this structure reduces organizational ambiguity and provides better alignment of the product portfolio and product line investment decisions (Haines, 2009). It was observed that all companies have such a structure in their organizations. Company C mainly performs marketing activities in Turkey as the "Local" company and therefore their organizational structure reflects mainly tactical and operational product teams, because it was stated that strategic decisions such as new product selection from the pipeline of TRM are imposed by the "Global" company. However, the Local and Global companies make the decision of "time-to-market" together. In other words, strategic "marketing-mix" decisions are made in the Local Company providing market feedback to the Global Company.

In the literature, it is stated that within the best-in-class companies, organizational structures typically have product managers reporting to the marketing department (Haines, 2009; Steinhardt, 2010). The main reason behind this is that the customer needs of market segments and market trends can be recognized easily which may affect the product and market strategies. As it was mentioned above, Company C is mainly a marketing organization. Company D has a difficulty in their organization regarding the effectiveness of management of the teams in the technical and marketing parts of the product management in an integrated manner. It has been learnt that this bottleneck in their product management has been solved recently by reorganizing the product management department under the marketing department. The CEO of the company is the product management leader who is also the Marketing Director of the company. The product management department is directly connected to the corporate Board of Directors in Company A. Company B has also cross-functional teams and the leader is the CEO of the company who is the ex-R&D Director of the company.

So in the context of product management, the leadership of this cross-functional team is represented by the Executive Management of the company and generally called as "Product Review Board" or "Product Portfolio Council" (Haines, 2009).

It can be concluded that the organizational structures of all companies in the field study are quite similar to the one described in the literature. Note that this hierarchical structure of the decision making framework is adapted in developing the proposed product management decision framework presented in section 3.2.

3. Product Planning Tools

Typically all companies are using *budgeting* as *short-term* planning tool. Except for one company, all companies are developing a *strategic product plan* for a five-year planning horizon.

The *strategy* which can be defined as the "coordinated set of long-term decisions" of a company is formulated by its executives (Steinhardt, 2010; p.50). So a strategic plan at the product level in the product management context first creates a vision and strategy for the products of the company consistent with the company's strategy. The *strategic product planning* is a complex, interrelated group of activities which creates strategic relationships with technological, development, manufacturing, logistics and marketing to generate the most advantageous strategic mix for the products of the company (Haines, 2009). More explicitly, the generation of this strategic mix requires the decision on the paired function of "market-product" in order to maximize the profits of the company (Ansoff, 1972). Thus, it can be stated that strategic product planning is the main tool to select the right products which generate the possible highest profits for the company for a pre-determined target market.

It should be noted that information on market share and size of the market are very important for all companies for their market related decisions and also daily business follow-up activities. Three of them are getting consultancy services externally. A.C. Nielsen is the common address providing market research analysis and also support to product launch decisions.

The strategic product planning is the highest management level of activity in product management. Except for Company A, this activity has been observed in all the companies in the field study. As mentioned before, Company C is the implementer of this activity as the marketing company of the Global Company. However, they do manufacturing in Turkey and the volume decisions in their production activity are based on the strategic product plan of the Global Company. Company B also prepares five year term strategic product plan and the Executive Management's product portfolio decisions with respect to targeted markets are based on this plan. Similarly, Company D has a five-year term strategic product plan in which TRM/PRM constitute the basic inputs. TRM/PRM are prepared for the product groups showing important milestones in terms of financial and technological data considering the time dimension with respect to the targeted markets in which those product groups are sold. Note that a *product group* is composed of the products which are using the same production technology, the same assembly line and the same key components.

It can be concluded that the existence of strategic product planning is a proof for the existence of a formal and proactive product management system in the companies studied in the field work. It provides a formal goal setting mechanism in the lower levels of product management, strategic link to corporate goals and strategies, a formal NPD approach and a systematic product and project proposal system. Strategies developed at the highest level of the product management are tied to more specific markets or segments and also include financial objectives that focus on an optimal portfolio of products and product investment options.

4. Major Difficulties in Product Management

In order to recognize the major decision making problem(s) in real life product management, the interviewers were asked several questions (See Appendix B). It was also asked to verbally define the biggest problem in their companies' product management. Company A defined the *adaptation to rapid market changes* as the biggest problem. This reply is quite consistent with their other answers, since

- they are in the "follower" position in the market,
- their major goal in their product management is "growth with market penetration" which implies a "maintaining" product strategy,
- their innovation efforts are heavily on modifications on their existing products; they produce "imitative" products,
- since they have weak NPD efforts, product line extensions and product diversifications are made through acquisitions and outsourcing,
- they have no formal product management work organization.

Company B has designated several problem areas as "the biggest difficulty" in their product management decision framework. One of them is the *cost management* area which is consistent with the other answers of the company, because

- they are also in "follower" position in the market, and
- the market leader puts a high competitive pressure to introduce new products so that Company B has to invest to in both NPD projects and in cost reduction in their

production technologies simultaneously which brings additional difficulty in allocation of resources in their product investment decisions. Note that a market leader company generally achieves cost effectiveness in their production.

Another important difficulty in their PM decision making process of Company B is stated as follows: *selection of right products under uncertainty*. So Company B explicitly states the *product mix problem under uncertainty* as one of the most important problems of product management framework.

Both Company C and Company D represent the market leader positions in their markets respectively. These companies identified inaccurate results in *forecasting* as the biggest problem in their product management frameworks. Forecasting is used by these companies to calculate the market potential, depict sales, and meet demand.

Regarding the existing products of the company data-driven forecasting approaches may create more realistic forecasts with the support of the common sense of the managers. Judgmental forecasting is another technique which is popular in real life in order to formulate the complex future state models of the company (Haines, 2009). However, it is known that most forecasts are not accurate. In the case of new products, forecasting is more difficult due to non-availability of the past information of the new products. This is really a big problem for the companies because product investment decisions need to derive forecasts and deliver the expected returns on these product investments. In short, without accurate forecasts, a product's market potential cannot be determined in a realistic way, because forecasting is a tool which links the market research to the strategic possibilities for the product. So, as Haines (2009) states, there is a need to find a better way.

It can be concluded that the difficulty of forecasting stated by the companies in the field study implies an important decision making problem in product management framework: *Decision making under uncertainty*. Several types of uncertainty are considered in product management, such as technological uncertainty, market uncertainty, regulatory uncertainty, social and political uncertainty, etc. which represent the environmental conditions of the product management framework. The term "uncertainty" refers to "market uncertainty" here. Market uncertainty reflects the unknown conditions of the market environment; unknown behavior of the customers, unknown actions of the competitors, unknown prices of the substitutive products can be considered as the main sources.

Forecasting the sales of the products requires

- to determine total size of the targeted market,
- to determine the attainable market share,
- to determine the number of products that the sales team commit to sell,
- to determine the number of units that can be produced,
- to determine the realistic pricing for the product,
- to translate the sales and demand forecasts into a realistic budget for the product (Haines, 2009).

As it was stated by the companies that forecasting is a cross-functional exercise which requires many interrelated activities carried through up and down the product management organization. The selection of the target market, and then, the strategic selection of the products should be made beforehand which is the major task of the “Executive Product Team”, namely “Product Review Board” or “Product Portfolio Council” of the company. Later, mainly the Marketing and Sales departments work on demand forecasting, the Manufacturing department works on production to meet the demand, and the Finance department contributes to convert all these into a realistic budget for the planning period.

These findings point out that the *product mix problem under uncertainty* is one of the most important problems in the product management framework and it involves determining which products should be selected for the coming planning period and the number of units to be produced from those selected products. It has been observed that the main body of the problem belongs to the strategic level of the product management framework which requires the determination of products to be served to the customers in the targeted market. Naturally, the product selection decision requires having a bundle of candidate products which are composed of new products as well as the existing products of the company. To determine the bundle of candidate products is, undoubtedly, another decision making problem which requires the *project prioritization decision* among all the project proposals and *product killing decision* among the existing products of the company. This important task belongs to the Product Review Board or Product Portfolio Council as it was mentioned before, and this is performed through the feedback mechanism from the lower levels of the product management organization. The decision on the mix of the products provides the input for the production planning framework of the company in which the detailed production plans are prepared to meet the targets given by the upper levels of the management considering the properties of the production system of the company such as characteristics of the manufacturing environment (make-to-order and/or make-to-stock), capacity of plants, human resources, etc. The issues concerned with how a company integrates customers related information into the manufacturing system is called as *demand management* which includes activities determining or forecasting the demand from customers (Vollmann et al., 2005). It is also understood that demand management activities should be in conformity to the corporate strategy, the manufacturing capabilities of the firm and the needs of customers in the product management framework.

In sum, professional product management is essentially a matter of well-organized processing of issues related to the products offered by the company. In other words, the *scope of product management* concerns the complete set of products for a company, the so-called the *product mix.* It should be noted that the terms *product mix* and *product portfolio* are used synonymously in the literature in some cases. In this study, product portfolio refers the set of products investments, i.e., the products under development. Thus, product management encompasses decision-making about the set of existing products, introducing new products by examining market trends, customer needs and product strategy, making decisions about the product life cycle, establishing partnerships and making decisions on the potential acquisitions and merging opportunities. So, it can be said that *successful product management is about achieving the goal of maximizing the financial value (profit) of the mix of the products by linking to the corporate strategy.*

Thus, our *main conclusion* is that the “*Product Mix Problem under Uncertainty” should be positioned at the strategic level in the framework of product management.* It has been realized that the formulation of the problem under consideration requires some further information, such as which product level is considered for the product selection decision at the strategic level. For this purpose, after the completion of the field study, several discussions and meetings have been organized with the product management expert of Company D which has the most formal organization of product management in our field study, during the formulation phase of the problem.

In the subsequent section, considering both the findings of the field study and the literature survey, a proposal for the product management framework is presented in detail. This developed framework constitutes the base for the formulation of *Product Mix Problem under Uncertainty* which is presented in Chapter 4.

3.2 THE PROPOSED PRODUCT MANAGEMENT FRAMEWORK

In this section, first a broad description of the proposed product management framework is described depending on the extensive literature survey and the findings obtained from the field study. The detailed description of the proposed product management framework is provided in the subsequent sections.

3.2.1 Description of the Proposed Product Management System

The proposed product management framework is developed considering both *holistic* and *systemic* views. While the holistic view requires to look at the activities in product management by integrating the "planning" phase (investment period in Figure 2.2) and "implementing" phase (market period in Figure 2.2), the systemic view requires the analysis of the components of the whole product management system, and identification of the interactions among these components. It has been also realized in conducting the field study that there are strong interactions and complicated relations among the activities and outcomes in product management. Hence, it is not possible to think of a linear framework in product management, which represents a sequential and ordered process of several stages of activities and decisions. Instead, there are many feedback loops which create disorder in planning and implementation activities and decisions. Remembering this reality, however, for the sake of simplicity, the activities are represented in a linear order for descriptive purposes. When necessary, the feedback mechanism and the revisions are shown in the detailed flowchart of the product management framework provided in Appendix C.

The scope of the product management (PM) concerns the complete set of products which are current and planned. In a broad sense, PM has two major aspects (activities):

(a) Product planning
(b) Product marketing

Product planning deals with mainly product strategy formation, gathering the market requirements, building the roadmaps (PRM and TRM), product defining and development, product differentiation and product selection. *Product marketing* deals with the product positioning, implementing the market plans to bring the new products, monitoring the competition and promoting the product externally. Note that the scope of our study focuses mainly on the product planning aspect of PM in the sense that we are not going into the details of product marketing issues. Concerning these broad activities, PM can be described as depicted in Figure 3.5. We may call this model as the "Elemental Product Management Model" (EPMM). Note that the product development phase in Figure 3.5 is based on Krishnan and Ulrich's (2001) study and the two-sided arrow represents the close interactions between product planning and product marketing (Figure 3.5).

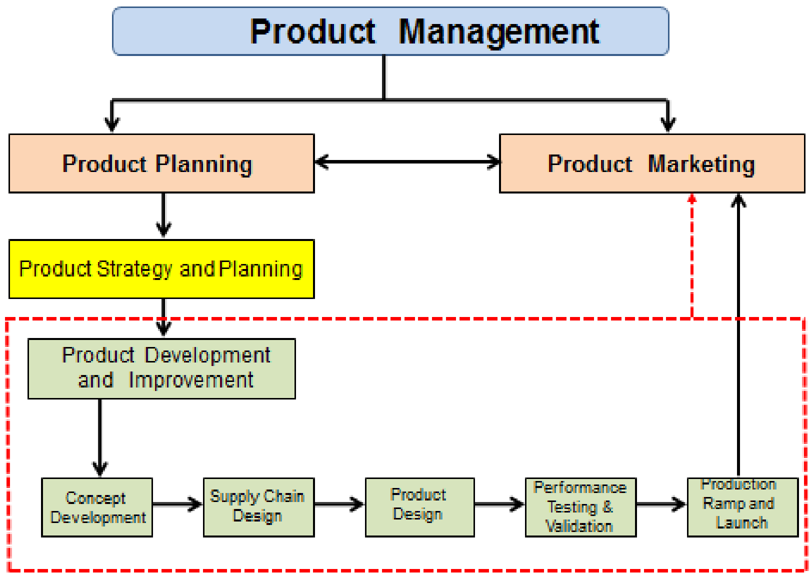

Figure 3.5: Major Aspects of Product Management–Elemental PM Model (EPMM)

One step further, an "activity model" in the corporate management context can be proposed considering the major activities of PM. The activity model is illustrated in Figure 3.6.

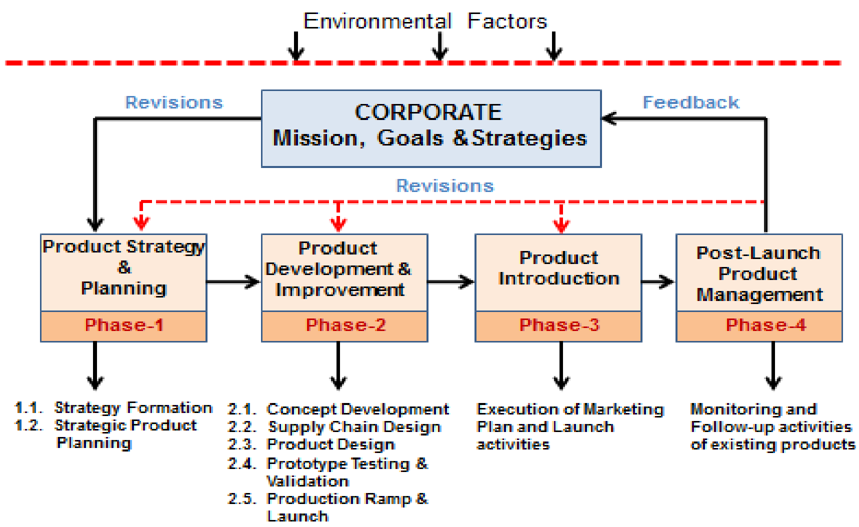

Figure 3.6: Proposed Activity Model of Product Management

The activity model of PM reflects mainly the following:

The mission, strategic intent and corporate goals control the product management process. In our approach, the first phase is called the “product strategy and planning” phase, in which the vision, product management strategies and objectives are established. The appropriate performance measures are also set in this phase. The output of this phase is the product and competition strategies, mission statements and roadmaps (PRM and TRM), hence the strategic product plan. The second phase represents the new product development and existing products improvement processes, which starts with idea generation, continues with the product definition and design, manufacturing, prototyping and production planning, and ends with the product launch planning activities. Phase-3 represents the implementation of the plans developed previously and the commercialization of the products is realized. The final phase is “day-to-day business” of PM , in which selling activities of products, promoting, contacts with customers, follow-up and monitoring activities take place. One should observe the cyclical nature of the PM activities is an important characteristic of PM. The mechanism of feedback and revisions reflect somehow the existence of a hierarchical management process of PM.

The purpose of generating the PM activity model is to describe the activities of PM comprehensively, but in a broad sense. Although it may show some differences from one company to another, the main stream of the activities remains the same as described in Figure 3.6, which represents integrated knowledge extracted from the literature-based survey and obtained from the field study.

The product management system (PMS) is developed by using the same approach which is followed in activity model development. In the literature, the main focus is NPD or innovation, which is accepted as the most important task in the companies for their success, even their survival. The companies extend their product ranges by means of NPD to satisfy the needs of their customers, to increase their market shares, to compete with the competitors and hence to achieve their goals. The main goal of the company is “growth”. Although NPD is an important success factor to achieve the goals of the companies, there are other business opportunities and tools serving the same purpose. In sum, in addition to “growth with innovation”, we consider the possibility of “growth without innovation”, in our proposed product management system, which is described below (see Figure 3.7). It may be worthwhile to remember that it is an option which is intensively used by the companies studied in the field study, especially in Company C and D.

The proposed PMS is composed of three important sub-systems:

- Existing Product Management System (EPMS)
- New Product Management System (NPMS)
- Product Innovation Management System (PIMS)

PIMS serves both EPMS and NPMS. Traditionally, R&D works in this sub-system, which basically provides basic research (e.g., technology development) and product development/improvement research. If the innovation proposes radical change, this effort brings a new product to the company. This activity is shown as the intersection part of PIMS and NPMS in Figure 3.7. On the other hand, the innovation effort may be incremental in the sense that it proposes an improvement or modification in the existing product. This activity is the intersection part of two sub-systems of PIMS and EPMS. The activities broadly described up to now represent the main activity of "growth with innovation" of the company in our PMS.

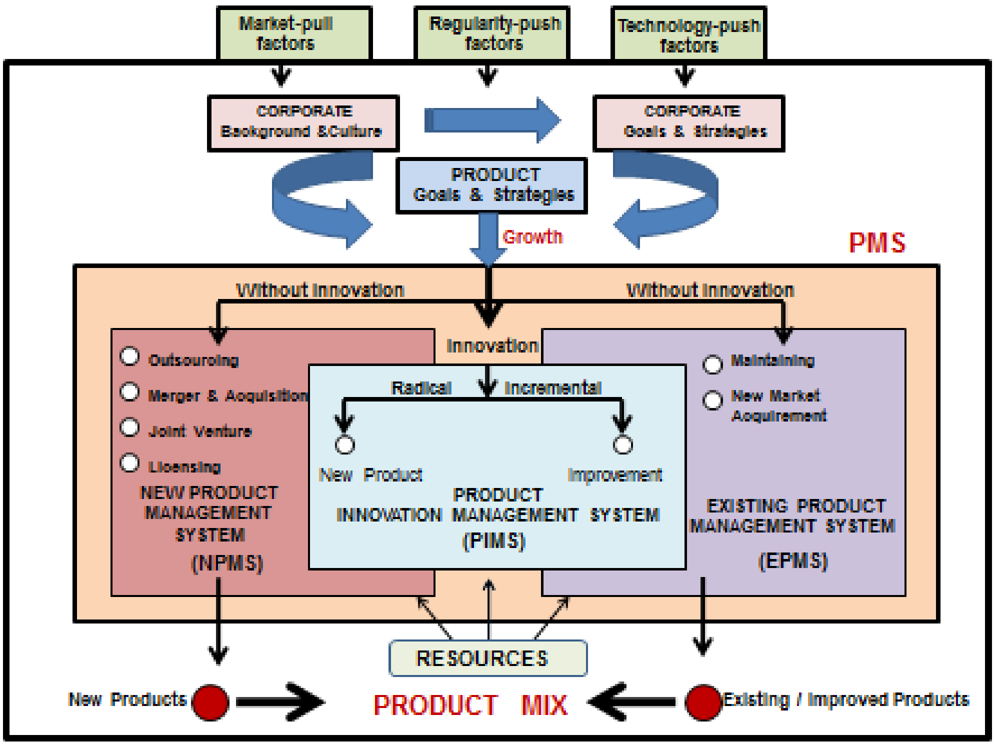

Figure 3.7: Proposed Product Management System (PMS)

"Growth without innovation" can be achieved in several ways:

- (Strategic) outsourcing
- Acquisitions and mergers, and other business relationships (joint venture, licensing, partnership, etc.)
- Market penetration (with existing products)
- New market acquirement (with existing products)

A typical product can be an extension of a base (core) product or a new product requiring a new technology. It can be developed internally or with outside sources. So, companies may consider "outsourcing" to develop their product lines externally. Although mergers and acquisitions are considered at the strategic level to extend the product range, they can be also considered for a critical supplier who provides input to the system.

It should be pointed out that the "new product" definition in our proposed PMS is different from the one in the literature. If one of the attributes of the product has been changed incrementally or radically, it is called a "new product" and it is referred as "new-to-market" and "new-to-world" respectively. In our PMS, we refer to "new product" as "new-to-company". Figure 3.7 depicts the the proposed PMS in our study.

The outputs of the NPMS and EPMS define the main input of the product mix decision which can be called as the the bundle of *candidate products* among which the products are selected to serve the targeted market(s). In this sense, the company may assign the products for each targeted market, or equivalently, the company considers the same working mechanism for each market before the product mix decision the target market decision is made by the company management.

The context analysis of the proposed PMS requires the identification of the factors affecting the decision making process of PMS, and specifically the product mix decision. These factors are extracted based on the existing literature of strategic planning, market research analysis, competitive analysis, NPD and technology management (Johnson, Scholes and Whittington, 2005; Brace, 2004 ; Porter, 1985 ; Szakonyi, 1999 ; Chien et al. ,1999). Some TRM studies were also considered in which the context analysis was employed to explore and articulate the nature of the planning and design issues of TRM (Phaal, Farrukh and Probert, 2004 ; McMillan, 2003). As a result, a long list of factors was obtained bringing out all the factors which should be taken into consideration in the decision making process of the PMS. Considering the major players of PMS, the following classification was made to present the factors:

1. Internal Factors
    - Strategic
    - Organizational
    - Information/Knowledge
    - Core competences
    - Resources

2. External Factors
    - Market-pull factors
    - Technology-push factors
    - Regulatory-push factors

Market-pull factors describe all the factors related to the market and the players (customers, suppliers, distributors, and competitors) in the market, which create impulses to the company decisions. *Technology-push factors* describe all the factors related to the technology except the technological capability of the company, which have been considered internally. *Regulatory-push factors* describe the macro-environmental conditions of the company. The term “regulatory-push” has been borrowed from the study of Brem and Voigt (2009). The detailed description of the factors is presented in section 3.2.3.

3.2.2 Decision Framework of Proposed Product Management System

In this section, our major goal is to establish a well-defined decision framework in product management (PM) of the organization, which enables us to articulate and specify our research problem with its all dimensions. Although the related literature on product management is vast, it was realized that there has been no comprehensive study regarding the subject. So we intend to fill this gap in the literature besides the constitution of the base for the product mix problem formulation.

There are several excellent review articles in some areas of product management (Ramdas, 2003; Krishnan and Ulrich, 2001; Loch and Kavadias, 2008). Among them, the article by Krishnan and Ulrich (2001) presents a comprehensive review of literature for *product development decisions*. The approach used in their study has considerable similarities to our methodology and approach, as explained in subsequent section. As it was mentioned in previous section, new product development (NPD) represents a subset of our proposed product management system (PMS). Therefore, these studies complement our efforts. The subsequent section describes the general methodology and approach used in constructing the decision framework of the PM problem.

The rest of the chapter is organized as follows: The detailed PM decision framework is illustrated by a flowchart which we simply call the *Flow Model* of PM. The Flow Model of PM is provided in Appendix C. The working mechanism in a typical organization is illustrated by an abstract form of the Flow Model is presented in the second section of this chapter, and it shows the basic structure of the decision framework of PM from a broad perspective. The detailed description of the Flow Model is given in section 3.2.3. An overview of the major problem areas and decisions and the validation of the Flow Model are presented in the sections 3.2.4 and 3.2.5 respectively. Section 3.2.6 contains our concluding remarks.

3.2.2.1 Methodology and Approach

We decided to use a *methodology* which combines both literature-based knowledge and the PM experts' knowledge in such a way that literature-based knowledge is supported by the PM experts' knowledge by a series of interviews at certain phases of the analysis. In our approach, the validation of the proposed decision framework is provided by the PM experts (Figure 3.8). The implementation steps of this methodology are shown in Figure 3.9.

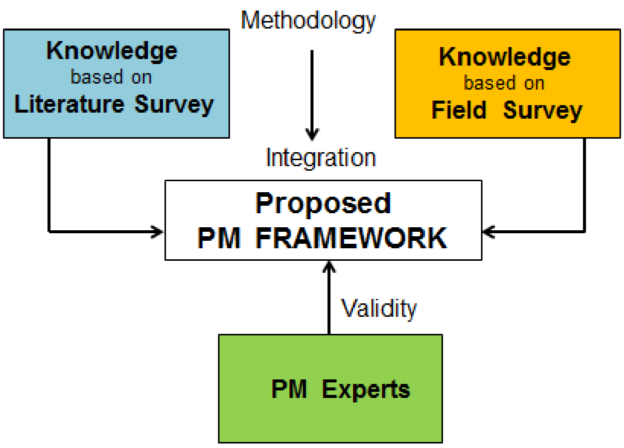

Figure 3.8: Description of the Methodology of the Proposed Product Management Framework

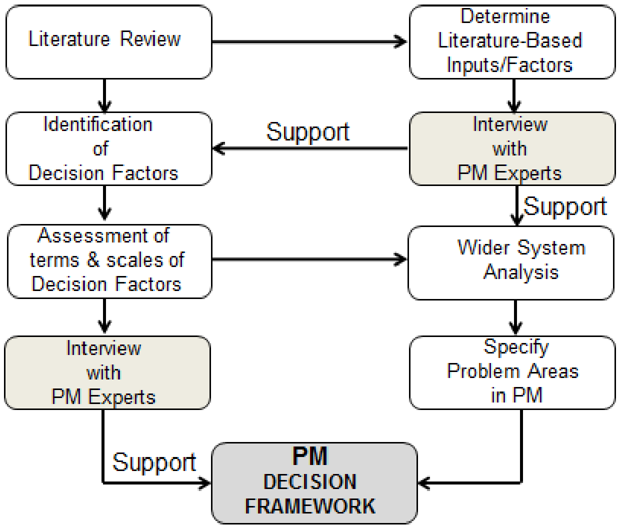

Figure 3.9: Methodology Used in Constructing the Framework of the Product Management Problem

We limit our literature review in the following ways:

1) We focus on product management within a *single firm*. So we exclude the studies which address at the level of an entire industry.
2) We devote our attention to *physical goods*. So we also exclude the studies which address the "service" types of products.
3) Finally, we focus on *decision making* in product management. Therefore, we are interested mostly in "*which*" and "*what*" types of questions.

Research Method:

As it was mentioned above, the Flow Model was developed conceptually through a review of literature and was supported by a series of interviews with PM experts. Following this methodology, we aim to identify the relationships of components of the problem at different levels of the management in their decision making processes. In this sense, the Flow Model is considered as the basis of our formulation of the problem. While following this methodology, "top-down" (deductive reasoning) and "bottom-up" (inductive reasoning) approaches are used simultaneously for information processing and knowledge ordering in constructing the Flow Model.

Using the "*top-down*" approach, the basic components of product management are analyzed which allow us a complete understanding of the system working in product management. Combining the "*top-down*" approach with "*bottom-up*" approach, a synthesis is made to extract the major problem areas and decisions in product management decision framework. Therefore, our approach for developing the decision framework of PM is initially deductive, and then we use inductive reasoning to make systematic generalizations of product management practice, on both our observations and results extracted during the field study conducted for industrial product management expertise, and our review of the literature. Besides, we had interviews with the PM expert at certain phases of our research study.

In a broad sense, a top-down approach is essentially the breaking down of a system to gain insight into its compositional sub-systems. So, deductive reasoning works from the more general to the more specific. On the other hand, a bottom-up approach is a type of information processing based on incoming data (input) from the environment to form a perception (output) so that inductive reasoning works the other way, moving from specific observations to broader generalizations. In other words, the term "top-down" is used generally as a synonym of analysis (or decomposition), and "bottom-up" of synthesis. In management and organizational arenas, the terms "top-down" and "bottom-up" are used to indicate how decisions are made. So we use an "organizational search perspective" to interpret simultaneous top-down and bottom-up approaches which allow us to determine the major decision areas in product management (Sting and Loch, 2009).

In the following section, the *basic decision making structure* in product management is presented in view of these approaches.

3.2.2.2 Basic Structure of Product Management Decision Making

Many organizations set up a hierarchy for making and revising product management processes. "A *hierarchy* refers to a system that is composed of interrelated subsystems, in which decisions in certain subsystems are subordinated to decisions in other parts of the system" (Joglekar et al.; appear in Loch and Kavadias, 2008; p.291). The complex and uncertain nature of the PM problem requires decisions at different managerial activity levels (Ansoff, 1972; Loch and Kavadias; appear in Loch and Kavadias, 2008). Figure 3.10 depicts this property of the PM problem. We will follow this hierarchical decision making structure in analyzing the PM system. We will touch the elements of the Figure 3.10 in a broad sense in this section. The details for each level are presented in the subsequent section.

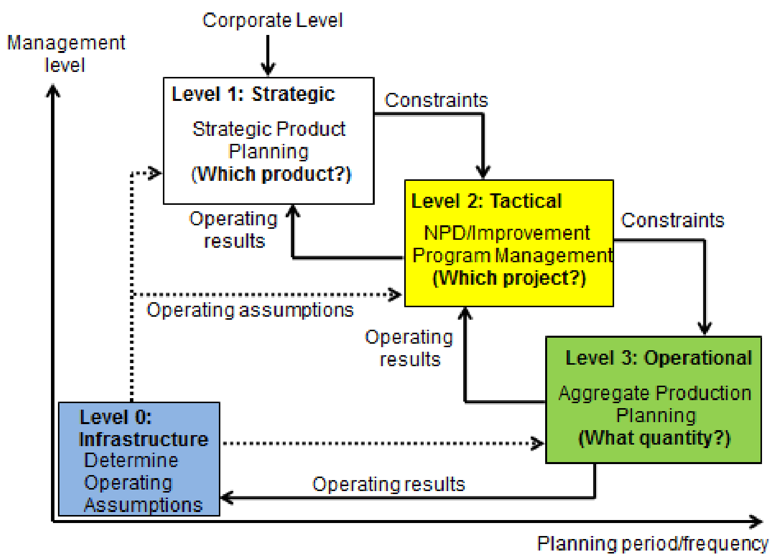

Figure 3.10: Basic Structure of Product Management Decision Making Process (Adapted from Joglekar et al., 2008)

Joglekar et al. (2008) use the "hierarchy" concept in constructing the product development planning framework. It is stated that hierarchical structures reduce planning complexity through a modular management of a network of NPD decisions. So we adopted this approach to our analysis of the PM decision making processes which is also in parallel to the top-down approach research method.

Figure 3.10 highlights PM decisions which are disaggregated into four different but linked levels – strategic, tactical, operational, and infrastructural. The frequency of reviews, choice of objectives, decision variables, and decision makers at each level are different. The decisions at each level inform each other through feed-back mechanism shown by arrows in the Figure 3.10. The abstract form of the PM decision framework illustrated by this figure shows the identification of typical constraints, decisions, feedbacks, objectives, and uncertainties at each level, and is briefly explained as follows:

Strategic Level: The major activity is to prepare a long term *strategic product planning*. During the strategic product planning, senior (top level) managers select and shape the product portfolio and product mix so that the profits of the company can be maximized.

Tactical Level: The major activity is *NPD management* which includes both new product development and the improvement of existing products of the firm. Tactical managers (level 2) are concerned with capacity acquisition, allocation and utilization of resources across all the projects, under the constraints imposed by the upper level management.

Operational Level: The operational level (level 3) managers are charged with the fastest and high quality execution of the individual projects. *Aggregate production planning* (APP) is the major activity at this level which has great importance in fulfilling the market demand. APP traditionally implements the long term business policy of an organization over a horizon of one year (or more) considering only the overall constraint of the business (Das et al., 2000). In other words, APP is considered at the tactical or top level activity of management *in the framework of the **production** management system* (Tang et al., 2010). However, production and related issues are considered at the operational level in the *framework of the **product** management system*. This is the reason why we considered APP at the operational level of the hierarchical structure of the decision making process of PM. We will go into details of APP and related issues in the appropriate place of the Flow Model in section 3.2.3.

Operating Assumptions: Operating assumptions can be *general* (system wide) and *company specific* (local). They represent the environmental conditions of the product management problem of the organization. The sources and nature of uncertainty are also quite different between the levels. Strategic product planning addresses uncertainty in the market (price and quantity to be sold), along with suitable choices of products in aggregate (Joglekar et al., 2008). Joglekar et al. (2008) point out that tactical PM activities are subject to fluctuations in the demand and availability of skilled labor which bring difficulty in their forecasting task.

Operating Results: They represent the bottom-up initiatives and execution or running the ongoing business. They provide a necessary feed-back mechanism to the higher level management in their decision making processes. So the decisions at any level feed into the uncertainty and shape the options (or decision making alternatives) available to the next level.

From the organizational perspective, top-down alignment and bottom-up initiatives are important and there should be interaction and coordination among the different levels of management of the organizations in complex and dynamic environments as in product management. In other words, different managerial levels of the organizations have vertical alignment by understanding and agreeing with the strategic priorities. However, vertical alignment is insufficient due to the complexity and ambiguity of strategic problems. Therefore problem solving is distributed across many actors which is called as decentralized problem solving and necessitates *horizontal alignment* or *coordination* (Sting and Loch, 2009).

In sum, the decision making process is distributed across layers and hence problem solving expertise is also distributed accordingly. Thus vertical alignment and horizontal coordination must co-exist and interact. As it was mentioned in the previous section, this is achieved through cross-functional product teams in the organization.

3.2.3 Detailed Description of the Flow Model

The illustration of the PM decision making framework is done by a flowchart which we call as the *Flow Model*. While developing the Flow Model, we aim to identify the relationships of the components of the problem under consideration at different levels of the management in their decision making processes. Therefore, the Flow Model can be seen as the basis of our formulation of the problem. In developing the Flow Model, we tackle the main question of *which* problem and decision areas exist in the product management of a typical manufacturing organization. Therefore we examine in detail which activities and decisions of product management are distributed and orchestrated.

The Flow Model consists of two main stages:

1. ***Strategic Product Planning and Management***
    - Strategic Product Planning (SPP)
    - Strategic Level Review

2. ***Tactical and Operational Product Planning and Management***
    - New Product Development Management
    - Post-Launch Product Management: Running the Business/Existing Product Management

Those two stages describe the *main frame of PM* at the corporate level which is located as the first page of Flow Model. Each page after the first page shows more detailed activity and decision levels than the activities of the levels seen in the preceding pages. Thus, *Strategic Product Planning* and *Strategic Level Review,* and *New Product Development* and *Post-Launch Product Management* are simply the sub-levels of ***Strategic Product Planning and Management*** and ***Tactical and Operational Product Management*** levels respectively. Figure 3.11 simply describes the structure of the Flow Model which is composed of seven pages in total, and it is presented in Appendix C.

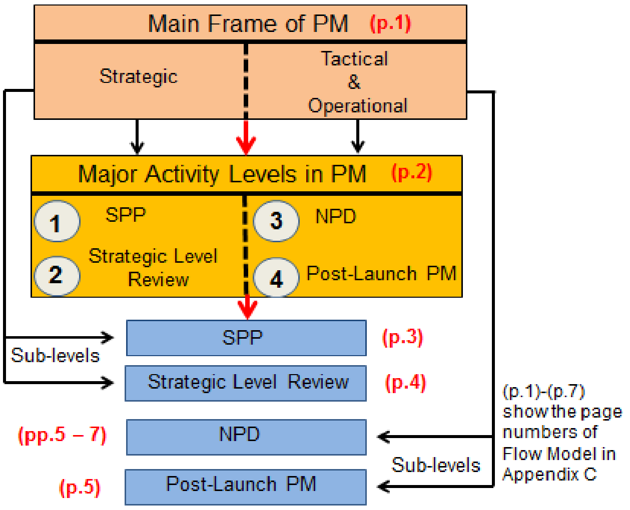

Figure 3.11: Description of the Flow Model Structure

In parallel to the structure of the Flow Model, the plan of its detailed description is as follows:

- Main Frame of PM
- Major Activity Levels in PM
- Strategic Sub-Levels
- Tactical and Operational Sub-Levels

Below, Figure 3.12 illustrates the main frame of PM at the corporate level and represents the most general layer (first page) of our Flow Model. Next, Figure 3.13 shows the levels of major activities and decisions included in the main frame. The cyclical nature of the PM function of the organization can be observed from these figures.

Main Frame of Product Management at the Corporate Level:

The first page of the Flow Model shows the main frame of PM at Corporate level (Figure 3.12). In the literature it is stated that complex and uncertain product development, and more generally product management processes are often modularized into multiple levels of decision making (Loch and Kavadias, 2008; Bean and Radford, 2000; Ansoff, 1972; Haines, 2009). Many organizations set up a hierarchy of planning levels for making and revising complex product management decisions: *strategic*, *tactical* and *operational*. Based on the discussions of our Flow Model with the PM experts, we can say that this hierarchical planning and management process reflects organizational realities.

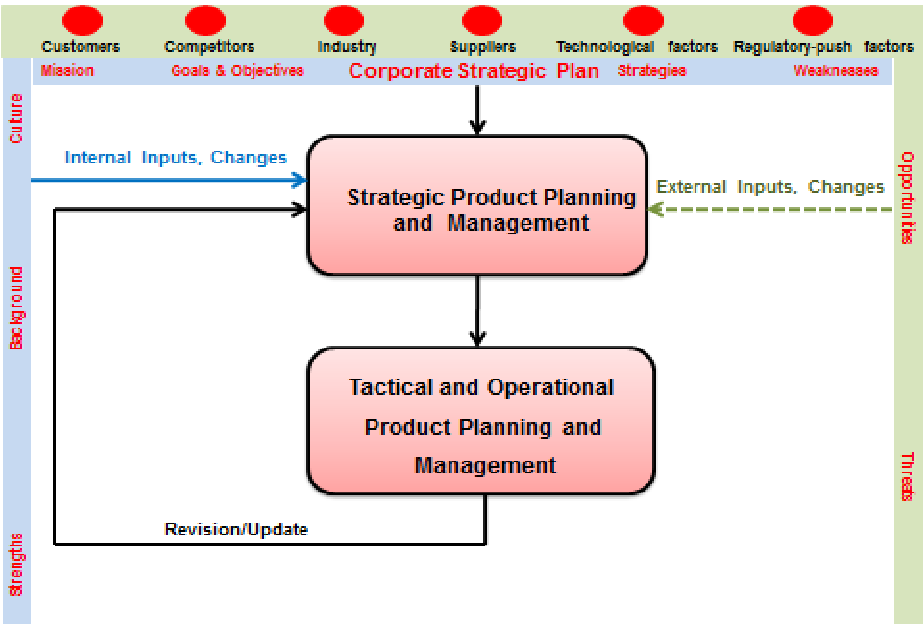

Figure 3.12: Main Frame of Product Management at the Corporate Level

Ansoff (1972) defines the *strategic decision* area as follows: "The strategic decision area is concerned with establishing the relationship between the firm and its environment" (Ansoff, 1972; p.14). In other words, the sources of uncertainty and also the degree of uncertainty are different at each level of management. Kavadias and Chao (appear in Loch and Kavadias, 2008) define a hierarchical perspective to the NPD decision framework which can be valid in our holistic view of PMS as well. They define the NPD problem in different ways at different management levels, stating that "across different organizational levels the decisions relate to

- the degree of knowledge regarding the solution space,
- the degree of knowledge regarding the underlying performance structure, and
- resource availability and flexibility" (Loch and Kavadias, 2008; p.142).

The key word above is "the degree of knowledge" and simply defines the degree of uncertainty. Considering Ansoff's definition of the strategic decision area (Ansoff, 1972) given above, we may conclude that at the strategic level, the degree of uncertainty is high and the decisions at this level involve several dimensions of complexity. These decisions at the strategic level include target market decisions, selection of products to be offered to those markets, selection of basic technologies and/or revolutionary technologies, strategic considerations of the organization, and external influences, like governmental law and regulations (Kavadias and Chao; Loch and Kavadias, 2008). In spite of the complexity of the decisions, the resources are regarded as flexible at the strategic level (Kavadias and Chao; Loch and Kavadias, 2008). The availability of the resources for the other levels are determined in the strategic level decision making process.

The decision making process differs across levels not only in its sources of uncertainty but also in its frequency of decisions, objectives and information available. Therefore the nature of the PM problem has different characteristics at each level. Ansoff (1972) points out the following generic properties of the decisions at each level:

- At the strategic level, decisions are centralized and usually non-repetitive.
- Tactical level decisions are usually triggered by strategic and operating problems.
- Operational level decisions can be a large volume of decisions and these decisions are repetitive decisions.

More explicitly, during strategic product planning and management, top managers select and shape the product combinations so that the revenues and profits can be maximized. Tactical managers are concerned with capacity acquisition and allocation and utilization of resources across all the projects. The operational managers are charged with the fastest and highest quality execution of individual projects (Ansoff, 1972). Consequently, the nature of uncertainty, the decisions and the frequency of planning are quite different between levels. Although the management and planning activities are disaggregated into three different levels, they are linked to each other and they are not separable (Bean and Radford, 2000), since the decisions at any one level of planning feed into the uncertainty and shapes the decision options available to next level. In short, the decisions at each level inform each other through feedback mechanism. Haines (2009) calls this mechanism as the "waterfall effect" of decisions existing among these levels. The starting point is "Strategic Product Planning and Management" which is the first stage in our Flow Model. Hence, we show the Strategic Product Planning and Management as the higher level box, and other levels of the PM as the second box in the diagram.

We assume that there exists a well-developed Strategic Plan at the corporate level which is the key input to the Strategic Product Planning and Management level of PM, in the sense that all the activities and decisions in this level should be in line with the corporate background, mission, corporate goals and objectives, culture and strategies. Gorchels (2006) states that "determining the vision and strategy of the overall company is a basic part of this analysis" (p.9). Therefore, the assessment of corporate goals, vision, organizational culture and strategies is an important input for strategic product management, because it identifies how the firm operates by showing the general operating philosophy, management style, etc. (Gorchels, 2006). Besides, the existence of a corporate SWOT analysis provides additional inputs for strategic level operations. A corporate SWOT analysis is helpful to understand the corporate strengths and weaknesses which are considered in strategy formulation processes. Strategies are the key decisions at the strategic level of PM and they should be consistent with the vision and strategies of the company. Corporate strengths which provide core competences and weaknesses that should be minimized are considered in the internal inputs category in our PM Flow Model.

Similarly, the SWOT analysis also provides an understanding about the threats and opportunities outside the firm, which are also considered as the inputs in strategy formulation. Since the sources of these inputs are beyond the boundaries of the firm, we consider them as external inputs. Customers, competitors, industry, suppliers, technological factors and regulatory-push factors are all the external inputs which will be explained later.

The outcomes of strategic level activities provide inputs for the decisions made in the tactical and operational levels of PM. The operating results of these levels usually create revision needs and provide the inputs for updating the higher level decisions. Hence, a cyclical feedback mechanism reflects the linkages between the levels in a business environment.

Levels of Major Activities and Decisions in PM:

The levels of major activities and decisions in the main frame of PM are shown in the second page of the Flow Model (Figure 3.13). In this page, Strategic Product Planning and Management is disaggregated into:

1. Strategic Product Planning (SPP), and
2. Strategic Level Review.

Strategic PM decisions are taken during the Strategic Level Review executed by the Product Review Board (PRB), using the required information provided through the SPP process.

Strategic PM decision is defined broadly as follows:

Strategic Decision = f (Market, Product)

In other words, the PM problem at this level is *"to select market-product mix which optimizes firm's profits"* (Ansoff, 1972; p.16). So, the PRB's major decisions are the *selection of target market(s)* and the *selection of the products* to be served in this market(s).

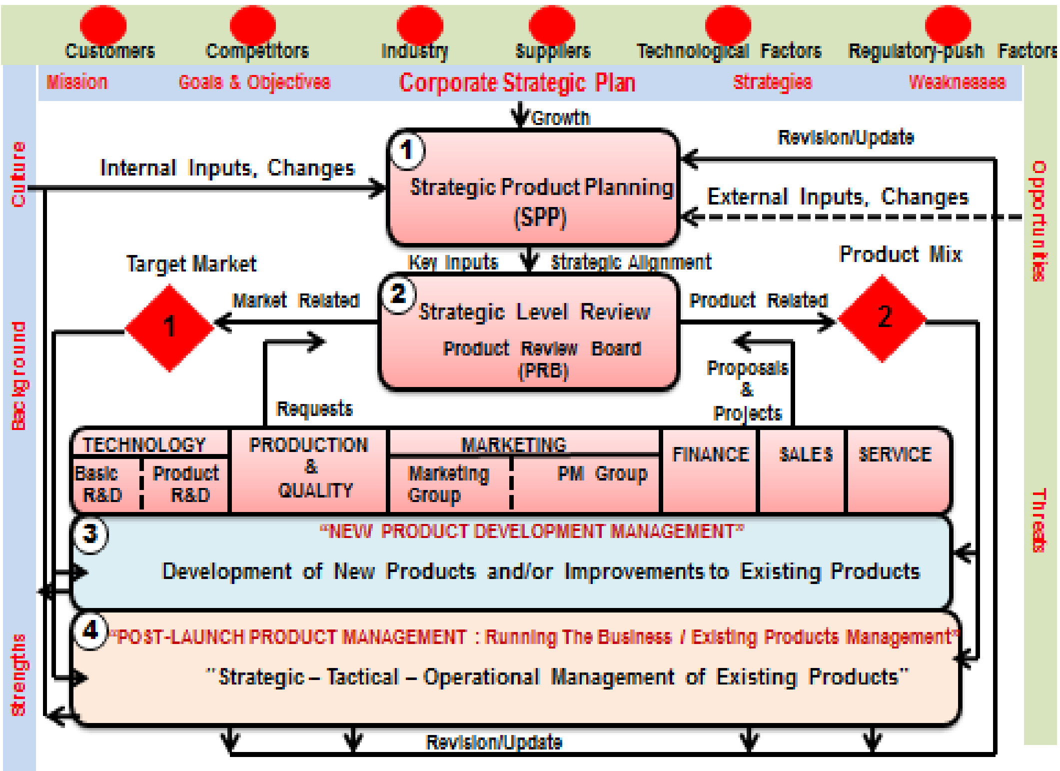

Figure 3.13: Levels of Major Activities and Decisions in Product Management

The "Tactical and Operational Product Planning and Management" levels of PM are shown by the numbers (3) and (4) together in Figure 3.13. In other words, Tactical and Operational Product Planning and Management are represented by two sub-levels:

- New Product Development Management, and
- Post-Launch Product Management.

New Product Development (NPD) Management (3) is an important area of PM. Krishnan and Ulrich (2001) define product development as "the transformation of a market opportunity into a product available for sale" (p.1). They also state that the product development process (i.e., *how* products are developed) may differ not only across firms but also within the same firm over time. However, they point out that *what* is being decided remains fairly consistent. Therefore, without being concerned about how these decisions are made, they identify several generic decisions in their study (Krishnan and Ulrich, 2001). Later we will briefly outline these decisions. In this activity level, tactical and operational decisions take place considering the "Growth" objective of the company which refers to the strategic alignment with the higher level of management, and requires the strategic considerations in the decision making process of this level. Project proposals regarding the development of new products and/or improvements to existing products are determined and presented to the PRB for strategic level review. These projects refer to investment proposals where the budgets for those investments are determined by the PRB.

Finally, we see the "Post-Launch Product Management" or "Existing Products Management" level of PM (4), which actually represents running the day-to-day business. In addition to the tactical and operational management of existing products, due to the cyclical nature of PM, the strategic management of existing products is handled. This part reflects the situation where all the products are in the market, they are followed up with continuous monitoring, and proposals are developed for the ones to be deleted from the market place.

All these activities shown in this page of the Flow Model are performed by the following major functional departments depicted in Figure 3.14.

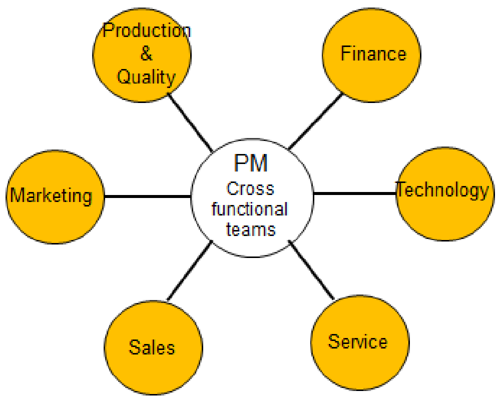

Figure 3.14: Major Functional Departments in the Product Management Organization

The product management is cross functional in nature and bridges many departments. A team structure allows both vertical and horizontal process flows. These cross-functional teams may be in a network team structure (e.g. Company C), or in a matrix structure (e.g. Company D) which is the most complex organizational structure in which dual reporting system takes place. This is a structure which is a combination of function and product structure and the product manager has no direct authority over the products being produced and sold. The overall responsibility of a product manager in this organization is "to integrate the various segments of a business into a strategically focused whole, maximizing the value of a product by coordinating the "production" of an offering with an understanding of market needs" (Gorchels, 2006; p.305).

The Product Review Board (PRB) members are the heads of the functional departments shown in Figure 3.14, and there may be also advisory members like legal, regulatory, or public relations. The Chairman of PRB is usually the CEO of the company as in the cases of our field study and stated in the literature (Haines, 2009; Steinhardt, 2010; Gorchels, 2006).

<u>Strategic Sub-Levels</u>:

The subsequent two pages of the Flow Model explain the two sub-levels of the *Strategic Product Planning and Management* activity level respectively as presented below:

(1) Strategic Product Planning

The third page of the PM Flow Model presents the basic elements of the strategic planning process for the products.

Ideally, corporate strategy sets the position in terms of market dominance (industry, technology, or demographics); financial objectives; and corporate "identity" positions such as culture, values, mission, and overarching goals (Haines, 2009).

The initial step of strategic product planning (SPP) is the creation of the vision for the product in the future. The company must be sure where it intends to focus its efforts to accomplish this. In sum, the strategic product plan development process begins with the creation or refinement of the long-term PM vision. Long-term planning requires usually considering more than three years into the future. The PM expert of Company D which supported our PM Flow Model construction denoted that they developed a five-year Strategic Product Plan, where the final 3 years of the planning horizon is subject to a continuous updating process.

The second step in the SPP development process is setting the PM goals and objectives. With the condition of being in line with the corporate goals and objectives, at the highest level, the usual PM objectives can be stated as follows:

(1) Growth
(2) Revenue and/or profit maximization
(3) Market share increase

These objectives represent the major generic objectives of a typical firm (Crawford and Di Benedetto, 2008). Besides, customer satisfaction, market leadership, minimizing product launch time, etc. can be considered and may have special importance in some companies.

In our case, we will consider the generic objective statement "to maximize the profit of the firm".

The final step in the SPP development process is to establish PM strategies. A strategy defines *what* is going to be done and *how* it is going to be done, so it requires a plan of action that encompasses a future time frame (Haines, 2009). Haines (2009) states that strategies formulated by the PRB propose the execution parameters for a product or for the portfolio of products to achieve the objectives. Well-formulated strategies set the stage for robust, ongoing planning and decision making throughout the PLC. SPP should take both current product mix and the future strategic direction into account in order to achieve the long-term goals of the company (Bean and Radford, 2000).

SPP is based on several inputs of which some provided internally, and some others are collected through the analysis of the environment of the company (the contextual analysis of the company). The factors affecting PM decisions have been determined in this study through a combined study of a literature survey and a field study conducted earlier. These inputs are broadly classified as *internal* and *external* inputs and the description of those inputs are provided briefly in Table 3.3 and Table 3.4 respectively.

Internal inputs are grouped mainly as follows:

- Strategic inputs
- Organizational inputs
- Information/Knowledge
- Core competences owned by the company
- Resources of the company
- Product performance data

The role of strategic inputs has been discussed briefly before; therefore we have just mentioned the items here.

Considering the cases of the field study and in the previous page of the Flow Model, major organizational characteristics of PM were discussed. Regarding our research problem, we assume simply the company has adequate organizational capabilities to perform PM effectively and the product mix decision is made in such an effective PM environment. Therefore, further aspects of PM organization and related issues are considered as beyond the scope of our work. Similarly, we assume the company is capable of managing the information/knowledge well. In sum, the most relevant inputs for our problem case have been shown in our PM Flow Model presented in Appendix C.

It should be pointed out that the company should also have adequate financial resources to support future investments in products. Therefore, the availability of resources is important in general so that activities of investment, manufacturing, marketing, etc. should be planned considering the availability of the resources of the company.

Capturing the product performance data is an important task for evaluating the existing products of the company. This information is the key input in generating the product strategy, and also provides the base information for future product investments.

Table 3.3: Internal Inputs

Strategic	*Organizational*	*Information/Knowledge*	*Core Competences*	*Resources*	*Product Performance Data* (Haines,2009)
Long-term view (3years or more), Goals and objectives, corporate strategy, Mission, corporate culture, corporate background, Corporate strengths and weaknesses, Existing procedures and processes (corporate charter).	Top management involvement, Role of the PM department, Teamwork, Integral involvement, Good communication, Close cooperation among different departments, A degree of trust, Customer-focused culture, Organizational strengths, such as marketing, manufacturing, technology, etc., Creative, adaptive, interactive and responsive organizational structure.	Quality of data collection and reporting, Usage of supporting tools (e.g. SWOT, QFD) Information management.	Management competence, Quality of corporate staff, Planning and control systems, Business image, reputation, brands, R&D facilities, Patents, skills, infra-structure, standards, Scientific knowledge, Relationships, contracts, Cost leadership, Ecosystems.	Financial resources, financial status, Capabilities, such as technological capabilities, innovation, commercial, analyzing capabilities.	Product life cycle performance: Revenue Profit Market share Pricing programs Promotional activity Distribution channel activity Product operational performance Product quality Customer satisfaction Repair and return data Inventory turns

Table 3.4: External Inputs

	Industry/Market	*Customers*	*Competitors*	*Suppliers*	*Distributors*	
Market-Pull Factors	Structure of the market. Market potential. Market demand. Market attractiveness in terms of market share. Market growth rate. Industry profitability.	Customer needs and preferences. Customer satisfaction level in terms of brand loyalty, quality, price, service ability.	Competitive factors in terms of competitive intensity, barriers to entry, barriers to exit, share volatility, availability of substitutes. New products and/or processes developed by competitors.	Suppliers' relationship. Supplier power. Supplier loyalty. Bargaining power.	Distribution channels. Sales force. Bargaining power.	
Technology-Push Factors	Nature of change in Technology.	Competitors' activity.	Rate of technological change.	Technological opportunities.		
	Political	*Economic*	*Legal*	*Sociocultural*	*Macro-technological*	*Environmental*
Regulatory-Push Factors	Government stability. Taxation policy. Regulations. Social welfare projects.	Business cycles. GNP trends. Interest rates. Money supply. Inflation. Unemployment. Disposable income.	Competition law. Employment law. Health and safety. Product safety.	Population. Income distribution. Social mobility. Lifestyle changes. Attitudes to work and leisure. Consumerism. Levels of education.	Government spending on research. Government and industry focus on technological effort. New discoveries. Speed of technology transfer. Rates of obsolescence.	Environmental protection laws. Waste disposal. Energy consumption.

External inputs are presented in three groups as follows:

1) *Market-pull factors*
2) *Technology–push factors*
3) *Regulatory-push factors*

All these external inputs represent the sources of uncertainty for the PM problem, and they are uncontrollable variables for the decision maker(s). Proactive management needs to consider them in the strategic product planning activities and decision making processes.

More specifically, SPP is developed considering both internal and external inputs, and it has three basic components:

1. Product Roadmap (PRM) for each product group/product,
2. Product technologies / Technology Roadmap (TRM),
3. Marketing and sales plans.

PRM is a framework for developing a product plan which is aligned with the firm's aggregate product strategy (Rafinejad, 2007). The PRM is developed under the full responsibility of the PM group of the company, and contains the following product information over the years (Haines, 2009):

- Product attributes/features
- Models/versions
- Design/styles
- Colors/sizes
- Technology used
- Market segment
- Performance levels/targets
- Safety elements
- Market/competitive positioning
- Outsourcing options
- Product budget progresses/targeted level

On the other hand, the TRM specifies the technological requirements for the products that a firm needs to enable its aggregate strategy (Rafinejad, 2007). McNally et al. (2009) examine the impact of managers' dispositional factors in product strategy implementation in the context of new product portfolio management context. They select three different strategic business units (SBU) to analyze the impact of managers' dispositional factors. One of them which is successfully positioned in its industry develops PRMs. The PRM identifies what products will be released, when they will be released, and who will be working on the projects. It is stated that the other firms which do not develop PRMs in their decision making processes show poorer performances in general. The authors conclude that developing product roadmaps helps to achieve "balancing product innovativeness, release dates and resource allocations for products differentiated through meeting latent customer need (strategic fitness in their case) and that target much higher price points than existing products (financial returns)" (McNally et al., 2009).

In our case, the PM expert indicated that a PRM is developed for each product group and is presented to the PRB in their organization. Additionally, the product R&D group builds a TRM for each product where four or five technologies are used/adapted in order to make the finished product item. The cooperation of the manufacturing group can be solicited when needed.

Marketing and sales plans are prepared together with the marketing and sales departments and contributed to by the PM group, manufacturing, customer service and finance departments. Product teams use the marketing plan to map the product's pathway into the market. It describes a variety of investments that need to be made and sets up a marketing budget for the products. "In many companies product managers and marketing managers report to the same person" (Haines, 2009; p.386). We see a similar organizational structure in the PM expert's company.

In general, the marketing function can be divided into two major activities:

- Inbound marketing
- Outbound marketing

Inbound marketing functions as the radar of the organization. The marketing people who are responsible of these activities constantly monitor and record the market place, identify market-based issues such as general industry trends, macro-economic signals and activities of competitors, and they conduct field research studies to collect the voice of the customers (VOC).

Outbound marketing deals with activities carried out to create programs that communicate the company's and product's messages to customers using advertising and public relations activities.

In short, the marketing plan is a contribution toward the future business of the product because it focuses on marketing mix elements (Product, Price, Promotion and Place/Distribution channel, i.e., 4 P's) (Haines, 2009).

In fact, market research and market segmentation are joint efforts, involving not only the cross functional team of the organization but also outside research firms (e.g. A.C. Nielsen). It is understood from both the literature and the PM expert that market research companies are much like consumer products rating organizations, they often provide relevant, useful data on market size and growth rates. Especially, prior to a new product launch period, an outside research firm is hired. In those cases, the organization has an explicit goal for its particular project. In such a case, it is expected that the research company should provide the organization with a detailed statement of work, a project plan, and a project estimate. The outcomes of such a study may require a revision in the marketing plan, and hence in the SPP. Other sources of revision in the SPP may be the requirements/warnings which are pointed out by product R&D, Marketing, Sales and Customer Service departments, as indicated by our PM expert.

(2) Strategic Level Review

The fourth page of the PM Flow Model describes the strategic level decisions. As it has been mentioned before, strategic decision requires the determination of the *"Market-Product Mix"* of the company. The Product Review Board (PRB) is the decision maker of this problem. The PRB actually represents a cross-functional team of the organization and the members are shown at the bottom of this page of the Flow Model (see also Figure 3.14). This board is an executive level team established for ongoing, periodic reviews of product portfolios or product line portfolios within the company. The PRB is the decision making body, guiding, prioritizing product investments for existing products, products in development, and product projects in various planning phases. The Chairman of the PRB is usually the CEO of the company (Haines, 2009). In the PM expert's company, the Director of Marketing group is the Chairman of the PRB, who is the CEO of the company as well. The PRB's meeting period is usually twice a year; every six-month or they have annual meeting.

Krishnan and Ulrich (2001) define the following categories of decisions in the context of *product development*:

1. Single project development decisions.
2. Decisions in an organizational context and in planning development projects.

Although product development decisions take place as NPD Management in the tactical level of our Flow Model, they have strategic components that we will briefly explain here.

At this moment, we consider the second category of decisions in the Krishnan and Ulrich (2001) study mentioned above, which is further divided as follows:

a) Product strategy and planning,
b) Product development organization, and
c) Project management.

We focus on the decisions related to "product strategy and planning" that include strategic decisions in setting up a new product development project. In a structured or formal product management environment, product planning results in "mission statements for projects and a product plan, namely product roadmap – a diagram illustrating the timing of planned projects" (Krishnan and Ulrich, 2001). They define five major generic decisions in the "Product Strategy and Planning" decision making process. This phase of the decision making process involves decisions about the firm's

- target market ("*What is the firm's target market*?")
- product/project portfolio ("*What portfolio of product opportunities will be pursued*?")
- project prioritization ("*What is the timing of product development projects*?")
- resource allocation, ("*What assets will be shared across products*?"), and
- technology selection ("*Which technologies will be employed in the planned products*?").

Cooper and Edgett (2010) propose a conceptual methodology for product innovation practices for the firms. It is understood that the firms which face this issue in real life prefer soft methods that are easily implementable in their decision making processes (Cooper et al., 2001). Cooper and Edgett (2010) develop such a framework which supports the decision makers by providing fast and practical solutions for the NPD portfolio management problem. The framework begins with the product innovation goals at the top and moves down to the tactical project selection decisions. Through the industry analysis and company analysis, first, they define "arenas of strategic focus". Then competitive strategies are defined (Attack/Entry strategy). Resource allocation and Strategic Portfolio decisions take place. The tool "Strategic Buckets" is used in earmarking the available funds for major development/R&D projects (NPD programs). The results are shown in a strategic product roadmap, which only shows the major initiatives of the company. In other words, the strategic product roadmap uses the tactical level PRM as an input, and does not show all details for the products. Chao and Kavadias (2008) criticize both mixed integer programming techniques at the operational level due to the "in" or "out" nature of the projects, and the strategic bucket tool due to the nonexistence of any theoretical background. However, they emphasize the results of a survey which specifically addresses the practice of strategic buckets as an NPD portfolio management tool, stating that "this research provides descriptive evidence of the use, benefits, and popularity of strategic buckets" (Chao and Kavadias, 2008; p. 909). Hence, Chao and Kavadias (2008) propose a theoretical framework for using strategic buckets, considering *environmental complexity* and *environmental instability* which are the important factors in balancing the radical and incremental innovation efforts. According to their proposal, if environmental complexity is high, the company should use radical product development strategy, and if environmental instability is high then the company should consider incremental product development strategy, in order to reduce risk (Chao and Kavadias, 2008).

In our Flow Model, the SPP is the key input for the strategic decision of *"Market-Product Mix"* of the company. Moreover, NPD projects prepared by the PM group and proposals for the "Problem Children", i.e., the candidate products to be considered for deletion from the current Product-Mix of the company, which are prepared by each member of PRB, are the other inputs for this strategic decision.

The PRB first determines the target market (Bean and Radford, 2000). Then the products are selected for the targeted market, because these products are served to the customers in this targeted market. This is the usual way of taking this strategic decision especially in market-driven or customer-driven companies, which also reflects the situation in our case as indicated by the PM expert.

Markets can be segmented based on a variety of characteristics, such as demographics indicators, values and beliefs of people, and loyalty indicators. In short, the common factor in segmentation is *customer needs*. Each customer segments is dominated by its own distinctive set of needs. Actually, any specific customer segment represents the target market for the company. So, the PRB needs to know about each of the market segments so that they can define which customers they should focus on to satisfy the needs of that specific group.

The target market selection decision is closely related to the market attractiveness which is based on the following major factors (Haines, 2009):

(1) The degree to which the segment is growing,
  - Higher growth rates offer sizeable opportunities for companies.

(2) The number of competitors,
  - If there are too many competitors in a given market area, customers may have too much choice and it may be more difficult to establish a differential advantage with the company products.

(3) The manner in which a segment is accessible by known distribution channels,

(4) The profit to be gained by bringing products to those segments.

We assume that the PRB selects the target market by evaluating all these factors properly.

Secondly, the PRB selects the combination of products to be served in the targeted market, which is the main focus in our problem case. The PM group is responsible for proposing a reasonable number of candidate new products or improvement projects for the existing products to the PRB. These projects can be considered as feasible product projects because all of them are filtered by the PM group before the evaluation of the PRB. Therefore, the PRB evaluates technological and financial resources in order to prioritize the product projects. Before the prioritization decision, the outsourcing decision may come into the picture as an option. The outsourcing decision is usually considered as tactical level issue in the literature (Krishnan and Ulrich, 2001; Haines 2009). Only a few studies in the literature consider this decision making area as a strategic issue (Arya et al., 2008; Humpreys et al., 2002). Regarding such a decision making situation, the PM expert of Company D told us the following outsourcing decision option: the company determines a specific customer need in the target market. They realize that to develop the product in-house requires a strategic long term capacity expansion decision which means that the competitor may introduce the product before the focal company during this period. So the company takes the outsourcing option to satisfy the perceived customer need. This decision making situation reflects the strategic "bottleneck" problem in the company.

Product projects in the bucket should be evaluated simultaneously with the products to be deleted from the bundle of existing products. The PRB makes decisions by evaluating existing products, product projects proposals from three broad perspectives (Haines, 2009):

1. Economic value,
2. Strategic impact,
3. Available resources (both financial and technological)

In the study by Banville and Pletcher (1986), it is stated that "the optimal product mix has been achieved when any change due to addition, modification, or elimination of a product, would detract from the attainment of the firm's goals. It follows then, that product management involves the manipulation of the product mix through the addition of new products, the modification of existing product lines, and the elimination of products no longer contributing toward the goals" (Banville and Pletcher, 1986; p.432).

Bean and Radford (2000) ask the following three questions in analyzing the existing products:

1. Which products can be kept without any alteration?
2. Which products should be improved to fit the target market?
3. Which products should be deleted?

Banville and Pletcher (1986) analyze the factors that affect product deletion decisions stating that the product management area neglects the elimination phase of the product life cycle. They outline four basic situations under which a product may be evaluated for possible elimination, which are given below:

1. Declining demand on an industry,
2. Coercion by external forces,
3. Incompatibility of distribution,
4. Poor product performance despite a generally viable market.

The results of their analysis indicate that: "following the primary consideration of financial data and overall profitability to the firm and secondary consideration of the market including growth potential and stability, the decision maker turns again to internal considerations based essentially on the product mix” (Banville and Pletcher, 1986; p. 438).

In our case, the PM expert of Company D indicated that the PLC performance of the existing products was evaluated to take the decision of withdrawing the product from the market. He stated that the candidate products to be deleted are called as “Problem Children” in the company. All members of the cross-sectional team of the PRB evaluate the existing products from their functional points of view, identify the problems regarding the existing products in the market, and prepare proposals for these products. “Problem Children” are usually two types of products:

(a) *Passive products:* They are not manufactured anymore, but they exist in inventory as *finished* items.
(b) *Out dated products:* They are not manufactured anymore, but their *components* exist in inventory.

Based on the number of deleted products and resource availability of the company, a number of new products/improvements are introduced as candidate products to be considered to determine the new product mix of the company. This decision constitutes the basis for forecasting and demand planning in order to determine the required quantities in the market which is in turn the necessary input for production planning of the selected products.

<u>Tactical and Operational Sub-Levels:</u>

In the fifth page of our PM Flow Model, two major management areas or the sub-levels of *Tactical and Operational Product Management* are presented denoting the major activities performed in each. These are namely,

(3) New Product Development Management (NPD)
(4) Existing Products Management (Post-Launch Product Management)

Actually this page of the Flow Model finalizes the description of PM, but NPD, as one of the most important management activity of PM, requires describing some further details which are shown in page 6 and page 7 of the Flow Model.

In general, strategic decisions taken by the PRB provide inputs for the activities of those management areas. Columns show the cross-sectional team members/departments/groups of the company. The major activities performed in those departments are shown for each department respectively. The outcomes of these activities, such as new product project proposals, “Problem Children” proposals, inbound market research results, marketing plan, VOC reports, repair and return reports, provide inputs for the SPP and hence decision factors for the PRB. A feedback mechanism is seen as it was mentioned before. So, through such a feedback mechanism the PRB receives the necessary supportive knowledge and required inputs for the decision making process. One of the major decisions is the product portfolio plan which specifies the mix of the products of the company and it includes both new and existing products. A *product portfolio* is a group of product investments which consists the investments of improvements on existing products and/or investments of the new ones. The NPD management area of PM mainly deals with management of those investment projects considering the strategic link to the upper level of PM and the constraints imposed by the executive management.

The PM group has the major responsibility in NPD management area. For any company having "Growth" objective, NPD has a vital importance. In the subsequent two pages of the PM Flow Model, PM group activities and interrelationships with other functional groups will be presented in more detail.

(3) New Product Development (NPD) Management

In order to gain a comprehensive understanding of PM, it is necessary to illustrate the way that PM transforms "good ideas" into successful products (Haines, 2009). This simply expresses the main function of NPD. NPD depends on both existing products and projects under development. The major functions of NPD management are shown in page 5 of the Flow Model. The subsequent pages 6 and 7 present the details of the NPD management area of PM.

For a given level of financial resources, managing the new product portfolio is a dynamic decision process which includes evaluating, selecting, and allocating resources to product development and improvement projects. These decisions are also called as "predevelopment pipeline decisions" (McNally et al., 2012). McNally et al. (2012) state that these decisions requires trade-offs across maximizing expected economic returns, minimizing risk, and maintaining product mix diversity. During this dynamic decision making process, the use of personal judgments of individual managers and their previous experience are still used as the dominant criteria on which potential projects are judged. Thus, McNally et al. (2012) emphasizing these factors, "focuses on the psychological and social-psychological characteristics of organizational members as the contextual factor affecting information processing" (p.246).

Crawford and Di Benedetto (2008) divide the NPD management into the following parts:

1. Opportunity identification/selection,
2. Concept generation
3. Concept/Project evaluation,
4. Development, and
5. Launch.

Haines (2009) defines NPD management through the following stages:

1. New Product Planning
    - Concept
    - Feasibility
    - Definition
2. New Product Introduction
    - Development
    - Launch

Although there are a few terminological differences in these descriptions of NPD, the basic stages are the same. In our Flow Model, the elemental PM model (Figure 3.5) presented in section 3.2.1 is considered to describe NPD management. Remember that "Product Development and Improvement" is based on the definition provided by Krishnan and Ulrich (2001) and it covers the main stages above given by Crawford and Di Benedetto

(2008) and Haines (2009). Below the details of NPD management is described placed on the sixth and seventh pages of Flow Model presented in Appendix C.

The PM group plays the key role in this management area together with the other functional groups. The major work area of PM group is New Product Planning which covers the "Front-End Activities of NPD". However, it should be pointed out that the phases in the NPD process do not have clear end lines, or do not follow a linear sequential process, in the sense that early phases may require movement with the later ones, while later phases may require re-evaluation of the earlier phases of the process. Therefore, there may be several loops in the product development process. The initial step in the process is the hard work of discovering customer needs. The key input for this work is "Voice of Customers" (VOC) which is collected by the marketing department through field research, opinions of the sales force in the market and also complaints/desires of customers obtained by the customer service department. There are three phases and three gates within this area:

1) Concept phase
2) Feasibility phase
3) Definition phase

The concept phase includes the assessment of ideas for new products as well as for line extensions, feature improvements of existing products. It is a process of screening ideas. At the conclusion of that phase, a decision review takes place:

- Either the concept/idea proceeds to the next phase, or
- It is rejected and the work stops.

For the ideas that pass the Concept phase, the Feasibility phase provides a more in-depth review of the market and the technical and financial dimensions of the proposal. The input to this phase is the opportunity statement and the outputs are preliminary business cases for the feasible product opportunities. A business case can be defined as a formal document used to justify investments in new products, product improvements and marketing expenditures. The term investment here is used as the required money to develop and launch the product. Therefore a business case should prove that the product can deliver a positive return to the company, and is forwarded to the PRB to request the required financial resource. The finance department and the PM group together work on feasibility studies. Meanwhile, the Product R&D group provides information on the technological feasibility to the PM group. If a project is considered feasible from the market, technical and financial points of view, it can move to the definition phase. If the opportunity does not meet the established criteria for acceptance, the project is stopped.

The product definition phase represents the following activities:

- In order to translate customer needs into product requirements, the PM group, together with the Product R&D group establishes a QFD team, and this team develops a feature matrix for the product.

- The PM group carries out a make-buy analysis for the outsourcing option, considering both the technological and manufacturing capabilities of the company. For this study, the Sales group provides the forecasted quantity, the Product R&D

group evaluates availability and adaptability of the existing technologies, and the Manufacturing group conducts an operational analysis regarding production resources, capacity and labor force.

- If the product is decided to be developed in-house, the product R&D and manufacturing group work together to design, build, prototype, validate and test the product.
- Meanwhile market research is completed and the future marketing mix is finalized.

A final business case, marketing plan and a set of baseline product requirements are the primary outputs of the definition phase. We should note that the development phase begins after the project is approved and funded. This phase can be characterized by a series of projects. It also includes production planning for manufacturing, quality control programs, software development and other programs with the actual delivery of the product in accordance with the product requirements. The product development phase for Company B which is depicted in Figure 3.2 is an example for this group of activities.

Manufacturing department has an important task at this phase which is the planning the production for the products decided to be produced in-house. Production planning requires several tactical and operational decisions considering the characteristics of the manufacturing system of the company and production strategies – make-to-stock and/or make-to-order. In traditional production planning literature, tactical decisions are concerned with the allocation of the resources available for production purposes. An appropriate planning horizon for these decisions is usually one year (Bitran et al., 1981). The basic operational decisions of production planning consist in establishing the quantity of each product that must be produced and the corresponding resources needed. Operational decisions are made subject to the limitations imposed by the upper level. This multilevel decision process in production planning is called "hierarchical production planning" in the literature (Nahmias, 2001; Mula et al., 2006; Bitran et al., 1981) in which APP represents top level planning in the framework of production planning decisions. Nahmias (2001) points out that the aggregation scheme for the products should be consistent with the firm's organizational structure and product line. Aggregate plans should be converted into detailed master schedules in which production levels are determined item by item (Master Production Schedule). As it was mentioned before, the PM decision framework is broader than the production decision framework and the issues related to production can be handled in operational level of the PM hierarchical decision making perspective.

The "Launch" is an integral part of PM which represents the activities to introduce the product to market. The management of the Launch is often driven by the Marketing group in organizations.

(4) Existing Product Management:

Existing Products Management is also called as "*Post-Launch Product Management*" which actually represents running the business of the company reflecting the cycling nature of PM. The main task of the PM group is to optimize the performance of existing products, consistent with the strategies of the organization. For this reason the PM group monitors and follows up the market performance of the existing products in a continuous manner. By analyzing the performances of the products, several strategic, tactical and operational decisions take place. The identification of the “in-market” life cycle state of the products is an important performance measurement tool in this management area of PM.

Financial and market-based performance measurement for the products is essential to understand and define the status of the products in the market. Each member of the cross functional PM team evaluates the market status of the product from their own point of views. For instance, the Finance department makes assessments of how well the product is performing against established plans. The post-feasibility studies and product audits are the major analytical tools employed for this purpose. The service department collects VOC for the products, thus the satisfaction of the customers or complaints about the products are important signals and inputs for product performance evaluation. Product R&D uses these inputs given by the front line people in cross functional team members, like service people, sales people and marketing people, and the product revision/improvement decision can take place. Sales and Marketing departments members check and follow the trends that shape the industry, current actions of competitors, and the evolution of customers’ needs.

In addition to the examination of industry and competitive effects, customer satisfaction analysis is done in targeted market/segment. As an important part of the running business, the cross sectional team review the outcomes of customer visit reports, and VOC documents as the means to validate customer needs.

As the product is active and moves through the market, marketing performance measurement and operational performance are the focus points for the team members. As it could be remembered, marketing mix is the strategic combination of investments in the product, its pricing schemes, promotional programs, and path to the end customer via the most efficient distribution channel. For this purpose, various combinations of marketing mix options are examined, executed and tracked.

Operational efficiency is important to support the success of the product in the market. Sourcing of materials and production of products and servicing customers are important operational elements in running the business of PM. These operational elements are referred to as “*supply chain* activities, and order processing time, on-time shipment, repair and return data, customer trouble reports, plant utilization statistics” and these operational data can be used as the operational performance measurements (Haines, 2009).

Depending on the financial and market-based inputs mentioned above, the members of cross sectional team prepare their own evaluation reports on current products, and “problem children” proposals are presented to PRB.

As mentioned before, “Existing Product Management” or “Post-Launch Product Management” represents running the ongoing business. Therefore, this level of management includes all kinds of decisions: strategic, tactical and operational, although we show this level under the “Tactical and Operational Product Planning and Management” stage of the main frame of PM. The main reason underlying this is the *cycling nature of the PM* problem.

The book of Haines (2009) is frequently used as one of the references in our study since the definition and approach used in PM is very close to our PMS, in the sense that the definition of PLC, which is the main underlying concept of PM, contains both "investment" and "market" phases of the product. However, Haines (2009) considers only strategic and tactical decisions in Post-Launch Product Management in his book –an approach with which we disagree at this point. He states that "Product management is *"an ongoing, multi-dimensional, multi-phase decision-making methodology that allows a business to achieve strategic, market, financial, and operational balance across each and every product in an organization, across all life cycle phases"* (Haines, 2009; p.524).

As a result, existing product management deals with the mix of new and old products. Existing products are evaluated on an ongoing basis to determine the product performance and spend efforts to increase revenues, reduce costs, or eliminate obsolete products by using the strategies maintain (good income stream), revitalize (market penetration) or rationalize (candidates to be deleted) for the existing products which are called as the generic product management strategies for the existing products (Gorchels, 2006).

3.2.4 Overview: Major Decisions in Product Management

In this section, we aim to express the *generic product management decisions* in an abstract form which is organized under certain groups in parallel to the functional logic of the Flow Model. We consider the studies by Krishnan and Ulrich (2001), Ramdas (2003), Yahaya and Abu-Bakar (2007) and Loch and Kavadias (2008) in organizing the PM decisions. All of the studies mentioned above are in the area of the NPD of PM. Among them, Ramdas (2003) presents a broader framework related to the product varieties.

Krishnan and Ulrich (2001) state that different organizations make different choices and may use different methods in their product development process, but all of them make decisions about a collection of common issues. In other words, "while how products are developed differs not only across firms, but within the same firm over time, *what* is being decided seems to remain fairly consistent at a certain level of abstraction". These decisions are called *generic decisions*, and the perspective that product development is a business process involving scores of such generic decisions, is called the *decision framework* (Krishnan and Ulrich, 2001). In the same review paper, in order to be able to see the interdependencies among the decisions, the authors handle the product development problem as a "cross-functional research problem". The product development decisions, encompassing the major steps in the development process, are grouped in two broad categories (Krishnan and Ulrich, 2001):

1. *Product development decisions within a project*
   - 1.1 Concept development
   - 1.2 Supply-chain design
   - 1.3 Product design
   - 1.4 Performance testing and validation
   - 1.5 Production ramp-up and launch

2. *Decisions in setting up a development project*
    2.1 Product strategy and planning
    2.2 Product development organization
    2.3 Project management

Another excellent integrative review paper is provided by Ramdas (2003) in which a framework for managerial decisions about product variety is introduced. It is pointed out that managing product variety requires decision making at different organizational levels, over different time horizons, before and after product launch. Therefore, we can say that Ramdas (2003) presents a broader framework. He defines the variety decisions as follows:

> "*variety-related decisions can be viewed as focusing on how to create variety in a product line, and on managing a firm's processes and supply chain to implement variety*" (Ramdas, 2003; p.80).

Rather than examine variety management from a functional perspective, or a methodological perspective based on the use of specific decision techniques, he uses the recurring decision themes and interdependencies among them, to examine both the key practical issues and the research in variety management. He focuses on understanding the spectrum of variety related decisions faced in practice. In his framework, the following common set of decision themes is considered:

1. *Variety-creation decisions*
    1.1 Dimensions of variety
    1.2 Product architecture
    1.3 Degree of customization
    1.4 Timing
2. *Variety-implementation decisions*
    2.1 Process and organizational capabilities
    2.2 Points of *variegation* (or decoupling)
    2.3 Day-to-day decisions

Variegation is defined as describing "how a firm's products are perceived as distinct from one another" (Ramdas, 2003; p.80). Note that product line decisions and specifically product mix decisions are seen in the major decision theme of *dimensions of variety* in the common set of *variety-creation* theme.

Thirdly, Yahaya and Abu-Bakar (2007) report their findings related to NPD management issues and their corresponding decision-making approaches. The study adopts grounded theory research method in which interview is used as the primary data source. They identify about a hundred management issues, sourced from sixteen senior managers from six organizations. These findings are presented in four categories of NPD management issues as follows:

1. Strategic NPD management issues
2. NPD project management issues
3. NPD process and structural issues
4. NPD people management issues

Finally, we consider the study by Loch and Kavadias (2008) which introduces "a theoretical framework that integrates research from various disciplines on different areas of NPD in a common context" (p.1). They describe the following elements of the NPD system:

1. A *variant generation process* which identifies new combinations of technologies, processes, and market opportunities with the potential to create economic value.
2. A *selection process*, which chooses the most promising among the new combinations for further investment.
3. A *transformation process*, which develops opportunities into economic goods, i.e., products.
4. A *coordination process*, which ensures the information flow, collaboration and cooperation among multiple parties, involved in the NPD activities.

The authors view NPD in an evolutionary framework. Thus, the multi-level evolutionary theory framework is proposed which sets the stage for grouping and comparing the different theories that have studied NPD phenomena. For this purpose, they provide a review of research which mainly contains the research efforts to organize research into frameworks. Their past overviews include Krishnan and Ulrich (2001) study and they state the following: "In summary, each of these frameworks have emphasized certain theories and phenomena within NPD but not targeted an overall view" (Loch and Kavadias, 2008; p.11). So in the context of their evolutionary theory, they present NPD-related theories as follows:

1. *Industry Level*
    - Industrial organization
    - Industry life cycles, network externalities, dominant design
    - Population ecology of firms
2. *Firm Level*
    - Technology strategy, including technology sourcing, first mover advantage, NPD contribution to strategy (features, cost, variants, new markets, etc.)
    - Theory of the firm, firm boundaries
    - Transaction cost economics
    - Architecture platforms and product variants
    - Complexity theory
3. *NPD Process Level*
    - Search and creativity theory
    - Design of experiments
    - Customer need identification
    - Portfolio theory, mathematical programming
    - Engineering design optimization
    - Organizational structure and collaboration across functions
    - Project management
    - New product diffusion theory

In sum, they outline an evolutionary view of NPD, including three levels of the "vary-select-elaborate-and inherit" cycle, they identify academic theories that aim to explain the dynamics and success factors of NPD. Thus, they believe it may help to better understand how the levels of aggregation interacts, how decisions at a higher level become constraints at a lower level, how new variants at the lower levels influence the choices at the higher level, etc.

Through the benefits obtained from all these studies in the existing literature, it is believed that the decision framework illustrated by the Flow Model in this study, without getting involved in the functional details of how the decisions are made, also seems to provide a comprehensive description of product management. Considering the complexity and broadness of the subject, to provide an integrative form of the major decisions in PM can be accepted as an initial attempt to fill this gap in PM literature. Therefore, it is aimed to express the *abstract form of the generic decisions of PM* in this section.

We organize the PM decisions considering the basic philosophy of product life cycle concept (holistic approach) and management levels within a typical multi-product manufacturing firm, which is also in parallel to the construction of the Flow Model. Figure 3.11 illustrates the organization of the major decisions of PM in our case.

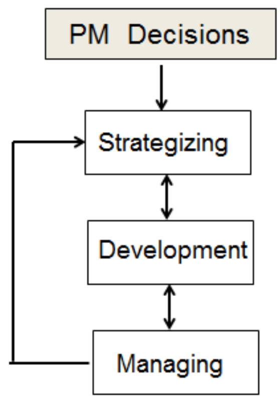

Figure 3.15: The organization of PM decisions

The double arrows in the figure represent the interdependency of the decisions, and the arrow between "Managing" and "Strategizing" decisions reflects both the interdependency between two decision groups and the cyclical nature of the PM decisions. These broad categories are subdivided as follows:

1. ***Strategizing decisions*** *(Long term strategy formulation decisions)*
2. ***Development decisions*** *(NPD and Improvement decisions)* (Krishnan and Ulrich, 2001)
   2.1 Strategic development decisions
   2.2 Tactical and operational development decisions
3. ***Managing decisions*** *(Ongoing business decisions)*
   3.1 Strategic managing decisions
   3.2 Tactical and operational managing decisions

Note that the third group of decisions represents the decisions in post-launch management or ongoing business of the firm. Normally any ongoing business of a manufacturing firm with existing products has two major functions in which *marketing* is responsible for generating demand and *operations* is responsible for fulfilling that demand. Krishnan and Ulrich (2001) considers the task of developing new products as *a discontinuity in ongoing operations*, which we totally agree with.

We express the decisions by questions in each group below. The decisions in the second group are mostly the decisions in the study Krishnan and Ulrich (2001) which are adopted to our classification.

As a result, by combining, refining, organizing, and synthesizing this set of decisions, we ended up with about 60 generic decisions. About half of this belongs to the broad area of PM, namely NPD and improvement area of PM. This set is the result of judgments about the appropriate level of detail of the decisions. The abstract form of the generic decisions of PM is presented in Tables 3.5 and 3.6 below.

Table 3.5: Major Decisions in Strategic Level of Product Management

Strategizing (Long Term) Decisions	***Strategic NPD Decisions***	***Strategic Post-Launch PM Decisions***
What *is the vision for the products?* ***What*** *are the market, financial and technical objectives?* ***What*** *is the competitive strategy?(cost minimization/product differentiation/market focus)* ***What*** *is the innovation strategy? (radical/incremental)* ***What*** *is the technology strategy?(in-house development /outsourcing/ acquisition)* ***What*** *is the product strategy?(overall)*	***What*** *is the market and product strategy to maximize economic success?* ***What*** *is the target market for the new product?* ***What*** *portfolio of product opportunities will be pursued?* ***What*** *is the timing of product development projects?* ***What*** *assets will be shared across which products?* ***Which*** *technologies will be employed in the products?* ***Who*** *will be the supplier of perceived product opportunity? (strategic outsourcing)*	***What*** *is the choice of the strategic options and opportunities for existing products? (change in strategic marketing mix, entrance new markets, competitive posture)* ***What*** *is the competitive positioning of the products?(strategic product positioning)* ***What*** *are the attack and defend strategies?* ***Which*** *market segments will be pursued?* ***Which*** *products will be retired and replaced with the new ones?* ***What portfolio/mix of the products will be offered to the market place?***

Table 3.6: Major Decisions in Tactical and Operational Levels of Product Management

	NPD		**Post-Launch PM**
Planning	<u>Organizational (1)</u> ***Will*** *a functional, project, or matrix organization be used?* ***How*** *will the team be staffed?* ***How*** *will be the physical arrangement and location of the team?* ***What*** *investments in infrastructure, tools, and training will be made?* ***What*** *type of development process will be employed?*	<u>Project Management (2)</u> ***What*** *is the relative priority of development objectives?* ***What*** *is the planned timing and sequence of development activities?* ***What*** *are the major project milestones and planned prototypes?* ***What*** *will be the communication mechanisms among team members?* ***How*** *will the project be monitored and controlled?*	***What*** *are the required technologies, architectures, or platforms to support new functionality?* ***What*** *pricing strategies are to be used to support product?* ***What*** *are the financial requirements for ongoing work?*
Development	<u>Concept (1)</u> ***What*** *are the target values of the product attributes, including price?* ***What*** *is the core product concept?* ***What*** *is the product architecture?* ***What*** *variants of the product will be offered?* ***Which*** *components will be shared across which variants of the product?* ***What*** *will be the overall physical form and industrial design of the product?* *and equipment?* <u>Design (3)</u> ***What*** *are the values of the key design parameters?* ***What*** *is the configuration of the components and assembly precedence relations?* ***What*** *is the detailed design of the components, including material and process selection?*	<u>Supply Chain (2)</u> ***Which*** *components will be designed and which will be selected? Who will design the components?* ***Who*** *will produce the components and assemble the product? (Make/Buy decision)* ***What*** *is the configuration of the physical supply chain?* ***What*** *type of process will be used to assemble the product?* ***Who*** *will develop and supply process technology and equipment?* <u>Testing & Validation (4)</u> ***What*** *is the prototyping plan?* ***What*** *technologies should be used for prototyping plan?* <u>Ramp-up and Launch (5)</u> ***What*** *is the plan for market testing and launch?* ***What*** *is the plan for production ramp-up?*	***What*** *is the improvement project for the existing products? (functionally, aesthetically)* ***With*** *which features or attributes?* ***What*** *promotional strategies are to be used to support product?* ***What*** *distribution strategies are to be used to support product?* ***What is volume of the product to be produced?*** ***What*** *are the quality guidelines?* ***What*** *are the customer satisfaction targets?* ***What*** *are repair and return goals?* ***What*** *is the inventory turns goals?*

3.2.5 Validity of the Flow Model

In general terms, *validity* is the assessment of how well a survey measures what is intended to measure. The validity of the Flow Model has been tested by the comments of PM experts. Hence, while we were developing the Flow Model, we communicated with the PM expert at certain phases, and evaluating his comments, we revised the Flow Model when necessary. Most of the comments were related to the clarity of the Flow Model. However, one revision has been made in "Strategic Level Review" part of the Flow Model which was in conflict with the literature-based knowledge: We added the "strategic outsourcing decision" to the decisions on the strategic level by the comment of the PM expert which was explained in the relevant part of the Flow Model. Contrary to the PM expert's comment, outsourcing decisions take place only on the tactical level of PM in the literature except in a few ones. Another important comment was related to the target market decision in the strategic level review. In our flowchart, the target market decision is represented by "left arrow", but together with the "right arrow" (strategic product selection decision) it was misleading the reader because these two arrows together were representing a parallel decision. By the comment of the PM expert we numbered the target market decision as the first decision, which was in line with the literature. When we completed our flowchart, we asked for the PM expert to evaluate our Flow Model in terms of

a) relevance,
b) clarity, and
c) ambiguity.

He established a cross-sectional team within the company and this team examined and evaluated the Flow Model. Finally, he confirmed the model in written form. Hence, we can say that the Flow Model is a joint work of the PM expert and us.

Specifically, the assessment of *content validity* typically involve an organized review of the survey's contents to ensure that it includes everything it should and does not include anything it should not (Litvin, 1995). "Content validity is a subjective measure of how appropriate the items to a set of reviewers who have some knowledge of the subject matter". It is also stated that "Although it is not a scientific measure of a survey instrument's accuracy, it provides a good foundation on which to build a methodologically rigorous assessment of a survey instruments' validity (Litvin, 1995; p.35).

Litvin (1995) strictly states that content validity is not quantified with statistics, rather it is presented as an overall opinion of a group of trained judges. However, over the years, some efforts have been made to find more quantifiable methods for determining the content validity. "Content Validity Index" (CVI), or "proportion agreement", is the one which is used as an objective method for quantitatively measuring the content validity (Wynd et al., 2003). The CVI allows two or more raters to independently review and evaluate the *relevance* of the domain of content. During the progress of the thesis study, the academic experts of the subject used their judgments about the degree of relevance of the domain of the content, i.e., literature-based knowledge obtained through a comprehensive literature survey. Getting the comments of the academic experts, the final form of the Flow Model is constructed and shaped, as given in Appendix C.

3.2.6 Concluding Remarks

To formulate the strategic product mix problem in product management context requires answering the following important questions:

- Who is the decision maker?
- What are the decision factors?
- What are the environmental (external) factors affecting the decision(s)?
- What should be the time period to be considered for the decision(s)?
- What types of interactions do exist in decisions which may affect the product mix decision?
- What are the priorities for those decisions? Is there a sequential decision making process?
- What are the objectives of the organizations?
- What is relative importance of the product mix decision among the other decision making problems?

In short, to clarify these questions, and hence, to understand the context of product mix problem requires to analyze and understand the product management in its entirety. Besides, in order to be able to locate properly the product mix problem in product management framework necessitates detecting and extracting the major decision making problem areas in product management. For these purposes, the product management literature was surveyed deeply. During the literature survey, it was realized that there is no a comprehensive study considering requirements of the holistic approach to product management. Realizing this gap in the existing literature, it was decided to make an attempt to fill it. In sum, the accumulated knowledge obtained in the literature survey study, with the contributions of the field study, was evaluated to develop an exhaustive decision framework of product management.

Our aim in developing this decision framework of product management is mainly twofold:

1. to understand the PM problem deeply that enables us to formulate our research problem efficiently,
2. to serve as a pointer to this vast body of literature on product management which requires dealing with several domains of literature.

As a result, our contribution in this work can be outlined as follows:

- The Proposed Product Management System (PMS) presented in section 3.2.1 (Figure 3.7), is based on a holistic approach to the product management at corporate level. It was realized that most of the existing literature is in the area of new product development. This literature considers mainly the pre-market (investment) period of the product. On the other hand, a large literature in marketing area of the product considers only the market period of the product regarding marketing strategies, product positioning in the market, promotional activities, etc. However, the holistic approach requires considering the whole life cycle (PLC) of the product. The PLC starts with the product idea and continues till the withdrawal of the product from the market. To the best of our knowledge there is no a comprehensive study concerning such a holistic and an integrative systemic approach. We should point out an exception of Haines' (2009) book in which a similar conceptual definition for PLC is used, and it is written as a desk reference for a product manager from practical implementation point of view. It should be pointed out that it does not cover a systemic view to the decision framework of product management.

- A structured approach is presented to organize the product management literature what we call the decision framework.

- The existing literature of new product development is integrated to our additional efforts on the other areas of product management so that the interested reader is able to follow the whole journey of the product and the major decisions taken during this journey in a typical manufacturing company.

The author believes that all the efforts to integrate the existing literature in this study and to present it in a comprehensive way can be viewed as an initial attempt to clarify the decision framework of product management based on holistic approach which does not exist in the existing literature. Since our focus is the strategic product mix problem in product management framework, it is thought that the decision framework of product management can be bounded as it is given above. Additionally, the work presented in this chapter can be improved further for the forthcoming studies in this area.

CHAPTER 4

PROPOSED PRODUCT MIX DECISION SUPPORT SYSTEM

As mentioned before, shaping and planning the optimum product mix is ultimate goal in an effective product management. Therefore, strategic product mix determination is a challenging problem for companies in all industries. Although the problem may vary from one industry to another or even one company to another company in the same industry, the fundamental issue remains the same: Which products should be selected for the coming period and how many should be produced from each in order to maximize the financial performance of the firm in that period? The first part of this question is related to shaping the product mix which requires the selection of the right products to be served to the customers. We mainly focus on the second part of the above question, that is "to determine the quantities of the products" in order to maximize the financial performance of the company. While doing this, the method proposed here aids the decision maker in deciding the selection of the right products providing fast and necessary information which assure a profitable future for the company.

This chapter covers, first, the definition and clarification of *Product Mix Problem* within the product management context. Then the working mechanism of the proposed decision support system in this framework is described in section 4.2. In section 4.3, formulation approach of the problem is explained including the mathematical models constructed in accordance to the framework of the formulation approach. Section 4.4 presents the scenario generation method and determining the optimal product mix.

4.1 DESCRIPTION OF THE PRODUCT MIX PROBLEM WITHIN PRODUCT MANAGEMENT CONTEXT

Up to this point, it has frequently been stated that the formulation of product mix problem is based on the detailed decision framework of the product management problem. Thus, the problem setting within the product management context is very important to be clearly defined before passing through the formulation phase of the problem. Below, the product-mix problem within the product management context is defined. In this definition, the production management relevance of the product-mix problem, the product level in the mix and different types of production strategies or systems existing in manufacturing environments of the companies and industries are considered. Next, the complexities of the problem are outlined. Finally, the major interdependencies of product-mix problem with the other decision making problems in PM context are briefly described.

4.1.1 Problem Setting

As it was mentioned before, the nature of product-mix problem requires decisions at different activity levels of the management. So, the product mix decision at the strategic level can be made evaluating the results of the lower levels of this framework, and lower level decisions are made considering the strategic alignment as discussed before. In other words, strategic level decisions are the inputs for the tactical and operational level activities. In that sense, the best results obtained for the strategic product mix problem provide valuable inputs for the lower level decisions and activities in the product management context. Therefore, strategic product mix problem is formulated from a macro point of view within the product management context. This macro perspective is depicted in Figure 4.1. Considering this macro view it can be stated that the details of production processes and the components of the products are out of our concern. Detailed explanations about this perspective are given below. Note that these issues have also been discussed in detail at the formulation phase of the problem.

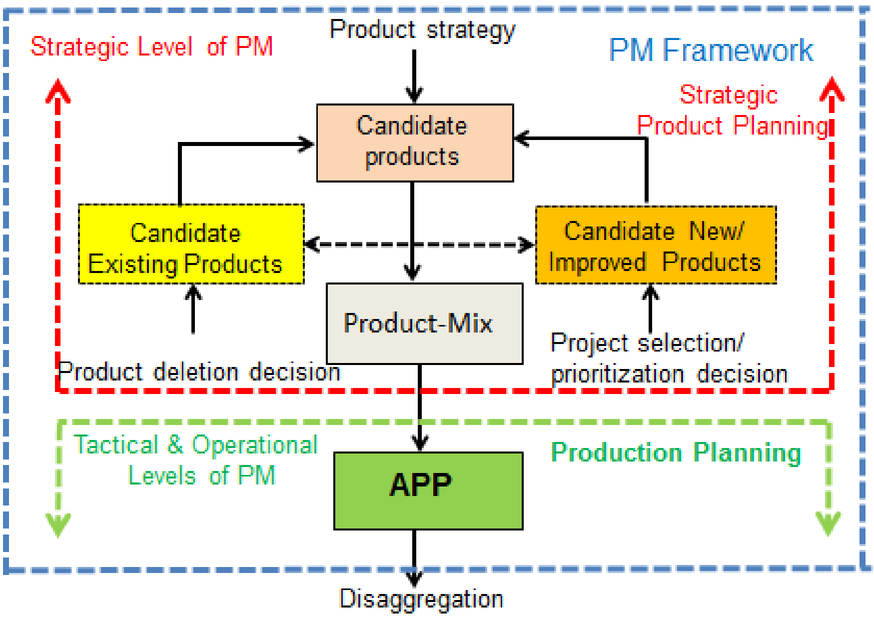

Figure 4.1: Product Mix Problem within Product Management Framework

As mentioned in Chapter 3, *aggregate production planning* (APP) is the major activity at the operational level of PM. It is knownt that, in the traditional approach, APP addresses the problem of deciding on the quantity and the mix of products to be produced and the staff level (Nahmias, 2001). Nahmias (2001) states that APP is generally considered as a macro planning tool for determining the overall workforce and production levels, and therefore macro planning strategies are seen as a fundamental part of the firm's overall business strategy in <u>production planning decision framework</u>. Therefore, APP is accepted as a <u>top level activity</u> in this latter framework, while it is seen as an operational level activity in product management framework which is accepted as a higher level of business activity.

Although APP is generally considered as a macro-planning tool, large companies may find APP useful at the plant level as well (Nahmias, 2001). Traditionally, APP begins with the forecast of demand (Figure 4.2). However, in PM decision framework, forecasting demand is the main task of the front line people, particularly sales department. Sales department prepares sales plan of the corporate which is based on these forecasts (see Appendix C: Flow Model, page 7) and shows the forecasted quantities and suggested prices of the products in this plan. Therefore, it is seen in tactical and operational planning and management level of the main frame of product management at the corporate level. This is the main reason why APP is considered at the operational level of our problem within the product management context.

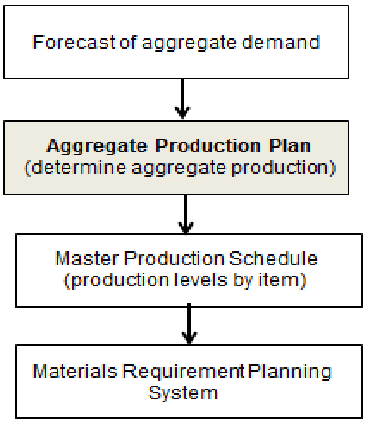

Figure 4.2: The Hierarchy of Production Planning Decisions (Source: Nahmias, 2001; p.116)

Forecasting demand is an important issue for the firms, which is used in their production planning to coordinate manufacturing capacity in order to be able to balance demand with supply. Vollman et. al (2005) considers forecasting issue in "demand management system" of "Manufacturing Planning and Control" (MPC) system in their book. Remember that it is also one of the most important problems considered in the product management of the companies studied in the field study. At this point it is worthy to discuss the role of demand management system in production planning framework, because it provides the link to the marketplace, plants, warehouses, and generally "customers", as the initial task in production planning. Demand management is defined as "*the activities that range from determining or estimating the demand from customers, through converting specific customer orders into promised delivery dates, to helping balance demand with supply*" (Vollman et al., 2005; p.17). So, it can be said that demand management plays a critical linkage role in both production management and in sales and operations in product management. The information provided through demand management to sales "is used to develop sales plans covering a year or more in a duration at a fairly high level of aggregation" (Vollman et al., 2005; p.24). Remember that in the proposed PM framework sales plans are prepared for the major product groups and presented to PRB for their strategic selection. Table 4.1 shows the summary of demand management framework in production management framework which is partly borrowed from Vollman et al. (p.30, 2005). It is indicated as the general principle that the nature of the forecast must be matched with the nature of the decision. In this table, the second column shows the strategic decisions, the third column indicates the tactical level decisions and the last column shows the operational decisions in *production management framework*. It is noted that source of the forecast can vary by needs of the company. In our research problem case, we do not consider MPS, but instead, consider APP in *product management framework.* Constructing a new plant, developing more supplier capacity, expanding internationally and other long-run company-wide considerations are some examples for the strategic decisions which can be considered both in product and production frameworks.

Table 4.1: Demand Management Framework

Nature of the Decision	Strategic Business Planning	Sales and Operations Planning	Master Production Scheduling (MPS)
Level of aggregation	Total sales or output volume	Product family units	Individual finished goods or components
Top management involvement	Intensive	When reconciling functional plants	Very little
Forecast frequency	Annual or less	Monthly or quarterly	Constantly
Length of forecast	Years by years or quarters	Several months to a year by months	A few days to weeks
Useful techniques	Management judgement, economic growth models	Aggregation of detailed forecasts, customer plans	Projection techniques(moving averages, exponential smoothing)

Hence, demand management activities should be in conformity with the strategy of the firm, the production capabilities and customer needs. Moreover, different manufacturing environments may shape differently the demand management activities. Below, the role of demand management in different production systems is described briefly referring to the definitions provided in section 2.1.3.

“In the make-to-stock (MTS) manufacturing environment, the key focus of the demand management activities is on the maintenance of finished goods inventories” (Vollman et al., 2005; p.21). This is because the customers buy directly from the available inventory. Moreover, there may be several locations from which the customers can buy the products. Therefore, the physical distribution of the products is an important concern in MTS environment in which replenishment of the inventories at each location should be determined. The important issue in satisfying the demand in MTS environment is to balance the level of inventory against the level of service to the customer. So, a trade-off between the cost of inventory and the level of customer service should be made. As a result, such a trade-off can be improved by better forecasts or knowledge of customer demand. Therefore the focus of demand management in MTS environment is on providing finished goods where and when the customers want them (Vollman et al., 2005).

"In the assemble-to-order (ATO) environment, the primary task of demand management is to define the customer's order in terms of alternative components and options" (Vollman et al., 2005; p.22). In ATO environment, customers should be informed of the allowable combinations. On the other hand, these combinations should be in parallel to the customers' desires in the marketplace. For example, a two-door versus four-door car, with or without antilock brakes are the options which may define customer's order in automative sector. In ATO environment, product configuration management is critical for the company. The inventory for such a company is the inventory of components, not the inventory of finished products. The main reason is that the inventory of finished products is usually greater than the inventory of components that are combined to produce the finished product. Consider for example, a personal computer for which there are 3 processor alternatives, 3 hard disk drive choices, 3 CD-DVD alternatives, 2 speaker systems, and 2 monitors available. Let us assume that all combinations of these 13 components are valid, then they can be combined into a total of 108 different PC configurations. Obviously, it is much easier to manage the forecast of the demand for 13 components than 108 computers. As a result, the primary task of demand management is to define the customer's order in terms of alternative components and options.

It is seen that the demand management in MTS and ATO environments considers the customer satisfaction from the appropriate inventory of finished goods and components, respectively. So, the company may know "what" the customers buy in MTS and ATO environments, but it may not know "if", "when", or "how many". On the other hand, in the make-to-order (MTO) manufacturing environment, company may not know "what" the customers will buy. Therefore, to get the information about the product specifications from the customers is an essential task in order to translate them to manufacturing terms in the company. In this environment, demand management task requires to determine how much engineering capacity is necessary to meet the future demand of customers. More generally, capacity management issue is considered as the most important task in MTO environment.

The goal of APP is to develop a production plan for the firm that maximizes profit over the planning horizon subject to constraints on capacity. The major simplifying assumption is that the demands are treated as known constants. APP is closely related to hierarchical production planning, in which purchasing, production and staffing decisions are made at several levels in the firm. In this approach, APP is accepted on the existence of an aggregate unit of production, which depends on the context of particular planning problem. For APP purposes, the following product hierarchy is recommended (Nahmias, 2001):

1. *Items*. They are defined as the end products to be delivered to the customer (e.g an individual model of washing machines).
2. *Families*. These are defined as a group of items that share a common manufacturing set up (e.g all washing mashines).

3. *Types*. They are groups of families with production quantities that are determined by a single APP (e.g Major Household Appliances).

Figure 4.2 shows the hierarchy of production planning decisions in parallel to above product hierarchy. Nahmias (2001) makes an important remark about this aggregation scheme: He states that such an aggregation method will not necessarily work in every business organization. He concludes that the aggregation method should be consistent with the firm's organizational structure and product line. As a result, it is understood that the definitions and implementations of APP can be adopted or changed to the problem situations accordingly. In short, our problem is formulated in view of this flexibility.

Considering this perspective of the Product Mix Problem, strategies formulated by the executive (top level) management of the company at the strategic level propose the execution of the parameters for the *families* of products. In other words, this level of the mix of the products will result in the mix of the families of products. As an example, let us consider a manufacturer who is a producer of consumer durables goods. The product profile (product range) for such a company is assumed as the composition of different product lines ("types" in Nahmias' definition) which is illustrated in Figure 4.3.

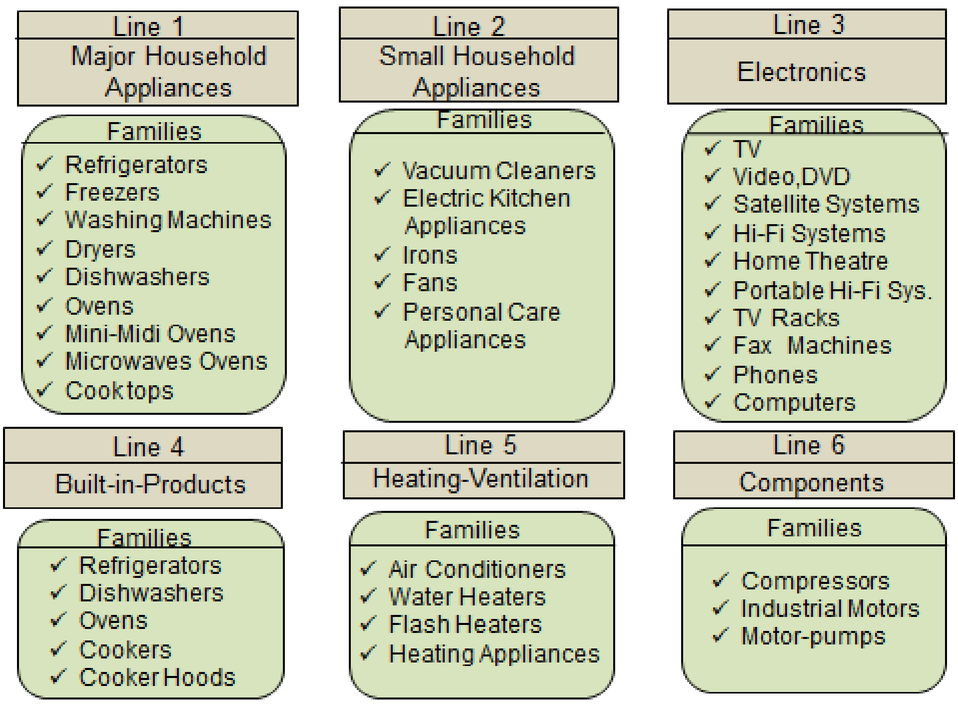

Figure 4.3: Product Profile (Product Range) for a Typical Manufacturer of Consumer Durables Goods (Source: Field Study-Company D)

Note that each product line is composed of the product units which are technologically different, serve to the same target market and have similar functionality. Traditionally, *product mix* is defined as the *entire set of the products* produced by the company (Steinhardt, 2010). In this case the composition of all the lines represent the product mix of this company. However, depending on the size of the company and the purpose of the management, product mix can be considered for each product line (Haines, 2009). In that case, the composition of families of products is defined as the product mix. Each family under the product lines are the product units which have the same technological foundation and each family has different types, styles, or models of product units which are called as *product variants* (Steinhardt, 2010). Similarly, each family can be considered as the mix of the product variants depending on the size of the company and the purpose of the management. Let us consider the "white goods" aggregation scheme of Company D as another example which represents the purpose of Company D in their product hierarchy presentation. The product line "white goods" is depicted in Figure 4.4.

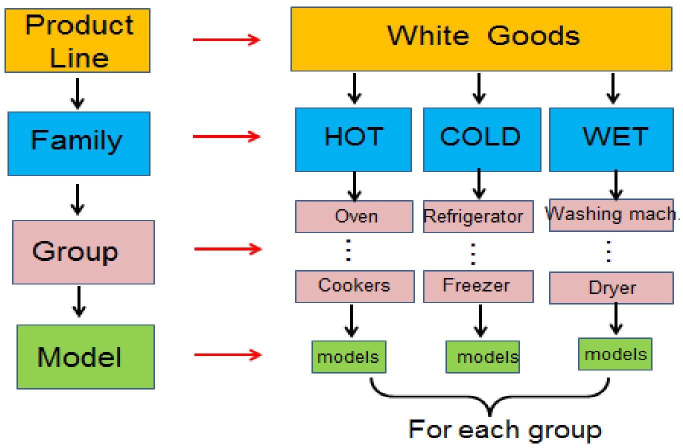

Figure 4.4: Product Aggregation Scheme (Product Hierarchy) of Company D

In Company D, families are composed of homogeneous groups. *Homogeneous group* is defined as *the group of products which has the same production technology, the same assembly line and the same key components.* The key components are "volume", "carcase" and "boiler" for the refrigerator, dish washer and washing machine respectively. For example, if the volume of the refrigerator changes, Company D uses different production technology or different assembly line. In such a case, the mix of different homogeneous groups in a family can be questioned by the company in order to consider the financial performance of these groups.

In our case, we assume the product mix as the mix of the lines and/or families of the product units believing that the definition and execution of the parameters of the problem are more meaningful at the strategic level decision making process.

4.1.2 Complexity of the Problem

Regarding the product management, the sources of complexity are outlined in section 2.1.5. These complexity sources are directly related, and hence, define the complexity of product mix problem since it exists in the boundary of the framework of product management. Thus, associated with the product mix decision problem, the sources of complexities can be outlined as follows:

1. Strategic alignment
2. Scarcity of resources
3. Product interactions
4. Uncertainty

Strategic alignment is considered in the formulation of the product mix decision problem through the fundamental input component of the product mix problem, namely, the set of candidate products. Product strategy of the corporate is reflected in selecting those candidate products. So, the strategic alignment issue can be considered when the set of candidate products are constructed as the input of the product mix problem. *Scarcity of resources* is considered by the limited production resources as in any product mix problem. *Product interaction* is one of the major complexities in the product mix problem. *Substitutability* and *complementarity* are two major interaction types among the products. Moreover, *cannibalization effect* of any product, which can occur among substitutable products, if it is selected into the mix, should be considered in making the product mix decision. Studying different candidate products sets while getting the solution to the product mix problem may give an insight to the management regarding this issue. The *uncertainty* is crucial for the formulation of the product mix problem. In our case, market uncertainties, regarding the costs and prices of products and also demands for the products, are the major sources of uncertainty to be considered in the formulation of the problem. Finally, note that we consider the families of (end) products (variants) of the company in the product mix problem of our study, in the sense that we do not have evolving nature of the NPD problem which necessarily requires the consideration of dynamic nature of the product management problem. So, we consider a single period product mix problem in our study. However, our problem can be extended to the multi-period case.

At the moment, our major concern is uncertainty in dealing with the product mix decision problem. We discuss this issue more in explaining the framework of the proposed decision support system. The way of handling this issue is explained in formulation phase of the problem.

4.1.3 Interactions with Other Decision Making Problems

Product mix decision making involves the simultaneous determination of the answers to the following major questions:

1. Which products are to be produced from a given set of candidate products?
2. What quantities of those products are to be produced?

The answer to the first question requires to know the set of candidate products from which the best products should be selected. Hence, to determine the set of candidate products is another major decision making problem which is closely related to the product mix problem. The set of candidate products are composed of both new and/or improved products of existing products and the kept products already existing in the line. Actually, new and/or improved products of existing products can be considered as the product investments of the company. Additionally, management of the company should evaluate the existing products in order to make product withdrawal/deletion decision. Figure 4.5 illustrates the composition of the set of candidate products.

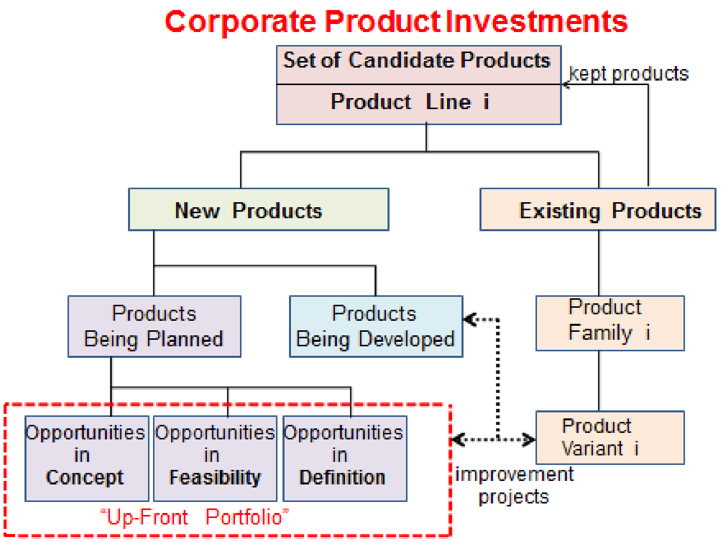

Figure 4.5: The Composition of the Set of Candidate Products (Adapted from Haines, 2009)

The answer to the second question requires the consideration of several issues. First, the company should determine sources of the products. Therefore, the question of "Who will produce?" should be answered by the company. If the source of the products is inhouse production, the market uncertainty and capacity issues should be considered. In sum, the framework of the product mix problem within product management context requires to consider the interactions of some other decision problems of product management. The major interdependencies of product mix problem with the other product management issues are shown in Figure 4.6.

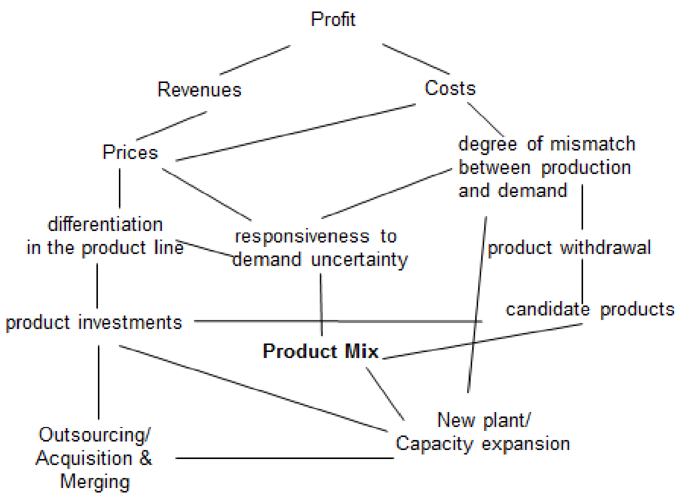

Figure 4.6: Major Interdependencies of Product Mix Problem within Product Management Context

One can observe from Figure 4.6 that most of the problems can be integrated under the headline of "product investment planning" of the company. Product investment planning implementation decisions and product mix decision together determine the company's responsiveness to demand, or more generally, market uncertainty, and hence improve the ability to maximize the company's profits. The framework of the proposed product mix decision support system (DSS) is developed focusing on this main idea which is explained in detail in the next section.

4.2 FRAMEWORK OF THE PROPOSED DECISION SUPPORT SYSTEM

4.2.1 Purpose of the Proposed Decision Support System

In a competitive environment, product mix determination is very critical decision for companies. Often, companies try to handle this problem by expanding their product lines. Competitors' pressure and willingness to respond to detailed customer preferences may lead the companies overextending their product lines which may have negative impact on manufacturing effectiveness (Quelc and Kenny, 1994). Moreover, overextended product lines can overload customers with information, which often makes it more difficult for them to find their favored product (Kuester, 2000). In fact, instead of extending product lines, extending the profits of the company is important. Product mix determination requires first the selection of right products as candidates. Then, the mix of products should be evaluated in terms of profits in order to achieve the maximum profit for the company. The selection of the right products is a difficult decision making problem. In case the decision maker would know the profit generated by the optimal mix of the products selected, she would easily decide on the products which the company should offer to the market to make their customers satisfied and earn maximum profit. Besides, the existence of such a decision mechanism would also help making the decision on budgeting properly. As a result, in this study, we aim to present a decision method to aid the decision makers

- to determine the optimal mix of the predetermined candidate products, so that using the proposed decision mechanism by changing the set of candidate products several times as required; the selection of right products to be offered to the market with the maximum profit can be made by evaluating the profit values under each of the different cases considered.
- In addition to this purpose, the proposed decision method can be used for budgeting purposes.
- It also provides a support to the decision maker for different product planning issues under "what-if" type of questions.
- Finally, it provides a valuable input for the demand management system of APP work.

It should be noted that uncertainties are a major element in any real-life decision problem where the information about the presence and the future unfolds iteratively. So, any system which is designed without considering uncertainty may not sufficiently reflect real life.

If uncertainty is not taken into consideration, the outputs of the decision support system might mislead the decision makers because the chosen product which is found to be the best one maximizing the sales revenues or profits by such a system might prove itself to be the poorest choice of all in reality later on. Therefore, uncertainty which is a significant attribute of the real life should be taken into consideration.

In reality, firms are faced with unknown demand for their products, and likewise the prices and costs of the products cannot be known precisely beforehand in a competitive environment. Therefore forecasting demands, prices and costs is a difficult task which is always subject to error. Sales of the products depend on unknown demands, and hence, profits derived from the sales also rely on unknown demands for the products, which in turn predict inaccurate and/or misleading results for the firm. In short, uncertainty is the major complexity of the problem and it may cause wrong decisions for the products to be chosen in the product mix of the company which results in sub-optimality regarding the financial performance measures of the firm.

As it was discussed briefly before, the primary function of demand management system in production management framework is forecasting demand in uncertain environmental conditions. The types of uncertainty also differ with respect to the different manufacturing environments. In MTS case, uncertainty is largely in the demand variations around the forecast. As it is known, the company having the MTS production system sells its products from the available inventory. So, these companies hold stocks in order to provide products to their customers. In ATO case, "the uncertainty involves not only the quantity and timing of customer orders but product mix as well" (Vollman et al., 2005; p.26). If timely and honest customer order promises are assumed, it can be said that for the MTO environment, the uncertainty of quantity and timing of customer order may not be high. In this case, the level of company resources and capacity adjustment issues should be the concern of the company to produce the products (Vollman et al., 2005). It should be noted that firms may produce their products in a combination of these environments. In all these environments, the most important issue is the quality of the information gathered in demand management system to enhance the performance of the firm. Therefore, to support the decision makers with high quality knowledge on time is very important in their real life decision making situations.

Our study considers a ***product mix problem under uncertainty*** of demand, product price and production cost parameters. This implies that the problem is more realistic since demand, price and cost forecasts are not precise, and they are usually given as more than a single value. Furthermore, due to demand uncertainty it may not be possible to meet all demands with the firm's available capacity. In our study, we assume MTS production system in which volatile demand conditions in the market appear as variations in demand of the "finished products". Since we do not deal with the "component" level of the products, ATO production system does not suit the case under consideration. It can be stated that MTO production system can be partly considered in our study, only by the inclusion of predetermined level of taken orders. Engineering and production capacities should be studied further in MTO case.

In order to deal with uncertainty, we develop a scenario-based scheme by generating different scenarios focusing on the major inputs or sensitive parameters of product mix model. The problem is introduced in detail further in the subsequent sections.

So, *our* ***primary goal*** *in modeling the product mix problem is to present an approach of dealing with uncertainty and the methodology developed for this purpose*. Therefore, the product mix optimization model is kept simple to capture the desired importance on the methodological approach which is unique for this problem to the best of our knowledge. Hence, it represents the major contribution of this Ph. D study. Although the approach has some similarities to simulation optimization approaches such as the one developed by Kaya et al. (2011), which considers an investment planning problem under uncertainty for a telecommunications company, these approaches have significant differences from ours.

By definition, a decision support system, which we aim to develop for this specific problem, requires a practical implementation for the decision makers, and it should provide fast and reliable results in their decision making process. Consider the following comments and conclusive remarks given in Kavadias and Chao (2008):

- *"Management researchers and practitioners have proposed many methodologies for tackling the complexity of the portfolio selection problem. The literature review suggests that quantitative research efforts have been restrained at the tactical level of analysis and they have not been widely adopted in practice because of the complexity associated with the decision"* (pp.154-155), and

- *"Although mathematical programming is a sound methodology for optimization problems, and it has been successfully applied in several specific cases, it has not found widespread acceptance by practitioners. This gap stems partly from the complexity and sophistication of the methods, which are difficult to understand and to adopt for people who are not trained in OR, and partly from the lack of transparency and from the sensitivity of the results to changes of the problem parameters. In addition, mathematical formulations in order to retain some level of analytical tractability they rarely account for dynamic decision making"* (p. 152) (i.e., different points in time).

Our ***secondary goal*** *in modeling is to provide an "effective" support to the decision makers, presenting computationally efficient and a practically implementable methodology in their decision making process, which allows obtaining the best solutions in a reasonable time.* The following subsection provides the working mechanism of the proposed DSS in the product management context.

4.2.2 Working Mechanism of the Proposed Decision Support System

The working mechanism of the proposed product mix DSS is illustrated in Figure 4.7. In this broad description, the product mix related problems are integrated under the headline of "investment planning". These problems related to the product mix problem present cases for generating the scenarios. In other words, the formulation of strategies in PM context is represented by the formulation of these scenarios of the strategic product mix problem in the proposed DSS. Thus, the major complexity, namely, uncertainty is handled through "scenarios" in the proposed DSS.

Formulation of Scenarios:

Let us consider a few cases to describe the formulation of scenarios in the working mechanism of the proposed DSS:

- As mentioned above, candidate product selection is another major problem in product management context. The proposed DSS allows evaluating different sets of candidate products with respect to the profits generated by them. Thus, the products in the pipeline of the company can be evaluated in different sets of candidate products which can support the "prioritization" decision or "time-to-market" decision.
- Besides, "cannibalization" effects of the products can be evaluated by constituting different sets of candidate products and using the proposed DSS. As it is known, cannibalization effect can occur among the substitutable products, and a product/family line is constituted by the substitutable products by definition. If company considers a new product introduction to the existing line, a new set of candidate products should be defined. The profitability of this set can be compared with the case in which this new product does not included. If newly introduced product cannibalizes the existing substitutable product which has generated higher level of profit previously, the expected profit of the new set can be lower than the one in the previous case. It should be noted that this case is more meaningful at the family product level.
- Similarly, the proposed DSS provides the results which enable the decision maker to decide on outsourcing versus in-house production of the products considering different sets of candidate products. Although we handle the product mix problem after the sourcing decision is made, an analysis of "make" decision of the products considered for outsourcing can be made by means of the proposed method. For this purpose, the products considered for outsourcing are included in the set of candidate products. After getting the results of this analysis, a further economic analysis can be done for "buy" decision. Also the analysis for the case without the

products considered to be outsourced should be made, and the results should be compared for the final outsourcing decision.

- The company can question the profitability of establishing the new product line in the product-mix. Note that this case requires the inclusion of investment modeling in the case under consideration. Alternatively, such a financial analysis can be done separately and can be injected to the method proposed here.
- The company can test the capacity expansion investment option for profitable products by trying different capacities in finding the optimal product mix and obtaining the information about the profit at the optimal solution. But the capacity expansion investment costs have to be handled separately in an investment analysis.
- Apart from the physical investment option, the company can question the "entrance of a new market versus market penetration" strategic decisions with the existing products of the company.

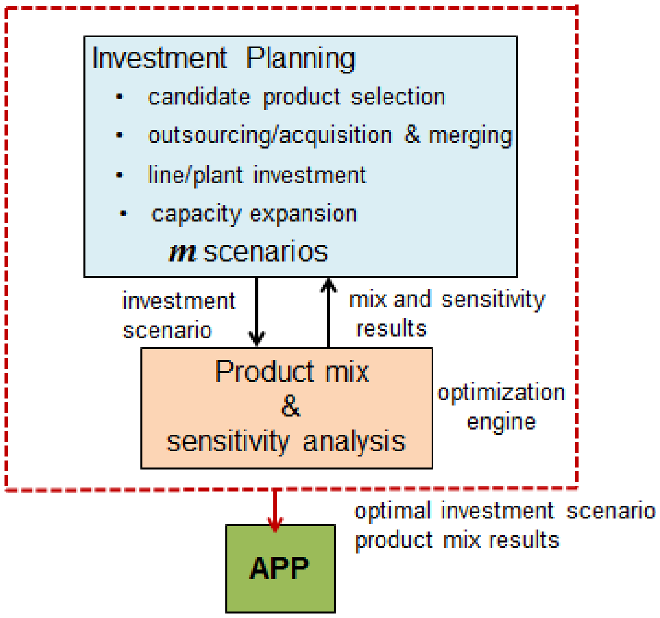

Figure 4.7: The Working Mechanism of the Proposed DSS

The expertise of the managers can be transferred through the formulation of the scenarios. Therefore, the approach used in the proposed DSS allows evaluating the scenarios generated by the judgments of the management of the company. This characteristic of the proposed DSS describes a method for interactive decision-making of product mix problem. Note that according to the investment scenario generated by the decision maker, some modifications can be considered in the product mix model.

Each investment scenario is evaluated through the product mix model and related information can be generated by the sensitivity analysis. The product mix model works as an optimization engine in the proposed DSS. It is used under each scenario developed to find the optimal product mix under that scenario. Then these product mix solutions are tested under all scenarios to find the most robust product mix that yields consistently high profits over all scenarios. The latter product mix and expected profits and ranges of profits can be chosen by the decision makers as inputs for APP so that disaggregation of this mix is considered for detailed production planning of the company. Thus APP may start with the optimal product mix results in the proposed approach. It means that the results provided by the proposed DSS improve the traditional demand management system of APP work which assumes deterministic demand values.

A well-developed demand management system within the production management system brings significant benefits to the company. In this case, capacity and the production of the company can be better managed and controlled. The capabilities of the firm can be developed better with better information. Additionally, the physical distribution activities can be improved significantly.

Appropriateness of the Proposed Approach for Different Types of Production Systems:

Remember that demand management activities are handled with the Sales and Operations (SOP) in PM framework (Appendix C: Flow Model, p.7). In these activities all sources of demand must be accounted for quantity in a certain planning period. It means that it may not be sufficient to simply determine the market needs for the product. To get a complete picture of the requirements for the production system, manufacturing capacity, engineering resources, material needs, pipeline profile, quality assurance needs and promotional requirements should be studied. All these issues are shown Sales and Marketing Plans. In the proposed DSS approach, product mix model is an appropriate tool for considering these requirements to communicate with the demand management system and SOP. It is essential to use proper units in this communication. Choosing the appropriate measures can vary with different production systems. For example, determining the capacity requirements can be different in these manufacturing environments. For instance, material capacity may be the most important in a MTS company. In this case, it should be included in product-mix model for such a company. Production capacity may be machine hours or labor hours in MTO case. In short, the product mix model can be modified in accordance with the significant measures for the company.

Vollman et al., (2005) states that the nature of information or demand management communication activity with SOP for different manufacturing environments is as follows:

- In MTS; Demand forecasts
- In ATO; Demand forecasts, product family mix
- In MTO; Demand forecasts, engineering (capacity)

SOP may "develop plans by product families, geographical regions, organizational units, or even combinations of these and other categories" (Vollman et al., 2005; p.25). As mentioned before, we assume MTS manufacturing environment in our study. In this case, the set of candidate products are constituted by the finished products. The main task of SOP is to get the reliable forecasts for aggregate units for these finished products. These results constitute the initial step in APP. SOP, after getting the results of APP, prepares the sales budget with the suggested prices to present the PRB of the company. In ATO manufacturing environment, the possible configurations of the components of the products can be grouped as the candidate family products if the number of possible configurations is not too high. In such a case, the proposed method can be used to get the optimum mix of families. Similarly, if the set of candidate products are properly constructed, the method proposed here can be used in MTO manufacturing environment. The modification in product mix model which include more detailed considerations in capacity issues of the company may require in this case.

As a result, the proposed DSS approach provides the major input to APP through the product mix model. The best result provided by this DSS is the optimal line or family mix for the company. Thus, the company starts with this result to APP work in production management, SOP may develop plans based on this result, regardless of the environment. In other words, the proposed approach is appropriate for different manufacturing environments. The most important issue is the quality of information/knowledge gathered in demand management system to develop APP and SOP plans in all these environments. So, the proposed approach improves the quality of this information by handling the issue of uncertainty.

4.3 FORMULATION OF THE PROBLEM

4.3.1 Assumptions

For a moment, let us consider the basic structure of PM framework depicted in Figure 3.10. As it is seen in this figure, operating assumptions in PM context should be considered in formulating the product mix problem. Operating assumptions of this research problem can be considered as general and company specific. The following general operating assumptions are considered in PM context:

1) The company is a commercial enterprise in the sense that it is a profit organization.
2) The primary business of the company is manufacturing.
3) The industry in which company operates is competitive.
4) The company has a formal (or well-structured) product management environment in the organization.

In this context, product mix problem is formulated considering the company specific assumptions regarding the following problem components:

- Product profile,
- Market profile,
- Product-market relations,
- Manufacturing environment (make-to-order, make-to-stock),
- Supply chain structure/channel map,
- Management/organization.

These problem components are explicitly described in modeling.

4.3.2 Formulation Approach

In general terms, the formulation and solution approach of the product mix problem under uncertainty can be seen as similar to the "simulation optimization approach". The DSS model embodies two basic types of formal models, namely;

- Deterministic Product Mix Model, and
- Simulation Model.

The first model represents a deterministic approach and constructs the decision support system that will take prices, demands and costs of the products as well as the production capacity as given and suggests the optimal product mix. The simulation model represents the probabilistic approach. In this approach the system is upgraded to another one which considers the uncertainty in the parameters mentioned above. Optimal product mix solutions are found using the deterministic model repeatedly under various scenarios defined as possible realizations of the uncertain parameters. Then, these optimal solutions are tested under the same set of scenarios and their performances are measured. The final step requires the analysis of these results by using the various solution approaches to get the optimal product mix. This approach is illustrated in Figure 4.8.

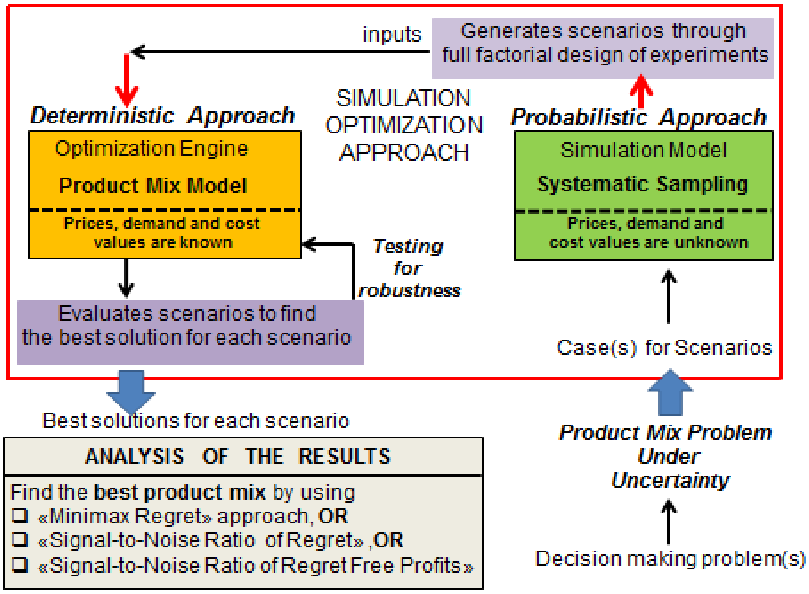

Figure 4.8: Formulation Approach of the Product Mix Problem under Uncertainty

In the subsequent section, the *Deterministic Model* and the *Probabilistic Model* are presented and the solution approach is explained in detail.

4.3.3 Models

4.3.3.1 Deterministic Model

The deterministic model works as an optimization engine for the probabilistic model in the framework of the proposed DSS (See Figure 4.8). In this subsection, the mathematical model of the deterministic approach is presented under the "company specific assumptions" established for a typical manufacturing company.

Problem Statement:

In the PM decision framework, we consider a typical manufacturing firm having a well-established organizational and managerial structure and efficiency, having the necessary access channels for the distribution of the products, and having the following product, market, and manufacturing environment profiles:

Product Profile:
It is assumed that the company is a multi-product producer. These products are considered in a certain aggregation scheme as described in Figure 4.4. Thus, the proposed DSS suggests the optimal mix of families of in the product line of, say, "white goods". Note that the company may question the "optimal mix of groups" in the family of, let us say "Hot". The appropriateness of the proposed DSS in different product schemes is discussed in the final Chapter of the study in detail.

Market Profile:
A typical multi-product company may serve its products in different markets. For example, Company D in our field study, sells certain products to certain countries, and some of the products are served only to the national market. Therefore, the proposed DSS model considers a multi-market company.

Product-Market Relations:
Product-market relations simply indicate which product(s) are sold in which market(s). As an example, let us consider a case for the Company D as illustrated in Table 4.2.

Table 4.2: Description of Product-Market Relation

Product Family	***National Market***	***Global Market***
HOT	✓	
COLD	✓	✓
WET		✓

In this descriptive example, "Hot" family is served only domestically, and "Wet" family is exported and not produced for national market, and "Cold" family is produced for both national and global markets. Note that the markets can be disaggregated for special purposes of the company. For example, Company D can disaggregate the Global market considering the individual countries, like Germany, United Kingdom, France, Romania, Litvania, etc. Also, instead of countries, the regions can be considered for structuring the markets. As an example, Company D has consolidated the markets of Germany, United Kingdom and France as "West Europe" market. Thus, depending on the purpose of the company, countries, regions, or market segments can be used in structuring the markets.

Manufacturing Environment:
As discussed in working mechanism of the proposed DSS approach, the major input item "the set of candidate products" can be considered differently for these different manufacturing environments through the formulation of scenarios. For example, different products having different configurations can be determined by the management in ATO manufacturing environment to be considered in the candidate products set. The interactive decision making characteristic of the proposed approach allows these formulations. Besides, deterministic product mix model can be adapted to different manufacturing environments. Since inventory management is important in MTS and ATO manufacturing environments, the mathematical model can include more detailed cost structures to handle this issue. On the other hand, committed orders in MTO manufacturing environment can be handled by the inclusion of lower bounds for the quantity to be produced. In MTO environment, the capacity issue may be more important for the company. Therefore, capacity requirements and availibility of the resources of the company can be considered in detail in modeling. In addition to this, capacity related scenarios can be formulated and tested in the proposed DSS through the deterministic product mix model.

For a single predetermined period of time, the product mix problem under consideration asks the following major questions which are translated into a type of decision variable in our deterministic product mix model. Hereinafter, this model will be named as the *Basic Model* in the total framework of DSS model.

a) Which feasible product combinations should be selected from a set of candidate products for production for each marketplace for the specified period of time?
b) In what quantities should the selected products be produced for each marketplace for the specified time period?

The input/output structure of the Basic Model is depicted in Figure 4.9.

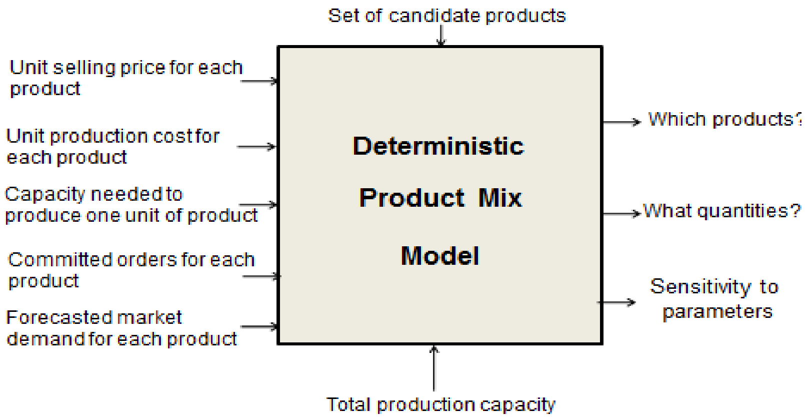

Figure 4.9: Input-Output Model of Deterministic Product Mix Model

Mathematical Model:

The outputs of the model are:

1) The optimal set of new/improved products (lines/families) and existing products (lines/families) to be kept in the product mix for each market in which this product set is sold.
2) The optimal amount of products (lines/families) to be produced for each market where these products are sold.

Since the main focus of the study is to guide product management decisions and to show the methodology developed for determining the best product mix under uncertainty, the deterministic model is kept as simple as possible. Therefore, a comprehensive optimization model is avoided. Thus, for the sake of simplicity, the model is constructed under the following assumptions:

1. Products are independent from each other.
2. All of the products produced are sold (zero inventory).
3. Company retains a stable workforce (out of planning consideration).
4. Single planning period is taken into consideration (say, one year).

<u>*Notation and Definitions:*</u>

i : identifying number to denote candidate products which are composed of new/improved products and existing ones, $i = 1,2,\ldots,k$

j : identifying number to denote markets in which products are to be sold, $j = 1,2,\ldots,J$

Decision Variables:

x_{ij} : number of units produced of product (family) i for market j

Parameters:

m_i : number of markets of product (family) *i*,

M_i : a set of markets in which product (family) *i* is to be sold

P_{ij} : unit profit of product (family) *i* in market *j* , and

$P_{ij} = SP_{ij} - PC_i$, where

SP_{ij} : (average) unit selling price of product (family) *i* in market *j*

PC_i : (average) unit production cost of product (family) *i*

c_{ij} : (average) capacity (machine hours) needed to produce one unit of product (family) *i* in market *j*

C_i : total production capacity (machine hours) for product (family) *i*

d_{ij} : total demand for product (family) *i* in market *j* (upper bound)

l_{ij} : minimum demand/committed order of product (family) *i* (lower bound)

Objective:

The objective of the problem is to maximize the total profit of the product lines/families composed of the selected products. So, the Basic Product Mix Model is as follows:

$$\text{Maximize} \quad \sum_{i=1}^{k} \sum_{j \in M_i}^{m_i} P_{ij} \times x_{ij}$$

Subject to

Capacity constraints:

$$\sum_{j \in M_i} c_{ij} \times x_{ij} \le C_i \ , \quad i = 1, 2, ..., k$$

Demand constraints and committed orders:

$$l_{ij} \le x_{ij} \le d_{ij} \ , \quad x_{ij} \text{ integers } , \ i = 1, 2, ..., k \quad j \in M_i$$

The model presented above is simply a bounded "knapsack" problem which is a well known combinatorial optimization (Johnson and Montgomery, 1974; Ravindran, 2008). These types of problems require complex solution algorithms and computational effort.

The standard knapsack problem in the literature is defined as follows:

> *"We are given an instance of the knapsack problem with item set N, consisting of n (or k) items j with profit p_j and weight w_j , and the capacity value c. Usually, all these*

values are taken from the positive integer numbers. Then the objective is to select a subset of N such that the total profit of the selected items is maximized and the total weight does not exceed c" (Kellerer, Pferschy and Psinger, 2004, p. 2).

Alternatively, a knapsack problem can be formulated as a linear integer programming (LIP) problem. The resulting problem is the simplest non-trivial integer programming model with binary variables, only one single constraint and only positive coefficients. Adding the integrality condition to the simple LP puts KP into the class of "difficult" problems. Complexity is in the context of the solution methods or algorithms and their implementation or running time. There are several solution methods developed for LIP problems. Most of them can be grouped as follows (Ravindran, 2008):

- Enumeration techniques,
- Cutting-plane techniques, or
- A combination of these.

Ravindran (2008) points out that none of these methods is totally reliable in view of computational efficiency, particularly in cases of high number of integer variables. The efficiency of the solution method or algorithm is usually measured in terms of the running time of an algorithm. The most efficient algorithms are those so-called *poynomial time algorithms* (Kellerer et al., 2004). As mentioned in section 4.2.1, the secondary goal of this research is to develop an effective DSS which provides fast and reliable results to the decision maker. Therefore, we clearly prefer to have polynomial time algorithm for our problem. However, Kellerer et al. (2004) states the following:

"…there is very strong theoretical evidence that for the knapsack problem and hence for its generalizations no polynomial time algorithm exists for computing its optimal solution. In fact, all these problems belong to a class of so-called NP-hard optimization problems. It is widely believed that there does not exist any polynomial time algorithm to solve an NP-hard problem to optimality"…(p.14).

In order to decrease the level of computational difficulty, we assume the unit production capacity as follows:

c_i : (average) capacity (machine hours) needed to produce one unit of product (family) i

In this case, the capacity constraints of the model are as follows:

$$c_i \sum_{j \in M_i}^{m_i} x_{ij} \le C_i \ , \quad i = 1, 2, ..., k$$

Furthermore, considering the demand constraints, we can define

$$Z_i = C_i - \sum_{j \in M_i} l_{ij} \text{ for } x_{ij} = l_{ij}$$

Additionally, we can define a new measure of total capacity for product i, $C_i^{'}$, in terms of the total number of units produced and sold in all markets $j \in M_i$ which is given as follows:

$C_i^{'} = Z_i / c_i$

where c_i is the unit production capacity for product *i* which is indifferent of market *j* in this case. So the model can be transformed into the following form,

$$Maximize \sum_{i=1}^{k} \sum_{j \in M_i} P_{ij} \times x_{ij}$$

$$s.t$$

$$\sum_{j \in M_i} x_{ij} \leq C_i^{'}, \quad i = 1, 2, ..., k$$

$$x_{ij} \leq d_{ij}, \; x_{ij} \text{ integers}, \; i = 1, 2, ..., k, \quad j \in M_i$$

Although it can be easier to get the solution to LIP problem in the transformed case, it may still have a very long running time and therefore it may not good for practicle cases. On the other hand, as mentioned above, deterministic product mix model functions as the optimization engine of our probabilistic approach. Therefore, we need to obtain hundreds and even thousands of solutions in only one scenario (formulated problem case) by using the above model. In order to be able to get easier and faster solutions for our probabilistic model, we may consider the LP relaxation of the above model. In general, due to the computational inefficiency of LIP, LP relaxation is often used for solving LIP problems. Note that if all integer variables are allowed to take continuous values, a LIP problem becomes an LP problem, which is called its LP relaxation (Ravindran, 2008). It is known that the feasible region of a LIP problem is a subset of the feasible region of its LP relaxation. Therefore, the optimal objective function value of a LIP is not better than that of its LP relaxation. However, the optimal solution to the LP relaxation will not satisfy all the integer restrictions in general. Once the optimal solution to the LP relaxation is obtained, we may round the noninteger values of integer variables to the closest integers. The possibility of infeasibility caused by rounding can be tolerated in the case that an integer variable assumes large values so that rounding up or rounding down will not lead to a significant financial impact on the optimal value of the objective function (Ravindran, 2008). The LP-relaxation of our model is presented below.

LP Relaxation of Bounded "Knapsack" Problem:

$$Maximize \quad \sum_{i=1}^{k} \sum_{j \in M_i}^{m_i} P_{ij} \times x_{ij}$$

Subject to:

Capacity constraints:

$$c_i \sum_{j \in M_i} x_{ij} \leq C_i \; , \quad i = 1, 2, ..., k$$

Demand constraints and committed orders:

$$l_{ij} \le x_{ij} \le d_{ij} \quad , \quad i = 1, 2, ..., k \qquad j \in M_i$$

Nonnegativity constraints:

$$x_{ij} \ge 0 \qquad i = 1, 2, ..., k \qquad j \in M_i$$

Note that we use LP- relaxation of the model in numerical experiments considering regular time costs, single planning period, zero inventory, and stable workforce assumptions. Besides, the linear demand system is assumed.

4.3.3.2 Probabilistic Model

In this section, the probabilistic model is presented where uncertainty is treated via a scenario based scheme using simulation. In the proposed scheme, in order to make analysis in a probabilistic environment, different price, demand and cost realizations, or *scenarios*, are generated. We focus on the following methods of scenario generation in our probabilistic model:

a) systematic sampling, and
b) judgmental forecasting.

The scenarios generated through systematic sampling are called as *structured scenarios* in our probabilistic model. In addition to the structured scenarios, different price, demand and cost values can be defined by the management of the company through judgemental forecasting. These scenarios are called as *unstructured* or *extreme scenarios* in our probabilistic model.

Definitions:

We define the following *parameters* in the probabilistic model:

- k : number of products
- m_i : total number of markets in which product i is sold
- m : total number of different markets
- h_{ij} : jth market of product i; h_{ij} is 1 if product i is sold in market j, otherwise it takes the value 0.

The input-output model considered in the probabilistic model is described in Figure 4.10.

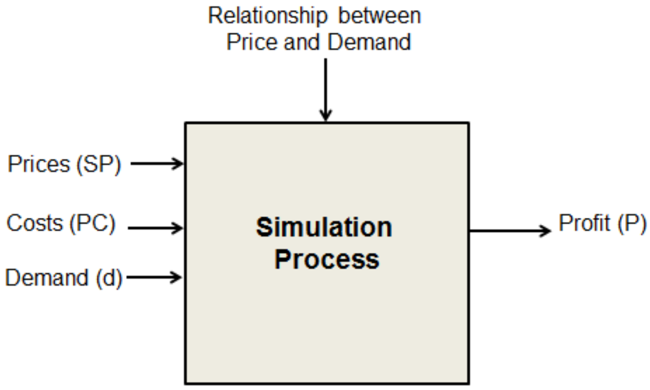

Figure 4.10: Input-Output Model of Probabilistic Model

Distributional Assumptions of Random Variables:

Referring to the input-output model in Figure 4.10, we consider the following random variables for each product *i* at each market *j* which are normally distributed for all products $i\ i = 1,2,\ldots,k$ and $j \in M_i$.

SP_{ij} : Selling price for product *i* in market *j*

$$SP_{ij} \sim N(\mu_{SP_{ij}}, \sigma^2_{SP_{ij}})$$

d_{ij} : Demand for product *i* in market *j*

$$d_{ij} \sim N(\mu_{d_{ij}}, \sigma^2_{d_{ij}})$$

PC_i : Production cost for product *i*

$$PC_i \sim N(\mu_{PC_i}, \sigma^2_{PC_i})$$

and, the response variable (or output) is profit P_{ij}.

Then, the 3-dimensional multivariate normal distribution has the following joint density function

$$f\left(\mathbf{Y_{ij}}\right) = \left(2\pi\right)^{-3/2} |\Sigma|^{-1/2} \exp\left[\frac{-\left(\mathbf{Y_{ij}} - \boldsymbol{\mu}_{\mathbf{Y_{ij}}}\right)^T \Sigma^{-1}\left(\mathbf{Y_{ij}} - \boldsymbol{\mu}_{\mathbf{Y_{ij}}}\right)}{2}\right]$$

where $\mathbf{Y}_{ij} = (SP_{ij}, d_{ij}, PC_i)^T$ is any point in the 3-dimensional real space, $|\Sigma|$ is the determinant of the covariance matrix Σ, and $\boldsymbol{\mu}_{\mathbf{Y_{ij}}} = (\mu_{SP_{ij}}, \mu_{d_{ij}}, \mu_{PC_i})^T$ is the mean of the distribution.

Relationships between Random Variables:

It is assumed that the random variables of price and cost of the products are independentfor the same product as well as for all products.Similarly, a product's price is assumed to be independent of another product's price or demand. However, the random variable of demand is assumed to be dependent on the price of the corresponding products. The functional relationship between demand and price random variables is assumed as linear. So, by the law of demand, the downward–sloping linear demand functions are considered for all products in all markets.

Let us remember the linear demand-price relationship in the literature which is presented in section 2.2.3. This linear model in matrix notation is represented as follows:

d = b – A (s), where **d** and **s** are the demand and price vectors respectively, **b** is a constant vector representing the vector of demand function intercept, and matrix **A** captures the demand sensitivity to prices. Note that all vectors are column vectors. This model represents the deterministic multiproduct case. For a single product *i*, *single demand function* is given as follows (Soon, 2011):

$d_i\ (SP_i) = b_i - a_{ii}SP_i + \sum_{j \neq i} a_{ij}\ SP_j$

In the case of *product independence*, we simply ignore the last term of the above equation.

In our multi-market probabilistic model, the above relation is reformed considering the market dimension in addition to the products as shown below.

Demand-Price Relation in Probabilistic Multimarket Model:

Assuming that the products are independent, the linear model for the random variables of demand and price for product *i* in market *j* can be written as follows:

$$d_{ij}(SP_{ij}) = b_{ij} - a_{ii,j}SP_{ij} + \varepsilon_{ij}$$

where

$SP_{ij} \sim N(\mu_{SP_{ij}}, \sigma^2_{SP_{ij}}), \quad \varepsilon_{ij} \sim N(0, \sigma^2_{\varepsilon_{ij}})$

ε_{ij} is the random error component which is considered in the experimental environment. Note that to determine the value of the response function at each treatment in simulation model requires the consideration of random error of the experiment. Generation of the combinations of these treatments and determining the levels of factors used in these combinations are discussed in the following subsection. Before passing this subject, let us show the general form of matrix notation of the individual product-market linear model of demand-price relation as;

$$\mathbf{d}_k = \mathbf{b}_k - \mathbf{J}_k\mathbf{S}_k\mathbf{h}_k + \mathbf{e}_k$$

Below the derivation of this general matrix notation for the multi-market probabilistic model is presented step by step including the definition of the notation.

- Define a binary "market" matrix **H**;

$$\mathbf{H} = \begin{pmatrix} h_{11} & \cdots & h_{1m} \\ \vdots & \ddots & \vdots \\ h_{k1} & \cdots & h_{km} \end{pmatrix}$$

so that the number of markets where product i is sold is $m_i = \sum_{j=1}^{m} h_{ij}$

- Define "demand" matrix **D**, and convert it into a column vector **d** with k partitions;

$$\mathbf{D} = \begin{pmatrix} d_{11} & \cdots & d_{1m} \\ \vdots & \ddots & \vdots \\ d_{k1} & \cdots & d_{km} \end{pmatrix} \qquad \mathbf{d}_k = \begin{bmatrix} d_{11} \\ \vdots \\ d_{1m} \\ \vdots \\ d_{k1} \\ \vdots \\ d_{km} \end{bmatrix}$$

- Define "intercept" matrix **B**, and convert it into a column vector **b** with k partitions;

$$\mathbf{B} = \begin{pmatrix} b_{11} & \cdots & b_{1m} \\ \vdots & \ddots & \vdots \\ b_{k1} & \cdots & b_{km} \end{pmatrix} \qquad \mathbf{b}_k = \begin{bmatrix} b_{11} \\ \vdots \\ b_{1m} \\ \vdots \\ b_{k1} \\ \vdots \\ b_{km} \end{bmatrix}$$

- Define the matrix **A** and **J** as follows:

$$\mathbf{A} = \begin{pmatrix} a_{11} & \cdots & a_{1k} \\ \vdots & \ddots & \vdots \\ a_{k1} & \cdots & a_{kk} \end{pmatrix}$$, and for independent products $$\mathbf{A} = \begin{pmatrix} a_{11} & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & a_{kk} \end{pmatrix}$$

$$\mathbf{J} = \mathbf{AH} = \begin{pmatrix} a_{11}h_{11} & \cdots & a_{11}h_{1m} \\ \vdots & \ddots & \vdots \\ a_{kk}h_{k1} & \cdots & a_{kk}h_{kk} \end{pmatrix} = \begin{pmatrix} a_{11,1} & \cdots & a_{11,m} \\ \vdots & \ddots & \vdots \\ a_{kk,1} & \cdots & a_{kk,m} \end{pmatrix}$$

and convert matrix **J** into a diagonal matrix with *k* diagonal partitions,

$$\mathbf{J}_k = \begin{bmatrix} a_{11,1} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \ddots & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & a_{11,m} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \ddots & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & a_{kk,1} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \ddots & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & a_{kk,m} \end{bmatrix}$$

- Define "price" matrix **S,** and convert it into a diagonal matrix with *k* diagonal partitions;

$$\mathbf{S} = \begin{pmatrix} SP_{11} & \cdots & SP_{1m} \\ \vdots & \ddots & \vdots \\ SP_{k1} & \cdots & SP_{km} \end{pmatrix} \qquad \mathbf{S}_k = \begin{bmatrix} SP_{11} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \ddots & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & SP_{1m} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \ddots & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & SP_{k1} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \ddots & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & SP_{km} \end{bmatrix}$$

- Convert matrix **H** and "random error" matrix **E** into column vectors with *k* partitions;

$$\mathbf{E} = \begin{pmatrix} \varepsilon_{11} & \cdots & \varepsilon_{1m} \\ \vdots & \ddots & \vdots \\ \varepsilon_{k1} & \cdots & \varepsilon_{km} \end{pmatrix} \qquad \mathbf{e}_k = \begin{bmatrix} \varepsilon_{11} \\ \vdots \\ \varepsilon_{1m} \\ \vdots \\ \varepsilon_{k1} \\ \vdots \\ \varepsilon_{km} \end{bmatrix} \qquad \mathbf{h}_k = \begin{bmatrix} h_{11} \\ \vdots \\ h_{1m} \\ \vdots \\ h_{k1} \\ \vdots \\ h_{km} \end{bmatrix}$$

- Obtain the matrix equation $\mathbf{d}_k = \mathbf{b}_k - \mathbf{J}_k\mathbf{S}_k\mathbf{h}_k + \mathbf{e}_k$

$$\begin{bmatrix} d_{11} \\ \vdots \\ d_{1m} \\ \vdots \\ d_{k1} \\ \vdots \\ d_{km} \end{bmatrix} = \begin{bmatrix} b_{11} \\ \vdots \\ b_{1m} \\ \vdots \\ b_{k1} \\ \vdots \\ b_{km} \end{bmatrix} - \begin{bmatrix} a_{11,1} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \ddots & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & a_{11,m} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \ddots & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & a_{kk,1} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \ddots & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & a_{kk,m} \end{bmatrix} \begin{bmatrix} SP_{11} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \ddots & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & SP_{1m} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \ddots & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & SP_{k1} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \ddots & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & SP_{km} \end{bmatrix} \begin{bmatrix} h_{11} \\ \vdots \\ h_{1m} \\ \vdots \\ h_{k1} \\ \vdots \\ h_{km} \end{bmatrix} + \begin{bmatrix} \varepsilon_{11} \\ \vdots \\ \varepsilon_{1m} \\ \vdots \\ \varepsilon_{k1} \\ \vdots \\ \varepsilon_{km} \end{bmatrix}$$

4.4 SOLUTION APPROACH

In many practical applications of scenario-based mathematical optimization models such as simulation optimization, discretization of continuous random variables is required to generate the scenarios. It is known that the objective function values obtained from a discrete approximation of the probabilistic variables become random variables (D'Errico and Zaino, 1988; Köksal and Fathi, 2003;Balibek and Köksalan, 2012; Better et al. 2008). Monte Carlo simulation is a commonly used method in generating the scenarios. This method of scenario generation is based on random sampling. As pointed out in the study of Balibek and Köksalan (2012), the quality of the scenario generation method is emphasized to make statistical inferences about the objective function values at a desirable level of confidence. Balibek and Köksalan (2012) use random sampling method for generating scenario instances, deal with the randomness in scenario generation, and develop a visual interactive method for scenario-based stochastic multi-objective problems in their study. The authors construct joint confidence regions for the objective function values using multi-variate statistical analysis of solutions obtained from their model. By the developed method, the effects of estimation errors in the scenario generation mechanism on the objective function values are demonstrated. In random sampling, a large number of scenarios is required to remove or minimize these estimation errors.

In our study, structured scenarios are generated through systematic sampling of levels of the problem parameters (factors) and design of experiments for use in a simulation study. Systematic sampling is based on a two-level full factorial design of experiment in our case. Each simulation run is performed according to a setup in the experiment. Each experimental setup or run corresponds to a scenario in which we have certain price, cost and demand realizations. So, under each scenario we can generate a product mix solution by using the deterministic product mix model. Then, it is possible to select the most robust solution that consistently yield high profits under all scenarios. In the subsequent section, scenario generation method is presented emphasizing the determination of the levels of factors and experimental design. Section 4.4.2 covers the solution procedure in findings the results. Finally, determining the optimal product mix is presented using the proposed performance criteria in section 4.4.3.

4.4.1 Scenario Generation

The settings of a factor in the experiment are called *levels* (Yang and El-Halik, 2009). For a continuous factor, as in our case, these levels correspond to different numerical values. For continuous factors, the range of variables is also important, because if it is too narrow, we may miss important and useful information. On the other hand, if the range is too large, the extreme values may give infeasible experimental runs. We have three factors (price, demand and cost) for each product at each market. Note that the cost factor is indifferent of market.

As mentioned before, we use systematic sampling to determine the levels of the factors. For this purpose, we use results of Köksal and Fathi (2003) and D'Errico and Zaino

(1988). In both studies, experimental design technique is discussed in statistical tolerancing analysis. Although the emphasis is on tolerance analysis, the techniques are generally applicable in the systems involving the evaluation of uncertainty to profitability predictions based on uncertain factors as in our problem case. In those cases, the important technical problem is to determine the probability distribution (or the moments of this distribution) of the response variable for a given set of factors which are statistically independent random variables. The methods used for solving this technical problem are listed as follows (D'Errico and Zaino, 1988; Köksal and Fathi, 2003):

1) Taylor-series methods
2) Monte Carlo methods
3) Numerical integration methods (quadrature methods)
4) Experimental design techniques (Taguchi's method)

The experimental design approach, which is attributed to Taguchi, is widely used due to its simplicity (D'Errico and Zaino, 1988). Taguchi's method is simply described as the procedure for assigning the levels for the factors considered in the experiments. To apply the method, it is assumed that the factors are statistically independent and normally distributed, and the system response function is known. In the original Taguchi's method, a three-level full factorial experiment is created and response variable is evaluated at all combinations of levels.

D'Errico and Zaino (1988) and Köksal and Fathi (2003) discuss the Taguchi's discretization approach. They state that a continuous random variable Y can be represented by a discrete random variable Y' so as to match the first few moments of them. If Y is normally distributed with mean μ and variance σ^2 then a two-point discrete distribution with equal mass at points $\mu-\sigma$ and $\mu+\sigma$ have the same first three moments as those of Y. Furthermore, if a two-level full factorial experiment of several independent normally distributed factors each at these two levels are conducted, then the first three moments of a linear function of these factors (and the first moment of a quadratic function of these factors) match with the corresponding sample moments of the function based on the experimental observations. Discretization at three or more levels with different weights are suggested by Köksal and Fathi (2003) and D'Errico and Zaino (1988) for better results. However, to keep the experiments to a minimum size we have chosen to experiment with two-levels in this study.

The factors and the response function of these considered in this study are given below.

- Price: $SP_{ij} \sim N(\mu_{SP_{ij}}, \sigma^2_{SP_{ij}})$
- Cost : $PC_i \sim N(\mu_{PC_i}, \sigma^2_{PC_i})$
- Demand: $d_{ij} \sim N(\mu_{d_{ij}}, \sigma^2_{\varepsilon_{ij}})$ and $\mu_{d_{ij}} = g(SP_{ij}) = b_{ij} - a_{ii,j} SP_{ij}$

  $d_{ij} = g(SP_{ij}) + \varepsilon_{ij}$, and $\varepsilon_{ij} \sim N(0, \sigma^2_{\varepsilon_{ij}})$

- Response function : *Profit = f (Price, Demand, Cost)= f* (SP_{ij}, d_{ij}, PC_i)

Note that our response function is a linear function of the factors. As a result, using the results of the study Köksal and Fathi (2003), we consider the typical levels of each factor as shown in Table 4.3.

Table 4.3: Levels of Factors

Factors	**High (H)**	**Low (L)**
Price	$\mu_{SP_{ij}} + \sigma_{SP_{ij}}$	$\mu_{SP_{ij}} - \sigma_{SP_{ij}}$
Demand	$g(SP_{ij}) + \sigma_{\varepsilon_{ij}}$	$g(SP_{ij}) - \sigma_{\varepsilon_{ij}}$
Cost	$\mu_{PC_i} + \sigma_{PC_i}$	$\mu_{PC_i} - \sigma_{PC_i}$

As mentioned above, the values for the levels for each factor can also be determined by management using judgmental forecasting approach. These levels are considered as "extreme scenarios" in our model. One of these latter scenarios is the one when all factors assume their mean levels. An example for a typical product (say *i*=1), the level matrix for multimarket probabilistic model is given in Table 4.4.

Table 4.4: An Example for Levels of Factors

Level Matrix for product i =1

			PC_1									
			H					L				
			$j=1$		...	$j=m_1$		$j=1$		...	$j=m_1$	
			d_{11}		...	d_{1m_1}		d_{11}		...	d_{1m_1}	
			H	L	...	H	L	H	L	...	H	L
$j=1$	SP_{11}	H	$g_{11}(H)_H$	$g_{11}(H)_L$	...	-	-	$g_{11}(H)_H$	$g_{11}(H)_L$	...	-	-
		L	$g_{11}(L)_H$	$g_{11}(L)_L$	...	-	-	$g_{11}(L)_H$	$g_{11}(L)_L$	...	-	-
...	...	...	...	...	...	...	...	...	...	...	...	...
$j=m_1$	SP_{1m_1}	H	-	-	...	$g_{1m_1}(H)_H$	$g_{1m_1}(H)_L$	-	-	...	$g_{1m_1}(H)_H$	$g_{1m_1}(H)_L$
		L	-	-	...	$g_{1m_1}(L)_H$	$g_{1m_1}(L)_L$	-	-	...	$g_{1m_1}(L)_H$	$g_{1m_1}(L)_L$

As an example, the full factorial design of experiments for two products which both are sold in two markets (k =2, m_1 =2 and m_2 =2) is partially illustrated in Figure 4.11.

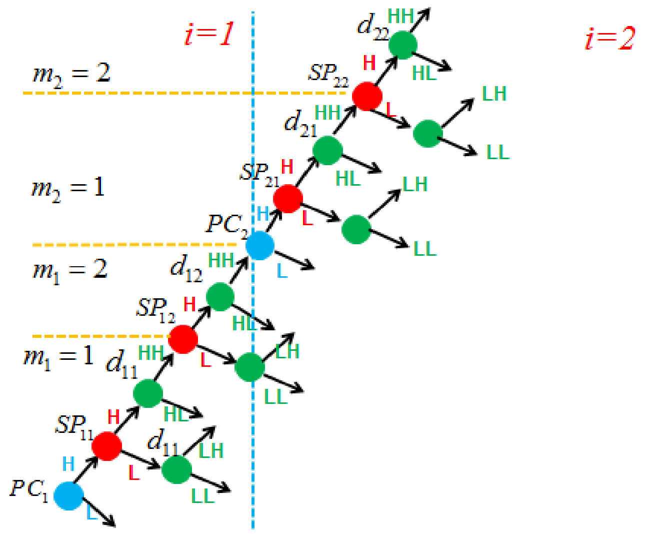

Figure 4.11: An Example for Full Factorial Design Tree

Observing Table 4.4 and Figure 4.11, it can be stated that cost of Product-1 may take either "High" (H) or "Low" (L) values in both markets "1" (m_1) and "2"(m_1) indifferently. While the cost of Product-1 takes, say High level, the price of Product-1 can take two different levels "High" (H) and "Low" (L). Let us assume that the price of Product-1 in market "1" takes "High" (H) value while its cost level is also "High" (H), in this case demand of Product-1 in market "1" may be either "High" (H) or "Low" (L). In short, the symbol "HH" denotes the "High" level of demand while the level of price is also "High". Similarly, the symbol "HL" shows the "Low" level of demand when the price level is "High".

For the example shown above the total number of scenarios (total number of level combinations) is $2\times(2\times2)^{m_1}\times2\times(2\times2)^{m_2} = 2\times(2\times2)^2 \times 2\times(2\times2)^2 = 1024$. So, for k products, and when each product i is sold in m_i markets, the total number of scenarios is as follows:

$$2\times(2\times2)^{m_1}\times\ldots\times2\times(2\times2)^{m_k} = 2^1\times2^{2m_1}\times\ldots\times2^1\times2^{2m_k} = 2^{2\sum_{i=1}^{k} m_i + k}$$

Although we consider product independency in our study, it can be noted that there is a more complicated situation for the product dependency case, because for each product, we need to consider both the pairwise interactions for the factors of price-demand and cost of the product itself, and the cross-price sensitivities of the demands of other products simultaneously. In this case the number of factors will be much higher than that of the product independency case.

4.4.2 Finding the Results

In this section, the solution procedure is given step by step and the solution approaches are explained. The solution procedure is described by the following flowchart depicted in Figure 4.12 below.

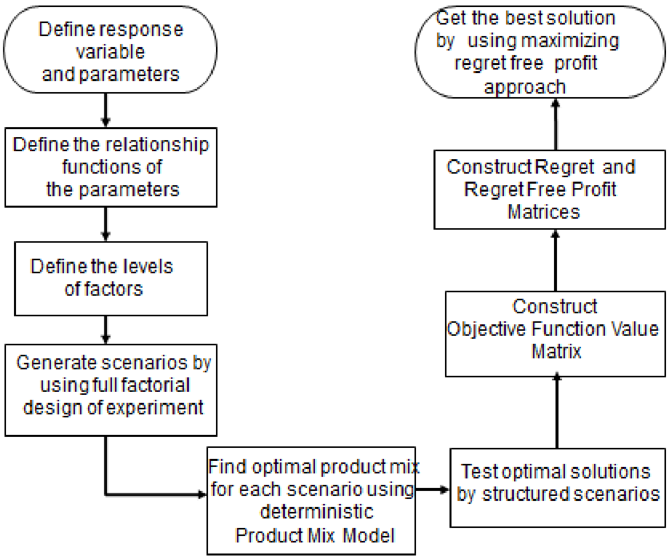

Figure 4.12: The Solution Procedure

In order to generate scenarios, we consider two levels for each factor, and a full factorial design of experiment is used. The first three steps in the solution procedure are described in detail in the previous section of the probabilistic model. So, we continue to explain the solution procedure with the fourth step, namely generation of scenarios. The *scenario matrix* is shown in Table 4.5.

Table 4.5: Full Factorial DOE-Scenario Matrix

	$i=1$						…	$i=k$						
$\neq$	PC_1	SP_{11}	d_{11}	…	SP_{1m_1}	d_{1m_1}	…	PC_k	SP_{k1}	d_{k1}	…	SP_{km_k}		d_{km_k}
1	H	H	HH	…	H	HH	…	H	H	HH	…	H	…	HH
2	H	H	HL	…	L	LH	…	H	H	HL	…	H	…	LH
3	H	L	LH	…	H	HL	…	H	L	LH	…	L	…	HL
4	H	L	LL	…	L	LL	…	H	L	LL	…	L	…	LL
	⋮		⋮			⋮		⋮		⋮			⋮	
⋮	L	H	HH	…	H	HH	…	L	H	HH	…	H	…	HH
	L	H	HL	…	L	LH	…	L	H	HL	…	L	…	LH
	L	L	LH	…	H	HL	…	L	L	LH	…	H	…	HL
n	L	L	LL	…	L	LL	…	L	L	LL	…	L	…	LL

$$n = 2^{2\sum_{i=1}^{k} m_i + k}$$

The total number of experiments (runs) in scenario matrix is $n = 2^{2\sum_{i=1}^{k} m_i + k}$. These are the structured scenarios. Extreme (unstructured) scenarios (n^*) can be added to the structured scenarios to obtain more alternative solutions (Table 4.6).

Table 4.6: Combined Scenario Matrix

	$i=1$						…	$i=k$					
$\neq$	PC_1	SP_{11}	d_{11}	…	SP_{1m_1}	d_{1m_1}	…	PC_k	SP_{k1}	d_{k1}	…	SP_{km_k}	d_{km_k}
1	H	H	HH	…	H	HH	…	H	H	HH	…	H …	HH
2	H	H	HL	…	L	LH	…	H	H	HL	…	H …	LH
3	H	L	LH	…	H	HL	…	H	L	LH	…	L …	HL
.	H	L	LL	…	L	LL	…	H	L	LL	…	L …	LL
.	.		.			.		.		.		.	
n	.		.			.		.		.		.	
1				…	Unstructured scenarios		…				…	…	
2				…			…				…	…	
.				…			…				…	…	
n^*				…			…				…	…	

$$n = 2^{2\sum_{i=1}^{k} m_i + k}$$

Next, under each scenario the product mix problem is solved by using deterministic product mix model and optimal solution set is found for every scenario. Table 4.7 shows these results.

Table 4.7: Optimal Solutions under the Scenarios

	x^*_{11} … $x^*_{1m_1}$	x^*_{21} … $x^*_{2m_2}$	…	x^*_{k1} … $x^*_{km_k}$	P^*
Scenario 1	$x^*_{1,11}$ … $x^*_{1,1m_1}$	$x^*_{1,21}$ … $x^*_{1,2m_2}$	…	$x^*_{1,k1}$ … x^*_{1,km_k}	P_1^*
Scenario 2	$x^*_{2,11}$ … $x^*_{2,1m_1}$	$x^*_{2,21}$ … $x^*_{2,2m_2}$	…	$x^*_{2,k1}$ … x^*_{2,km_k}	P_2^*
…	…	…	…	…	…
Scenario n	$x^*_{n,11}$ … $x^*_{n,1m_1}$	$x^*_{n,21}$ … $x^*_{n,2m_2}$	…	$x^*_{n,k1}$ … x^*_{n,km_k}	P_n^*
…	…	…	…	…	…
Scenario $n+n^*$	$x^*_{n+n^*,11}$ … $x^*_{n+n^*,1m_1}$	$x^*_{n+n^*,21}$ … $x^*_{n+n^*,2m_2}$		$x^*_{n+n^*,k1}$ … $x^*_{n+n^*,km_k}$	$P^*_{n+n^*}$

Then the optimal solution found for a scenario is tested under all other scenarios generated in scenario matrix, and the objective function values P* are found. This is repeated for each other optimal solution of a scenario. In short, every solution found through the deterministic product mix model is evaluated with all the other scenarios. Then, objective function values for all optimal solutions and for all scenarios are found and located to a matrix. Note that the extreme scenarios which are added to get more alternative solutions still need to be tested under the full factorial setting. This matrix is shown in Table 4.8.

Table 4.8: Objective Function Values Matrix (Profit Matrix)

Best solutions	Scenarios			
$x_{11}^{*} \cdots x_{1m_1}^{*} \cdots x_{k1}^{*} \cdots x_{km_k}^{*}$	1	2	...	n
Scenario 1	$P_{1,1}^{*}$	$P_{1,2}^{*}$	...	$P_{1,n}^{*}$
Scenario 2	$P_{2,1}^{*}$	$P_{2,2}^{*}$	...	$P_{2,n}^{*}$
⋮	⋮	⋮	⋮	⋮
Scenario n	$P_{n,1}^{*}$	$P_{n,2}^{*}$		$P_{n,n}^{*}$
⋮	⋮	⋮	⋮	⋮
Scenario $n+n^{*}$	$P_{n+n^{*},1}^{*}$	$P_{n+n^{*},2}^{*}$	...	$P_{n+n^{*},n}^{*}$

At this point, we should consider the possibility of having infeasible solutions due to the upper bound constraint of x_{ij} , that is $x_{ij} \leq d_{ij}$, where d_{ij} is generated in two levels depending on the level of price SP_{ij} in our probabilistic model. Therefore, when the optimal solution for the scenario r (row), where $r=1, 2, \ldots, n+n^{*}$, is tested under the other scenarios c (column) where $r \neq c$, and $c = 1, 2, \ldots, n$, in the scenario matrix, the possibility of occurrence of the case $x_{ij}^{*} > d_{ij}$ should be considered and evaluated in the objective function. For such a case, the company is not able to sell the quantity $x_{ij}^{*} - d_{ij}$, because it produces more than it can sell. In this case, a penalty can be charged to the company which is represented as *overage penalty* in the objective function as follows:

$$P_{rc} = \sum_{i}\sum_{j}\left[x_{ij}^{*} - \max\left\{(x_{ij}^{*} - d_{ij}), 0\right\}\right] \times SP_{ij} - \sum_{i}\sum_{j}\left[x_{ij}^{*} - \max\left\{(x_{ij}^{*} - d_{ij}), 0\right\}\right] \times PC_{i} - \sum_{i}\sum_{j}(x_{ij}^{*} - d_{ij}) \times o_{i}$$

where o_i is the *unit overage cost* and $o_i = \rho \times PC_i$. ρ can be considered as the interest rate of bank deposits depending on the opportunity cost principle. Now, the regret of using solution r in scenario c, R_{rc}, can be determined as follows:

$R_{rc} = P^{*}_{cc} - P_{rc}$, and since $P^{*}_{rc} = P_{rc}$ for $r = c$, $R_{rc} = 0$.

New results can be shown in a regret matrix presented in Table 4.9.

Table 4.9: Regret Matrix with Maximum Regrets

Best solutions	Scenarios				Maximum Regret	SNR
$x_{11}^{*} \cdots x_{1m_1}^{*} \cdots x_{k1}^{*} \cdots x_{km_k}^{*}$	1	2	...	n		
Scenario 1	0	$R_{1,2}$	...	$R_{1,n}$	R_1	SNR_1
Scenario 2	$R_{2,1}$	0	...	$R_{2,n}$	R_2	SNR_2
⋮	⋮	⋮		⋮	⋮	⋮
Scenario n	$R_{n,1}$	$R_{n,2}$		0	R_n	
Scenario $n+n^{*}$	$R_{n+n^{*},1}$	$R_{n+n^{*},2}$	...	$R_{n+n^{*},n}$	$R_{n+n^{*}}$	$SNR_{n+n^{*}}$

4.4.3 Determining Optimal Product Mix

Optimal product mix can be found by using the following performance criteria:

1. *Minimax Regret Criterion*:

The concept of regret is based on the lost opportunities. Once the regret matrix is obtained (see Table 4.8) the minimax criterion is applied that advices to take the maximum value of each row and then choose the solution which gives minimum of the row maximums (Ravindran, 2008).

2. *Signal-to-Noise Ratio of Regret Values*:

Taguchi proposes a summary statistic which combines information about the mean and variance, called *signal-to-noise ratio* (SNR) (Montgomery, 2009; p. 490). For a smaller-the-better measure such as regret, Signal-to-Noise Ratio is defined in such a way that a maximum value of the ratio minimizes the mean as well as variability transmitted from the noise variables. The formula of Signal-to-Noise ratio of regret values is as follows:

$SNR_R = -10\log_{10}(\mu_R^2 + \sigma_R^2)$ where μ_R is the mean of the regret values, and σ_R^2 is the variance of regret values.

3. *Signal-to-Noise Ratio of Regret Free Profit (P-R) Values*:

We propose an SNR measure for *regret free profit* values (P−R) in order to protect against a solution at which both regret and profit values are high. In such a case, the decision maker can be in a trade-off situation that a higher value of profit may be attainable with a higher value of regret. Subtracting the regret values from the corresponding profit values, we first obtain the mean square reciprocal of the regret free profits. Then the SNR measure for the regret free profit (SNR_{P-R}) is given as follows:

$$SNR_{P-R} = -10\log_{10}\left\{\frac{1}{n}\sum_{j=1}^{n}\left[\frac{1}{(P_{ij}-R_{ij})^2}\right]\right\} = -10\log_{10}\left\{\frac{1}{\mu_{P-R}^2}\left[1+3\frac{\sigma_{P-R}^2}{\mu_{P-R}^2}\right]\right\}$$

where n is the total number of structured scenarios, μ_{P-R} is the mean value of regret free profits and σ_{P-R}^2 is the variance of regret free profit values. The second part of this equation can be claimed based on Phadke (1989, p.111). This is a larger-the-better type of a measure, and maximization of it requires that μ_{P-R} is maximized while σ_{P-R}^2 is minimized.

A a result, the optimal product mix with the smallest maximum regret and/or the best SNR_R and/or $SNR_{P\text{-}R}$ value can be chosen according to these approaches.

Some statistics are generated for the measures of regrets, profits and regret free profits. An example of these statistics is shown in Table 4.10 for the regret values.

Table 4.10: Regret Data

Best solutions	Scenarios				Average Regret	St.Dev. Regret	Skewness
$x_{11}^* \cdots x_{1m_1}^* \cdots x_{k1}^* \cdots x_{km_k}^*$	1	2	...	n	$\bar{R}$	S_R	υ_R
Scenario 1	0	$R_{1,2}$	...	$R_{1,n}$	$\bar{R}_1$	S_{R_1}	υ_{R_1}
Scenario 2	$R_{2,1}$	0	...	$R_{2,n}$	$\bar{R}_2$	S_{R_2}	υ_{R_2}
⋮		⋮			⋮	⋮	⋮
Scenario n	$R_{n,1}$			0	$\bar{R}_n$	S_{R_n}	υ_{R_n}
⋮		⋮			⋮	⋮	⋮
Scenario $n+n^*$	$R_{n+n^*,1}$	$R_{n+n^*,2}$	...	$R_{n+n^*,n}$	$\bar{R}_{n+n^*}$	$S_{R_{n+n^*}}$	$\upsilon_{R_{n+n^*}}$

The final three columns of Table 4.10 represent the estimates for the first three moments of the random variable Regret. These estimates are obtained from systematic sampling as mentioned before. Regret values are the results obtained from the objective functions corresponding to runs of the two-level full factorial design. The levels of factors are discretized equivalents of the continuous random factors which are normally distributed. In other words, by the results of Köksal and Fathi (2003), the normal distributions of the factors are replaced by a two-point discrete distribution with equal weights ½ and ½, at points

- $\mu_{SP_{ij}} - \sigma_{SP_{ij}}$ and $\mu_{SP_{ij}} + \sigma_{SP_{ij}}$ for price,
- $g(SP_{ij}) - \sigma_{\varepsilon_{ij}}$ and $g(SP_{ij}) + \sigma_{\varepsilon_{ij}}$ for demand, and
- $\mu_{PC_i} - \sigma_{PC_i}$, and $\mu_{PC_i} + \sigma_{PC_i}$ for cost.

As an example of such a discrete distribution for product price SP_{ij} is shown in Figure 4.13.

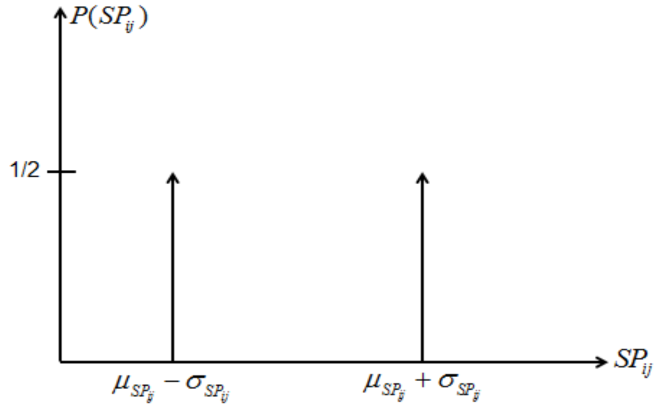

Figure 4.13: Discrete Distribution of Random Variable SP_{ij}

Regret is a linear function of these factors such as selling price, production cost and demand which are normally distributed. Based on Köksal and Fathi (2003) we can claim that the first three moments of the continuous regret random variable are identical to the sample moments of regret values obtained from the full factorial experiment. Therefore, for any optimal solution *i*, we have the following unbiased estimators:

- $\bar{R}_i = \sum_{j=1}^{n} \frac{R_{i,j}}{n} = E(R_i^c)$
- $s_{R_i}^2 = \sum_{i=1}^{n} \frac{(R_i - \bar{R}_i)^2}{n} = V(R_i^c)$
- $\upsilon_{R_i} = \sum_{i=1}^{n} \frac{(R_{i,j} - \bar{R}_i)^3}{n} = \upsilon(R_i^c)$

where R_i^c represents the continuous rbegret random variable at the optimal solution *i*, and *n* represents the total number of *structured scenarios*.

Let us consider the example illustrated in Figure 4.11. In this case, for two products (k =2) where each product is sold in two markets (m_1=1,2 and m_2=1,2), the total number of structured scenarios is n = 1024 and the total number of factors in the experiments is
$2\,(m_1 + m_2) + k = 2(4) + 2 = 10$.

Using the *Bayes Theorem* of conditional probabilities, we can write

$$E(R) = \sum_{j=1}^{1024} (\frac{1}{2})^{10} \times R_{i,j} = (\frac{1}{2})^{10} \sum_{j=1}^{1024} R_{i,j} = \frac{1}{1024} \sum_{j=1}^{1024} R_{i,j} = \frac{\sum_{j=1}^{1024} R_{i,j}}{1024} = \overline{R}_i$$

Note that $n \times (\frac{1}{2})^{2\sum_{i=1}^{k} m_i + k} = 1$, and $p_i = (\frac{1}{2})^{2\sum_{i=1}^{k} m_i + k}$ which is the probability of occurrence of scenario i. As it can be observed from Table 4.9, extreme scenarios are excluded for the calculation of the moments of the regret values, since these scenarios are assumed to have zero probability in the experimental setup based on two-level discretization of the factors and inclusion of them may cause the bias and disturb the distributional assumptions of the factors.

The final step in our methodology is to obtain experimental results with these three approaches and to analyze them to get the best solution to the problem. A MATLAB code was written to conduct all these experiments and collect the necessary regret and SNR data (Appendix D). Experimental results and the suggested approaches for various different numerical cases are presented in Chapter 5.

CHAPTER 5

EXPERIMENTAL RESULTS

This chapter covers the numerical examples and their experimental results that are presented to show the implementation of the methodology developed to solve the product mix problem under uncertainty. First, the cases studied in the examples are described including the formulation of the scenarios. Next, numerical results are presented for these cases showing the stages of the methodology. Finally, the results are analyzed and discussed.

5.1 DESCRIPTION OF THE CASES STUDIED

During the field study conducted in this research and developing the proposed framework for product management, we have had several contacts with the experts in Company D operating in "consumer durables" sector. These discussions contributed a lot to construct the DSS developed to solve the product mix problem under uncertainty in the product management framework. The information obtained in these contacts helped to clarify the product aggregation schemes, the product and market profiles in formulating and modeling the research problem. Due to this familiarity, we prefer to consider a typical manufacturer operating in "consumer durables" sector to get the numerical results for the developed methodology in our study.

Before passing to the description of the specific cases, let us describe a general company case, focusing on the product and market profiles which constitute the base scenario. Note that this description does not reflect the real case for the Company D.

Base Case Description:

Base case simply describes the existing conditions of the company regarding the product mix problem under uncertainty. Let us suppose that the company has the product mix which is composed of two broad lines;

- Major Household Appliances (White Goods)
- Small Household Appliances

It is known that each product line has several families, and each family has several groups which are composed of hundreds of variants. Although our research problem considers the determination of "family mix" under uncertainty, the strategic product mix composed of product lines can also be studied with the methodology developed in this research study. Thus, the following *product scheme* of the company (Figure 5.1) is considered in formulating the scenarios for the experiments. Note that we consider the families of "White Goods" line in the numerical examples, therefore the families of "Small Household Appliances" are not shown in Figure 5.1.

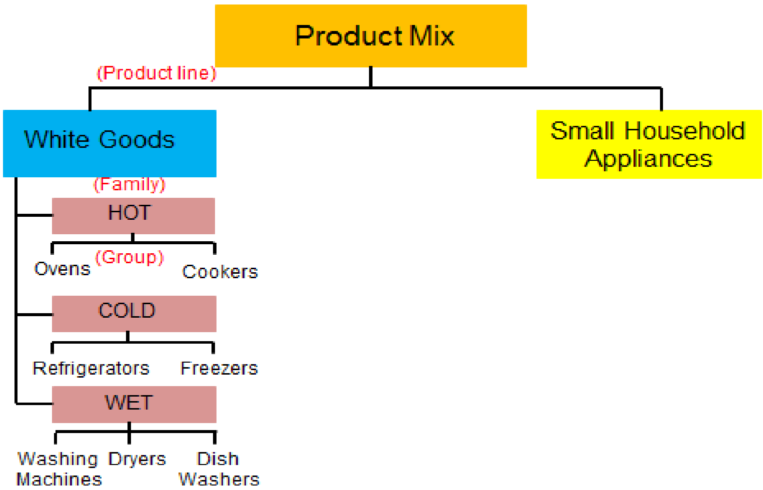

Figure 5.1: Product Hierarchy Illustration for Numerical Example

We assume two broad classifications for *market structure* of the company; *National* and *Global*. This market structure can be detailed depending on the purpose of the analysis. For instance, Company D is a market leader with more than 50% market share in national market. Uncertainty of the national market is relatively lower than the uncertainty in global market regarding the product prices, production costs and demands for the products. In spite of this, some of the products may be quite sensitive to some demographic indicators in the national market, like income levels. We have learned that the freezers in Cold family and dish washers in Wet family are sensitive products in the national market in the sense that customers can easily sacrifice these products in crisis periods of the economy. If a deeper analysis is required, the national market can be disaggregated into sub-segments, like "High Income", "Average Income" and "Low Income" segments.

Similarly, global market can be subdivided into several segments depending on the purpose of the formulation of the scenario. Actually, Company D sells its products in more than 70 countries other than Turkey. For example, 64% of the total production of refrigerators is sold to 70 countries. However, it was also learnt that more than 80% of global selling activities is realized in 5 big markets. In such a case, these countries can be restructured as the regions which can provide reasonable and satisfactory consolidation for the global market in terms of total sales. As an example, Company D considers the following regions in its global market structure:

- *West Europe*: Italy, Spain, Germany, France, United Kingdom, Belgium
- *East Europe* : Russia, Poland, Romania, Ukraine, Lithuania
- *Other* : South Africa, etc.

So, the following *product-market relations* are considered in the experiments:

Table5.1-a: Illustrative Product-Market Relations for Product Lines

Product Line	**National Market**	**Global Market**
Major Household Appliances (White Goods)	✓	✓
Small Household Appliances	✓	

Table 5.1-b: Illustrative Product-Market Relations for Families of White Goods

Families of White Goods	**National Market**	**Global Market**
HOT	✓	
COLD	✓	✓
WET	✓	✓

The product-market matrix will be provided separately for each case in numerical results.

As mentioned before, both MTS and MTO manufacturing environments can be studied in the proposed DSS. Depending on the specific case under consideration, some modifications can be employed in the deterministic product mix model when necessary. In fact, many firms may serve a combination of these environments in real life. This is the case in Company D. It is known that although Company D keeps both component and finished item inventories, the levels of these inventories are not at the significant levels. The Company D expert stated that the major underlying reason is the powerful supply chain activities and distribution system. It is also understood that globalization has forced Company D to establish stronger supply chain and distribution systems.

Formulation of the Scenarios:

In order to provide the numerical results for the developed methodology, we consider several cases in formulating the scenarios. Note that these cases do not limit the applicability of the methodology, but just aim at showing the working mechanism of DSS by means of some descriptive cases. The cases are as follows:

1. Product Mix Example with 2 Product Lines
2. Family Mix Example with 3 Families
3. Different Candidate Products Set Example with 2 Product Lines
4. Volatile Market Conditions Example with 2 Product Lines
5. New Market Entrance Example with 2 Product Lines

Product Mix and *Family Mix* examples describe simply the existing conditions of the company. The company may study the performance of the company with its existing products for the coming fiscal period by means of our methodology. So, the methodology can be applied for budgeting purposes for these cases. These examples provide also a basis for the other numerical examples.

By introducing *different candidate products sets*, the following decision making cases can be studied by means of the developed methodology:

a) To support “Time-to-Market” decision
b) To support “Outsourcing” decision

Time-to-market decision is closely related to the “Prioritization” decision and “Cannibalization” issue in Product Management. Regarding the product mix problem in this framework, considering the different sets of candidate products in the proposed DSS supports this decision. The company may consider different product projects for the coming period and test their profitability by constituting different sets of candidate products accordingly. For this purpose, mean values and variances of the prices and the production costs of the products should be reconsidered in the targeted market(s). Considering different sets of candidate products may require considering the impact of new product introduction to the production side of the company. This issue is briefly discussed in the final section.

On the other hand, the analysis of “Make versus Buy” can be done by means of the proposed DSS considering the different sets candidate products. Our model used in the proposed DSS determines the products produced in-house. Therefore, the company is able to evaluate the case “Make” by using the proposed approach. Then, the optimum quantities determined by the model can be analyzed for the option “Buy” spending some additional efforts. Thus, outsourcing decision is supported under uncertainty conditions of product prices, costs and demand values.

Volatile market conditions require considering higher uncertainty in the market in terms of product prices of competitors and instability of the customers’ demands. These conditions can be reflected by the higher variances of product prices and demands. In addition to higher variances of product prices and demands, variances of product costs can also be higher than those at a stable market due to the frequently changeable prices of the suppliers. So, this case is formulated by introducing higher values of variances of the three parameters in the market(s) which is (are) considered as volatile.

Entrance of a new market requires considering higher uncertainty for the existing products of the company for the desired market under consideration. This issue can be handled by the proposed DSS introducing higher values of variances of product prices and so the demand values for the targeted market.

5.2 NUMERICAL RESULTS

Suppose that the company has the product scheme shown in Figure 5.1. The existing product-market profile of the company is assumed as the illustrative cases shown in Table 5.1-a and Table 5.1-b for the product line mix description and the family mix description, respectively. The data required to obtain the numerical results are established through internet searches and the discussions with the PM expert of Company D. The numerical results are presented in the format of the methodology stages of the experiments. For the purpose of brevity and convenience, we present Example 1, which is the case with the smallest size, in accordance with this format in detail. The output obtained via MATLAB for this case is provided in Appendix E. The results for the other numerical examples are presented in some appropriate summary tables. Note that all the results are reproducible by the data given below for each example and the MATLAB code provided in Appendix D.

EXAMPLE 1: ***Product Mix Example with 2 Product Lines***

This example describes the existing conditions of the company.

Parameters:

- k=2 (White Goods (WG), Small Household Appliances (SHA))
- m_1 =1,2 and m_2 =1 ("1": National market (N), "2": Global market (G))
- Product-Market Matrix (H)

$$\mathbf{H} = \begin{bmatrix} 1 & 1 \\ 1 & 0 \end{bmatrix}$$

- Product Prices (SP_{ij}): (Average prices for each product line at each market)

$$SP_{ij} \sim N(\mu_{SP_{ij}}, \sigma^2_{SP_{ij}})$$

$\mu_{SP_{ij}}$ (TL)	*j*= 1 (N)	*j*= 2 (G)
i= 1(WG)	1 580	1 975
i =2 (SHA)	190	0

where it is assumed that $\sigma^2_{SP_{ij}} = 0.10 \times \mu_{SP_{ij}}$.

$\sigma^2_{SP_{ij}}$ (TL)	*j*= 1 (N)	*j*= 2 (G)
i= 1 (WG)	158	197.5
i =2 (SHA)	19	0

- Demand (d_{ij}):

$$d_{ij}(SP_{ij}) = b_{ij} - a_{ii,j} \times SP_{ij} + \varepsilon_{ij}, \quad \varepsilon_{ij} \sim N(0, \sigma^2_{\varepsilon_{ij}})$$

where $\sigma^2_{\varepsilon_{ij}} = 0.10 \times \mu_{d_{ij}}$, $\mu_{d_{ij}} = g(SP_{ij}) = b_{ij} - a_{ii,j} \times SP_{ij}$

b_{ij} (units) (intercept)	*j*= 1 (N)	*j*= 2 (G)
i= 1 (WG)	11 200	13 400
i =2 (SHA)	4 800	0

$a_{ii,j}$ (units) (elasticity)	j= 1 (N)	j= 2 (G)
i= 1 (WG)	5	3
i =2 (SHA)	4	0

- Production Cost (PC_i):

$$PC_i \sim N(\mu_{PC_i}, \sigma^2_{PC_i}) \text{ and } \sigma^2_{PC_i} = 0.10 \times \mu_{PC_i}$$

	i= 1 (WG)	i= 2 (SHA)
μ_{PC_i} (TL)	1 058	123
$\sigma^2_{PC_i}$ (TL)	105.8	12.3

- Lower bounds for decision variables x_{ij} :

l_{ij} (units) (lower bounds))	j= 1 (N)	j= 2 (G)
i= 1 (WG)	350	540
i =2 (SHA)	450	0

- Unit production capacities:

$c_i = (c_1, c_2) = (0.000608, 0.00219)$ hrs.

- Total production capacities:

$C_i = (C_1, C_2) = (8700, 8700)$ hrs.

Levels of Parameters (Factors):

(TL)	PC_1	PC_2	SP_{11}	SP_{12}	SP_{21}
High (H)	1068.2859	126.5071	1592.5698	1989.0535	194.3589
Low (L)	1047.7141	119.4929	1567.4302	1960.9465	185.6411

where $SP_{ij}(H) = \mu_{SP_{ij}} + \sigma_{SP_{ij}}$, $SP_{ij}(L) = \mu_{SP_{ij}} - \sigma_{SP_{ij}}$ and

$$PC_i(H) = \mu_{PC_i} + \sigma_{PC_i} \quad , \quad PC_i(L) = \mu_{PC_i} - \sigma_{PC_i} .$$

(Units)	SP_{11} (H)	SP_{11} (L)	SP_{12} (H)	SP_{12} (L)	SP_{21} (H)	SP_{21} (L)
d_{11} (H)	3255.1431	3381.1871				
d_{11} (L)	3219.1589	3344.5109				
d_{12} (H)			7460.1027	7544.5779		
d_{12} (L)			7405.5763	7489.7431		
d_{21} (H)					4042.6207	4077.5787
d_{21} (L)					4002.5081	4037.2926

where $d_{ij}(H) = g(SP_{ij}) + \sigma_{\varepsilon_{ij}}$, $d_{ij}(L) = g(SP_{ij}) - \sigma_{\varepsilon_{ij}}$ and $g(SP_{ij}) = b_{ij} - a_{ii,j} \times SP_{ij}$, $\sigma^2_{\varepsilon_{ij}} = 0.10 \times g(SP_{ij})$.

Number of Structured Scenarios:

$$n = 2^{2\sum_{i=1}^{k} m_i + k} = 2^{2(m_1+m_2)+k} = 2^{2(3)+2} = 2^8 = 256$$

Scenario Matrix: See Table 5.2.

Optimal Solutions under each Scenario: See Table 5.3.

Profit Matrix: See Table 5.4.

Regret Matrix: See Table 5.5.

Regret Data: See Table 5.6.

Table 5.2: Scenario Matrix (Example 1)

Scenario	PC_1 **(10^3)**	SP_{11} **(10^3)**	d_{11} **(10^3)**	SP_{12} **(10^3)**	d_{12} **(10^3)**	PC_2	SP_{21}	d_{21} **(10^3)**
1	1.0477	1.5674	3.3445	1.9609	7.4897	119.4929	185.6411	4.0373
2	1.0477	1.5674	3.3445	1.9609	7.4897	119.4929	185.6411	4.0776
3	1.0477	1.5674	3.3445	1.9609	7.4897	119.4929	194.3589	4.0025
4	1.0477	1.5674	3.3445	1.9609	7.4897	119.4929	194.3589	4.0426
5	1.0477	1.5674	3.3445	1.9609	7.4897	126.5071	185.6411	4.0373
6	1.0477	1.5674	3.3445	1.9609	7.4897	126.5071	185.6411	4.0776
7	1.0477	1.5674	3.3445	1.9609	7.4897	126.5071	194.3589	4.0025
8	1.0477	1.5674	3.3445	1.9609	7.4897	126.5071	194.3589	4.0426
9	1.0477	1.5674	3.3445	1.9609	7.5446	119.4929	185.6411	4.0373
10	1.0477	1.5674	3.3445	1.9609	7.5446	119.4929	185.6411	4.0776
11	1.0477	1.5674	3.3445	1.9609	7.5446	119.4929	194.3589	4.0025
…	**…**	**…**	**…**	**…**	**…**	**…**	**…**	**…**
247	1.0683	1.5926	3.2551	1.9891	7.4056	126.5071	194.3589	4.0025
248	1.0683	1.5926	3.2551	1.9891	7.4056	126.5071	194.3589	4.0426
249	1.0683	1.5926	3.2551	1.9891	7.4601	119.4929	185.6411	4.0373
250	1.0683	1.5926	3.2551	1.9891	7.4601	119.4929	185.6411	4.0776
251	1.0683	1.5926	3.2551	1.9891	7.4601	119.4929	194.3589	4.0025
252	1.0683	1.5926	3.2551	1.9891	7.4601	119.4929	194.3589	4.0426
253	1.0683	1.5926	3.2551	1.9891	7.4601	126.5071	185.6411	4.0373
254	1.0683	1.5926	3.2551	1.9891	7.4601	126.5071	185.6411	4.0776
255	1.0683	1.5926	3.2551	1.9891	7.4601	126.5071	194.3589	4.0025
256	1.0683	1.5926	3.2551	1.9891	7.4601	126.5071	194.3589	4.0426
257(*)	1.0580	1.5800	3.3000	1.9750	7.4750	123.0000	190.0000	4.0400

(*) Extreme Scenario (Mean values of the parameters)

Table 5.3: Optimal Solutions under Each Scenario (Example 1)

Scenario	x^*_{11} (10^3 units)	x^*_{12} (10^3 units)	x^*_{21} (10^3 units)	***Profit*** (10^6 TL.)
1	3.3445	7.4897	4.0373	8.8451
2	3.3445	7.4897	4.0776	8.8478
3	3.3445	7.5446	4.0025	8.8777
4	3.3445	7.5446	4.0426	8.8807
5	3.3445	7.5446	4.0373	8.8168
6	3.3445	7.5446	4.0776	8.8192
7	3.3445	7.5446	4.0025	8.8496
8	3.3445	7.5446	4.0426	8.8524
9	3.3445	7.5446	4.0373	8.8952
10	3.3445	7.5446	4.0776	8.8979
…	**…**	**…**	**…**	**…**
247	3.2551	7.4056	4.0025	8.7970
248	3.2551	7.4056	4.0426	8.7997
249	3.2551	7.4601	4.0373	8.8427
250	3.2551	7.4601	4.0776	8.8454
251	3.2551	7.4601	4.0025	8.8753
252	3.2551	7.4601	4.0426	8.8783
253	3.2551	7.4601	4.0373	8.8144
254	3.2551	7.4601	4.0776	8.8168
255	3.2551	7.4601	4.0025	8.8472
256	3.2551	7.4601	4.0426	8.8499
257 (*)	3.3000	7.4750	4.0400	8.8479

(*) Extreme scenario solution

Table 5.4: Profit Matrix (10^6 TL.) (Example 1)

Scenario	**1**	**2**	**3**	**4**	**5**	**…**	**252**	**253**	**254**	**255**	**256**
1	8.8451	8.8451	8.8734	8.8803	8.8168	**…**	8.7444	8.6809	8.6809	8.7091	8.7161
2	8.8401	8.8478	8.8683	8.8763	8.8115	**…**	8.7404	8.6755	8.6833	8.7038	8.7118
3	8.8428	8.8428	8.8777	8.8777	8.8148	**…**	8.7418	8.6788	8.6788	8.7137	8.7137
4	8.8445	8.8455	8.8727	8.8807	8.8161	**…**	8.7448	8.6802	8.6812	8.7084	8.7164
5	8.8451	8.8451	8.8734	8.8803	8.8168	**…**	8.7444	8.6809	8.6809	8.7091	8.7161
6	8.8401	8.8478	8.8683	8.8763	8.8115	**…**	8.7404	8.6755	8.6833	8.7038	8.7118
7	8.8428	8.8428	8.8777	8.8777	8.8148	**…**	8.7418	8.6788	8.6788	8.7137	8.7137
8	8.8445	8.8455	8.8727	8.8807	8.8161	**…**	8.7448	8.6802	8.6812	8.7084	8.7164
9	8.7848	8.7848	8.8130	8.8200	8.7565	**…**	8.6829	8.6194	8.6194	8.6476	8.6546
10	8.7798	8.7875	8.8080	8.8160	8.7511	**…**	8.6789	8.6140	8.6218	8.6422	8.6503
…	**…**	**…**	**…**	**…**	**…**	**…**	**…**	**…**	**…**	**…**	**…**
248	8.7212	8.7222	8.7494	8.7574	8.6928	**…**	8.8281	8.7635	8.7645	8.7917	8.7997
249	8.7716	8.7716	8.7998	8.8068	8.7433	**…**	8.8779	8.8144	8.8144	8.8426	8.8496
250	8.7666	8.7743	8.7948	8.8028	8.7379	**…**	8.8739	8.8090	8.8168	8.8372	8.8453
251	8.7693	8.7693	8.8042	8.8042	8.7412	**…**	8.8753	8.8123	8.8123	8.8472	8.8472
252	8.7709	8.7702	8.7992	8.8072	8.7426	**…**	8.8783	8.8137	8.8147	8.8419	8.8499
253	8.7716	8.7716	8.7998	8.8068	8.7433	**…**	8.8779	8.8144	8.8144	8.8426	8.8496
254	8.7666	8.7743	8.7948	8.8028	8.7379	**…**	8.8739	8.8090	8.8168	8.8372	8.8453
255	8.7693	8.7693	8.8042	8.8042	8.7412	**…**	8.8753	8.8123	8.8123	8.8472	8.8472
256	8.7709	8.7720	8.7992	8.8072	8.7426	**…**	8.8783	8.8137	8.8147	8.8419	8.8499
257 (*)	8.7195	8.7195	8.7544	8.7544	8.6914	**…**	8.8111	8.7470	8.7475	8.7752	8.7827

(*): Profit value of extreme scenario

Table 5.5: Regret Matrix (Example 1)

Scenario	**1**	**2**	**3**	**4**	**…**	**253**	**254**	**255**	**256**
1	0	2.6649×10^{3}	4.3643×10^{3}	398.9025	**…**	1.3349×10^{5}	1.3587×10^{5}	1.3811×10^{5}	1.3385×10^{5}
2	5.0546×10^{3}	0	9.4189×10^{3}	4.3861×10^{3}	**…**	1.3884×10^{5}	1.3349×10^{5}	1.4346×10^{5}	1.3813×10^{5}
3	2.3009×10^{3}	4.9658×10^{3}	0	3.0031×10^{3}	**…**	1.3555×10^{5}	1.3793×10^{5}	1.3349×10^{5}	1.3621×10^{5}
4	668.5181	2.3124×10^{3}	5.0328×10^{3}	0	**…**	1.3420×10^{5}	1.3556×10^{5}	1.3882×10^{5}	1.3349×10^{5}
5	3.2969×10^{-7}	2.6649×10^{3}	4.3643×10^{3}	398.9025	**…**	1.3349×10^{5}	1.3587×10^{5}	1.3811×10^{5}	1.3385×10^{5}
6	5.0546×10^{3}	3.4086×10^{-7}	9.4189×10^{3}	4.3861×10^{3}	**…**	1.3884×10^{5}	1.3349×10^{5}	1.4346×10^{5}	1.3813×10^{5}
7	2.3009×10^{3}	4.9658×10^{3}	1.7695×10^{-7}	3.0031×10^{3}	**…**	1.3555×10^{5}	1.3793×10^{5}	1.3349×10^{5}	1.3621×10^{5}
8	668.5181	2.3124×10^{3}	5.0328×10^{3}	1.7881×10^{-7}	**…**	1.3420×10^{5}	1.3556×10^{5}	1.3882×10^{5}	1.3349×10^{5}
9	6.0324×10^{4}	6.2989×10^{4}	6.4688×10^{4}	6.0723×10^{4}	**…**	1.9500×10^{5}	1.9738×10^{5}	1.9962×10^{5}	1.9536×10^{5}
10	6.5378×10^{4}	6.0324×10^{4}	6.9743×10^{4}	6.4710×10^{4}	**…**	2.0035×10^{5}	1.9500×10^{5}	2.0497×10^{5}	1.9964×10^{5}
…	**…**	**…**	**…**	**…**	**…**	**…**	**…**	**…**	**…**
248	1.2398×10^{5}	1.2562×10^{5}	1.2834×10^{5}	1.2331×10^{5}	**…**	5.0914×10^{4}	5.2273×10^{4}	5.5534×10^{4}	5.0206×10^{4}
249	7.3514×10^{4}	7.6179×10^{4}	7.7879×10^{4}	7.3913×10^{4}	**…**	-3.1106×10^{-7}	2.3823×10^{3}	4.6205×10^{3}	361.5289
250	7.8569×10^{4}	7.3514×10^{4}	8.2933×10^{4}	7.7900×10^{4}	**…**	5.3513×10^{3}	-3.2037×10^{-7}	9.9718×10^{3}	4.6435×10^{3}
251	7.5815×10^{4}	7.8480×10^{4}	7.3514×10^{4}	7.6517×10^{4}	**…**	2.0569×10^{3}	4.4392×10^{3}	-1.6950×10^{-7}	2.7217×10^{3}
252	7.4183×10^{4}	7.5827×10^{4}	7.8547×10^{4}	7.3514×10^{4}	**…**	707.7604	2.0672×10^{3}	5.3283×10^{3}	-1.7323×10^{-7}
253	7.3514×10^{4}	7.6179×10^{4}	7.7879×10^{4}	7.3913×10^{4}	**…**	0	2.3823×10^{3}	4.6205×10^{3}	361.5289
254	7.8569×10^{4}	7.3514×10^{4}	8.2933×10^{4}	7.7900×10^{4}	**…**	5.3513×10^{3}	0	9.9718×10^{3}	4.6435×10^{3}
255	7.5815×10^{4}	7.8480×10^{4}	7.3514×10^{4}	7.6517×10^{4}	**…**	2.0569×10^{3}	4.4392×10^{3}	0	2.7217×10^{3}
256	7.4183×10^{4}	7.5827×10^{4}	7.8547×10^{4}	7.3514×10^{4}	**…**	707.7604	2.0672×10^{3}	5.3283×10^{3}	0
257(*)	3.6937×10^{4}	3.9083×10^{4}	4.1301×10^{4}	3.6793×10^{4}	**…**	6.7386×10^{4}	6.9248×10^{4}	7.2006×10^{4}	6.7204×10^{4}

(*): Regret values of extreme scenario

Table 5.6: Regret Data (Example 1)

Scenario	***Maximum Regrets***	***Mean of Regrets***	***Standard Deviation of Regrets***	***Regret SNR (SNR_R)***	***Skewness of Regrets***	***Regret Free Profit SNR ($SNR_{P\text{-}R}$)***
1	2.3964×10^{5}	1.1014×10^{5}	6.6359×10^{4}	-235.2868	0.1189	319.3943
2	2.4499×10^{5}	1.1314×10^{5}	6.6424×10^{4}	-235.6895	0.1185	319.3803
3	2.3998×10^{5}	1.1073×10^{5}	6.6356×10^{4}	-235.3647	0.1189	319.3915
4	2.4035×10^{5}	1.1030×10^{5}	6.6364×10^{4}	-235.3093	0.1189	319.3935
5	2.3964×10^{5}	1.1014×10^{5}	6.6359×10^{4}	-235.2868	0.1189	319.3943
6	2.4499×10^{5}	1.1314×10^{5}	6.6424×10^{4}	-235.6895	0.1185	319.3803
7	2.3998×10^{5}	1.1073×10^{5}	6.6356×10^{4}	-235.3647	0.1189	319.3915
8	2.4035×10^{5}	1.1030×10^{5}	6.6364×10^{4}	-235.3093	0.1189	319.3935
9	3.0115×10^{5}	1.4345×10^{5}	7.9912×10^{4}	-240.1773	0.0500	319.2375
10	3.0650×10^{5}	1.4645×10^{5}	7.9965×10^{4}	-240.4983	0.0499	319.2235
…	**…**	**…**	**…**	**…**	**…**	**…**
247	1.9741×10^{5}	1.0293×10^{5}	5.1003×10^{4}	-233.0322	-0.0731	319.4249
248	1.9778×10^{5}	1.0251×10^{5}	5.1014×10^{4}	-232.9672	-0.0730	319.4269
249	1.4727×10^{5}	8.0180×10^{4}	3.7812×10^{4}	-227.8488	-0.2392	319.5337
250	1.5262×10^{5}	8.3185×10^{4}	3.7925×10^{4}	-228.4648	-0.2371	319.5199
251	1.4762×10^{5}	8.0767×10^{4}	3.7806×10^{4}	-227.9677	-0.2393	319.5310
252	1.4798×10^{5}	8.0346×10^{4}	3.7821×10^{4}	-227.8834	-0.2390	319.5330
253	1.4727×10^{5}	8.0180×10^{4}	3.7812×10^{4}	-227.8488	-0.2392	319.5337
254	1.5262×10^{5}	8.3185×10^{4}	3.7925×10^{4}	-228.4648	-0.2371	319.5199
255	1.4762×10^{5}	8.0767×10^{4}	3.7806×10^{4}	-227.9677	-0.2393	319.5310
256	1.4798×10^{5}	8.0346×10^{4}	3.7821×10^{4}	-227.8834	-0.2390	319.5330
257 (*)	1.7353×10^{5}	9.5304×10^{4}	3.7273×10^{4}	-230.7197	0.2104	319.4659

(*) Extreme scenario

Best Solutions of Example 1 with respect to Solution Approaches:

Performance Measure	**Structured Scenarios**	**Deterministic Case**
Max. Regret	1.4727×10^{5} (min-max regret solution)	1.7353×10^{5} (extreme scenario solution)
Max. Regret SNR	− 227.8488 (regret SNR solution)	−230.7197 (extreme scenario solution)
Max. (P-R) SNR	319.5337 ((P-R) SNR solution)	319.4659 (extreme scenario solution)

Table 5.7: Results of Example 1 (Product Mix Example with 2 Product Lines)

a) Best Solutions of Decision Variables

Solution Approach	Scenario #	x^*_{11} (10^3)	x^*_{12} (10^3)	x^*_{21} (10^3)
Min-Max Regret	121, 125, 249, 253	3.2551	7.4601	4.0373
Max. of Regret SNR	121, 125, 249, 253	3.2551	7.4601	4.0373
Max. of (P-R) SNR	121, 125, 249, 253	3.2551	7.4601	4.0373
Deterministic Case	257	3.3000	7.4750	4.0440

b) Statistics Generated for the Best Solutions $(x^*_{11}, x^*_{12}, x^*_{21})$

Scenario #	***Profit Range*** (10^6)	***Mean Profit*** (10^6)	***Profit Std. Dev.*** (10^5)	***Regret Range***	***Mean Regret*** (10^4)	***Regret Std. Dev.*** (10^4)	***P−R Range*** (10^6)	***Mean P−R*** (10^6)	***P−R Std. Dev.*** (10^5)
121	(8.5229, 9.0983)	8.7662	1.4563	$(-3.4831\times10^{-7}, 1.4727\times10^{5})$	8.0180	3.7812	(8.3822, 9.0979)	8.6860	1.6528
125	(8.5229, 9.0983)	8.7662	1.4563	$(0, 1.4727\times10^{5})$	8.0180	3.7812	(8.3822, 9.0979)	8.6860	1.6528
249	(8.5229, 9.0983)	8.7662	1.4563	$(-4.0978\times10^{-7}, 1.4727\times10^{5})$	8.0180	3.7812	(8.3822, 9.0979)	8.6860	1.6528
253	(8.5229, 9.0983)	8.7662	1.4563	$(-9.6858\times10^{-8}, 1.4727\times10^{5})$	8.0180	3.7812	(8.3822, 9.0979)	8.6860	1.6528
257	(8.5081, 9.0328)	8.7511	1.3670	$(3.5556\times10^{4}, 1.7353\times10^{5})$	9.5304	3.7273	(8.3536, 8.9839)	8.6558	1.4897

EXAMPLE 2: ***Family Mix Example***

This example describes the existing conditions of the company on family base of White Goods product line.

<u>Parameters</u>:

- k=3 (HOT, COLD and WET Families)
- m_1 =1, m_2 =1,2 and m_3 = 1,2 ("1": N and "2": G)
- Product-Market Matrix (H)

$$\mathbf{H} = \begin{bmatrix} 1 & 0 \\ 1 & 1 \\ 1 & 1 \end{bmatrix}$$

- Product Prices (SP_{ij}):

$$SP_{ij} \sim N(\mu_{SP_{ij}}, \sigma^2_{SP_{ij}}) \text{ and } \sigma^2_{SP_{ij}} = 0.10 \times \mu_{SP_{ij}}$$

$\mu_{SP_{ij}}$ (TL)	j= 1 (N)	j= 2 (G)
i= 1 (HOT)	896	0
i =2 (COLD)	2224	2780
i =3 (WET)	1420	1775

$\sigma^2_{SP_{ij}}$ (TL)	j= 1 (N)	j= 2 (G)
i= 1 (HOT)	89.6	0
i =2 (COLD)	222.4	278.0
i =3 (WET)	142.0	177.5

- Demand (d_{ij}):

$$d_{ij}(SP_{ij}) = b_{ij} - a_{ii,j} \times SP_{ij} + \varepsilon_{ij}, \quad \varepsilon_{ij} \sim N(0, \sigma^2_{\varepsilon_{ij}})$$

$$\sigma^2_{\varepsilon_{ij}} = 0.10 \times \mu_{d_{ij}}, \mu_{d_{ij}} = g(SP_{ij}) = b_{ij} - a_{ii,j} \times SP_{ij}$$

b_{ij} (units) (intercept)	j= 1 (N)	j= 2 (G)
i= 1 (HOT)	3800	0
i =2 (COLD)	13700	14500
i =3 (WET)	6500	7200

$a_{ii,j}$ (units) (elasticity)	j= 1 (N)	j= 2 (G)
i= 1 (HOT)	3	0
i =2 (COLD)	5	4
i =3 (WET)	4	3

- Production Cost (PC_i):

  $PC_i \sim N(\mu_{PC_i}, \sigma^2_{PC_i})$ and $\sigma^2_{PC_i} = 0.10 \times \mu_{PC_i}$

	i= 1 (HOT)	i= 2 (COLD)	i= 3 (WET)
μ_{PC_i} (TL)	627.0	1334.0	923.0
$\sigma^2_{PC_i}$ (TL)	62.7	133.4	92.3

- Lower bounds for decision variables x_{ij} :

l_{ij} (units) (lower bounds))	j= 1 (N)	j= 2 (G)
i= 1 (HOT)	380	0
i =2 (COLD)	650	750
i =3 (WET)	420	500

- Unit production capacities:

  $c_i = (c_1, c_2, c_3)$ = (0.00438, 0.00122, 0.00168) hrs.

- Total production capacities:

  $C_i = (C_1, C_2, C_3)$ = (8700, 8700, 8700) hrs.

<u>Levels of Parameters (Factors):</u>

(TL)	PC_1	PC_2	PC_3
High (H)	634.9183	1345.5499	932.6030
Low (L)	619.0817	1322.4501	913.3927

(TL)	SP_{11}	SP_{21}	SP_{22}	SP_{31}	SP_{32}
High (H)	905.4657	2238.9131	2796.6733	1431.9164	1788.3229
Low (L)	886.5343	2209.0869	2763.3267	1408.0836	1761.6771

(Units)	SP_{11} (H)	SP_{11} (L)
d_{11} (H)	1094.0125	1151.0760
d_{11} (L)	1073.1933	1129.7182

(Units)	SP_{21} (H)	SP_{21} (L)
d_{21} (H)	2521.2631	2670.8583
d_{21} (L)	2489.6059	2638.2727

(Units)	SP_{22} (H)	SP_{22} (L)
d_{22} (H)	3331.5093	3465.2585
d_{22} (L)	3295.1043	3428.1279

(Units)	SP_{31} (H)	SP_{31} (L)
d_{31} (H)	781.1227	876.9805
d_{31} (L)	763.5461	858.3507

(Units)	SP_{32} (H)	SP_{32} (L)
d_{32} (H)	1848.5776	1928.5242
d_{32} (L)	1821.4850	1900.8498

Number of Structured Scenarios:

$$n = 2^{2\sum_{i=1}^{k} m_i + k} = 2^{2(m_1+m_2+m_3)+k} = 2^{2(1+2+2)+2} = 2^{12} = 8192$$

Best Solutions of Example 2 with respect to Solution Approaches:

Performance Measure	**Structured Scenarios**	**Deterministic Case**
Max. Regret	4.4809×10^5 (min-max regret solution) 4.5609×10^5	3.8215×10^5 (extreme scenario solution)
Max. Regret SNR	−248.6079 (regret SNR solution)	−249.8595 (extreme scenario solution)
Max. (P-R) SNR	320.2827 ((P-R) SNR solution)	320.1542 (extreme scenario solution)

Table 5.8: Results of Example 2 (Family Mix with 3 Families)

a) Best Solutions of Decision Variables

Solution Approach	Scenario #	x_{11}^{*} (10^3)	x_{21}^{*} (10^3)	x_{22}^{*} (10^3)	x_{31}^{*}	x_{32}^{*} (10^3)
Min-Max Regret	8193	1.1120	2.5800	3.3800	820.0000	1.8750
Max. of Regret SNR	3472, 3488,3984, 4000	1.0940	2.5213	3.4281	781.1228	1.8486
	7568, 7584, 8080, 8096	1.0940	2.5213	3.4281	781.1228	1.8486
Max. of (P-R) SNR	3568, 3584, 4080, 4096	1.0940	2.5213	3.3315	781.1228	1.8486
	7664, 7680, 8176, 8192	1.0940	2.5213	3.3315	781.1228	1.8486
Deterministic Case	8193	1.1120	2.5800	3.3800	820.0000	1.8750

b) Statistics Generated for the Best Solutions $(x_{11}^*, x_{21}^*, x_{22}^*, x_{31}^*, x_{32}^*)$

Scenario #	***Profit Range*** (10^6)	***Mean Profit*** (10^6)	***Profit Std. Dev.*** (10^5)	***Regret Range***	***Mean Regret*** (10^5)	***Regret Std. Dev.*** (10^4)	***P−R Range*** (10^6)	***Mean P−R*** (10^6)	***P−R Std. Dev.*** (10^5)
3472	(8.9423, 9.5859)	9.2521	1.4130	$(-0.0026, 4.4809\times10^5)$	2.3219	9.3455	(8.5056, 9.5859)	9.0199	2.1947
3488	(8.9423, 9.5859)	9.2521	1.4130	$(-0.0025, 4.4809\times10^5)$	2.3219	9.3455	(8.5056, 9.5859)	9.0199	2.1947
3568	(9.0720, 9.5577)	9.2507	0.95814	$(-7.3016\times10^{-7}, 1.8547\times10^5)$	2.3358	9.5219	(8.6346, 9.5577)	9.0171	1.6511
3584	(9.0720, 9.5577)	9.2507	0.95814	$(-1.4156\times10^{-7}, 1.8547\times10^5)$	2.3358	9.5219	(8.6346, 9.5577)	9.0171	1.6511
3984	(8.9423, 9.5859)	9.2521	1.4130	$(-0.0032, 4.4809\times10^5)$	2.3219	9.3455	(8.5056, 9.5859)	9.0199	2.1947
4000	(8.9423, 9.5859)	9.2521	1.4130	$(-0.0031, 4.4809\times10^5)$	2.3219	9.3455	(8.5056, 9.5859)	9.0199	2.1947
4080	(9.0720, 9.5577)	9.2507	0.95814	$(-0.0032, 4.5609\times10^5)$	2.3358	9.5219	(8.6346, 9.5577)	9.0171	1.6511
4096	(9.0720, 9.5577)	9.2507	0.95814	$(-0.0034, 4.5609\times10^5)$	2.3358	9.5219	(8.6346, 9.5577)	9.0171	1.6511
7568	(8.9423, 9.5859)	9.2521	1.4130	$(0, 4.4809\times10^5)$	2.3219	9.3455	(8.5056, 9.5859)	9.0199	2.1947
7584	(8.9423, 9.5859)	9.2521	1.4130	$(-3.4786\times10^{-4}, 4.4809\times10^5)$	2.3219	9.3455	(8.5056, 9.5859)	9.0199	2.1947
7664	(9.0720, 9.5577)	9.2507	0.95814	$(0, 4.5609\times10^5)$	2.3358	9.5219	(8.6346, 9.5577)	9.0171	1.6511
7680	(9.0720, 9.5577)	9.2507	0.95814	$(-3.4757\times10^{-4}, 4.5609\times10^5)$	2.3358	9.5219	(8.6346, 9.5577)	9.0171	1.6511
8080	(8.9423, 9.5859)	9.2521	1.4130	$(-6.1654\times10^{-4}, 4.4809\times10^5)$	2.3219	9.3455	(8.5056, 9.5859)	9.0199	2.1947
8096	(8.9423, 9.5859)	9.2521	1.4130	$(-9.6242\times10^{-4}, 4.4809\times10^5)$	2.3219	9.3455	(8.5056, 9.5859)	9.0199	2.1947
8176	(9.0720, 9.5577)	9.2507	0.95814	$(-6.0997\times10^{-4}, 4.5609\times10^5)$	2.3358	9.5219	(8.6346, 9.5577)	9.0171	1.6511
8192	(9.0720, 9.5577)	9.2507	0.95814	$(-9.4994\times10^{-4}, 4.5609\times10^5)$	2.3358	9.5219	(8.6346, 9.5577)	9.0171	1.6511
8193	(8.8548, 9.4570)	9.2212	1.1196	$(1.6291\times10^5, 3.8215\times10^5)$	2.6304	4.2552	(8.4736, 9.2844)	8.9582	1.3950

EXAMPLE 3: ***Different Candidate Products Set***

Suppose new product is introduced to White Goods product line. Then, a different candidate products set is represented by different mean prices of White Goods and 15% decrease is assumed in unit production capacity of White Goods.

Parameters:

- k=2 (WG and SHA)
- m_1 =1,2 and m_2 =1 ("1": N and "2": G)
- Product-Market Matrix (H)

$$\mathbf{H} = \begin{bmatrix} 1 & 1 \\ 1 & 0 \end{bmatrix}$$

- Product Prices (SP_{ij}):

$$SP_{ij} \sim N(\mu_{SP_{ij}}, \sigma^2_{SP_{ij}}) \quad \text{and } \sigma^2_{SP_{ij}} = 0.10 \times \mu_{SP_{ij}}$$

$\mu_{SP_{ij}}$ (TL)	j= 1 (N)	j= 2 (G)
i= 1(WG)	1 769	2 212
i =2 (SHA)	190	0

$\sigma^2_{SP_{ij}}$ (TL)	j= 1 (N)	j= 2 (G)
i= 1 (WG)	176.9	221.2
i =2 (SHA)	19	0

- Demand (d_{ij}):

$$d_{ij}(SP_{ij}) = b_{ij} - a_{ii,j} \times SP_{ij} + \varepsilon_{ij}, \quad \varepsilon_{ij} \sim N(0, \sigma^2_{\varepsilon_{ij}})$$

$$\sigma^2_{\varepsilon_{ij}} = 0.10 \times \mu_{d_{ij}}, \mu_{d_{ij}} = g(SP_{ij}) = b_{ij} - a_{ii,j} \times SP_{ij}$$

b_{ij} (units) (intercept)	j= 1 (N)	j= 2 (G)
i= 1 (WG)	11 200	13 400
i =2 (SHA)	4 800	0

$a_{ii,j}$ (units) (elasticity)	j= 1 (N)	j= 2 (G)
i= 1 (WG)	5	3
i =2 (SHA)	4	0

- Production Cost (PC_i):

$$PC_i \sim N(\mu_{PC_i}, \sigma^2_{PC_i}) \text{ and } \sigma^2_{PC_i} = 0.10 \times \mu_{PC_i}$$

	i= 1 (WG)	i= 2 (SHA)
μ_{PC_i} (TL)	1 132	123
$\sigma^2_{PC_i}$ (TL)	113.2	12.3

- Lower bounds for decision variables x_{ij} :

l_{ij} (units) (lower bounds))	j= 1 (N)	j= 2 (G)
i= 1 (WG)	450	620
i =2 (SHA)	450	0

- Unit production capacities:

$c_i = (c_1, c_2) = (0.0052, 0.00219)$ hrs.

- Total production capacities:

$C_i = (C_1, C_2) = (8700, 8700)$ hrs.

<u>Levels of Parameters (Factors):</u>

(TL)	PC_1	PC_2	SP_{11}	SP_{12}	SP_{21}
High (H)	1142.6395	126.5071	1782.3004	2226.8728	194.3589
Low (L)	1121.3605	119.4929	1755.6996	2197.1272	185.6411

(Units)	SP_{11} (H)	SP_{11} (L)	SP_{12} (H)	SP_{12} (L)	SP_{21} (H)	SP_{21} (L)
d_{11} (H)	2303.6258	2437.0632				
d_{11} (L)	2273.3702	2405.9408				
d_{12} (H)			6745.3034	6834.7117		
d_{12} (L)			6693.4598	6782.5251		
d_{21} (H)					4042.6207	4077.5787
d_{21} (L)					4002.5081	4037.2926

<u>Number of Structured Scenarios</u>:

$$n = 2^{2\sum_{i=1}^{k} m_i + k} = 2^{2(m_1+m_2)+k} = 2^{2(3)+2} = 2^8 = 256$$

Best Solutions of Example 3 with respect to Solution Approaches:

Performance Measure	**Structured Scenarios**	**Deterministic Case**
Max. Regret	1.8545×10^5 (min-max regret solution)	1.8755×10^5 (extreme scenario solution)
Max. Regret SNR	− 231.6876 (regret SNR solution)	−233.6834 (extreme scenario solution)
Max. (P-R) SNR	319.9787 ((P-R) SNR solution)	319.9095 (extreme scenario solution)

Table 5.9: Results of Example 3 (Different Candidate Products Set)

a) Best Solutions of Decision Variables

Solution Approach	Scenario #	x_{11}^* (10^3)	x_{12}^* (10^3)	x_{21}^* (10^3)
Min-Max Regret	121, 125	2.3036	6.7453	4.0373
	249, 253	2.3036	6.7453	4.0373
Max. of Regret SNR	121, 125	2.3036	6.7453	4.0373
	249, 253	2.3036	6.7453	4.0373
Max. of (P-R) SNR	121, 125	2.3036	6.7453	4.0373
	249, 253	2.3036	6.7453	4.0373
Deterministic Case	257	2.3550	6.7640	4.0440

b) Statistics Generated for the Best Solutions $(x_{11}^*, x_{12}^*, x_{21}^*)$

Scenario #	***Profit Range*** (10^6)	***Mean Profit*** (10^6)	***Profit Std. Dev.*** (10^5)	***Regret Range***	***Mean Regret*** (10^4)	***Regret Std. Dev.*** (10^4)	***P−R Range*** (10^6)	***Mean P−R*** (10^6)	***P−R Std. Dev.*** (10^5)
121	(8.7638, 9.2818)	8.9776	1.3096	$(-6.2957\times10^{-7}, 1.8547\times10^5)$	9.6724	4.6699	(8.5854, 9.2814)	8.8809	1.5818
125	(8.7638, 9.2818)	8.9776	1.3096	$(0, 1.8547\times10^5)$	9.6724	4.6699	(8.5854, 9.2814)	8.8809	1.5818
249	(8.7638, 9.2818)	8.9776	1.3096	$(-7.3016\times10^{-7}, 1.8547\times10^5)$	9.6724	4.6699	(8.5854, 9.2814)	8.8809	1.5818
253	(8.7638, 9.2818)	8.9776	1.3096	$(-1.4156\times10^{-7}, 1.8547\times10^5)$	9.6724	4.6699	(8.5854, 9.2814)	8.8809	1.5818
257	(8.7272, 9.2313)	8.9618	1.2399	$(5.0942\times10^4, 1.8755\times10^5)$	1.1247×10^5	3.7874	(8.5530, 9.1768)	8.8494	1.4133

EXAMPLE 4: ***Volatile Market Conditions***

Suppose that "Global" market is defined as a volatile market due to economic crisis in Europe. Then company wants to see the results of Global market in two broad regions: West Europe Market and East Europe Market. The variances of the parameters in these markets are higher than the existing conditions of the company.

Parameters:

- k=2 (WG and SHA)
- m_1 =1,2,3 and m_2 =1 ("1": N, "2": West Europe (WE), "3": East Europe(EE))
- Product-Market Matrix (H):

$$\mathbf{H} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & 0 & 0 \end{bmatrix}$$

- Product Prices (SP_{ij}):

$$SP_{ij} \sim N(\mu_{SP_{ij}}, \sigma^2_{SP_{ij}}) \ , \ \sigma^2_{SP_{ij}} = 0.25 \times \mu_{SP_{ij}} \text{ for } i = 1 \text{ and } j = 2, 3$$

$$\sigma^2_{SP_{ij}} = 0.10 \times \mu_{SP_{ij}} \text{ for } i = 1, j = 1, \text{ and } i = 2, \ j = 1$$

$\mu_{SP_{ij}}$ (TL)	j= 1 (N)	j= 2 (WE)	j= 3 (EE)
i= 1(WG)	1 580	2 170	1 780
i =2 (SHA)	190	0	0

$\sigma^2_{SP_{ij}}$ (TL)	j= 1 (N)	j= 2 (WE)	j= 3 (EE)
i= 1 (WG)	158	542.5	445
i =2 (SHA)	19	0	0

- Demand (d_{ij}):

$$d_{ij}(SP_{ij}) = b_{ij} - a_{ii,j} \times SP_{ij} + \varepsilon_{ij}, \quad \varepsilon_{ij} \sim N(0, \sigma^2_{\varepsilon_{ij}})$$

$$\sigma^2_{\varepsilon_{ij}} = 0.25 \times \mu_{d_{ij}}, \ \ \mu_{d_{ij}} = g(SP_{ij}) = b_{ij} - a_{ii,j} \times SP_{ij}$$

b_{ij} (units) (intercept)	j= 1 (N)	j= 2 (WE)	j= 3 (EE)
i= 1 (WG)	11 200	7 800	5 600
i =2 (SHA)	4 800	0	0

$a_{ii,j}$ (units) (elasticity)	j= 1 (N)	j= 2 (WE)	j= 3 (EE)
i= 1 (WG)	5	3	2
i =2 (SHA)	4	0	0

- Production Cost (PC_i):

$PC_i \sim N(\mu_{PC_i}, \sigma^2_{PC_i})$ and $\sigma^2_{PC_i} = 0.15 \times \mu_{PC_i}$ for i =1, $\sigma^2_{PC_i} = 0.10 \times \mu_{PC_i}$ for i =2.

	i= 1 (WG)	i= 2 (SHA)
μ_{PC_i} (TL)	1 058	123
$\sigma^2_{PC_i}$ (TL)	158.7	12.3

- Lower bounds for decision variables x_{ij} :

l_{ij} (units) (lower bounds))	j= 1 (N)	j= 2 (WE)	j= 3 (EE)
i= 1 (WG)	350	340	200
i =2 (SHA)	450	0	0

- Unit production capacities:

$c_i = (c_1, c_2)$ = (0.000608, 0.00219) hrs.

- Total production capacities:

$C_i = (C_1, C_2)$ = (8700, 8700) hrs.

<u>Levels of Parameters (Factors):</u>

(TL)	PC_1	PC_2	SP_{11}	SP_{12}	SP_{13}	SP_{21}
High (H)	1070.5976	126.5071	1592.5698	2193.2916	1801.0950	194.3589
Low (L)	1045.4024	119.4929	1567.4302	2146.7084	1758.9050	185.6411

(Units)	SP_{11} (H)	SP_{11} (L)
d_{11} (H)	3265.5990	3391.8440
d_{11} (L)	3208.7030	3333.8540

(Units)	SP_{12} (H)	SP_{12} (L)
d_{12} (H)	1237.5903	1378.3130
d_{12} (L)	1202.6701	1341.4366

(Units)	SP_{13} (H)	SP_{13} (L)
d_{13} (H)	2020.1584	2105.0055
d_{13} (L)	1975.4616	2059.3745

(Units)	SP_{21} (H)	SP_{21} (L)
d_{21} (H)	4054.2762	4089.2846
d_{21} (L)	3990.8526	4025.5866

Number of Structured Scenarios:

$$n = 2^{2\sum_{i=1}^{k} m_i + k} = 2^{2(m_1+m_2)+k} = 2^{2(3+1)+2} = 2^{10} = 1024$$

Best Solutions of Example 4 with respect to Solution Approaches:

Performance Measure	**Structured Scenarios**	**Deterministic Case**
Max. Regret	2.8603×10^5 (min-max regret solution)	2.7989×10^5 (extreme scenario solution)
Max. Regret SNR	− 240.7114 (regret SNR solution)	−241.3956 (extreme scenario solution)
Max. (P-R) SNR	306.7590 ((P-R) SNR solution)	306.6263 (extreme scenario solution)

Table 5.10: Results of Example 4 (Volatile Market Conditions)

a) Best Solutions of Decision Variables

Solution Approach	Scenario #	x_{11}^* (10^3)	x_{12}^* (10^3)	x_{13}^* (10^3)	x_{21}^* (10^3)
Max-Min Regret	1025	3.3000	1.2900	2.0400	4.0400
Max. of Regret SNR	505, 509	3.2656	1.2376	2.0202	4.0256
	1017,1021	3.2656	1.2376	2.0202	4.0256
Max. of (P-R) SNR	505, 509	3.2656	1.2376	2.0202	4.0256
	1017,1021	3.2656	1.2376	2.0202	4.0256
Deterministic Case	1025	3.3000	1.2900	2.0400	4.0400

b) Statistics Generated for the Best Solutions $(x_{11}^*, x_{12}^*, x_{13}^*, x_{21}^*)$

Scenario #	***Profit Range*** (10^6)	***Mean Profit*** (10^6)	***Profit Std. Dev.*** (10^5)	***Regret Range***	***Mean Regret*** (10^5)	***Regret Std. Dev.*** (10^4)	***P−R Range*** (10^6)	***Mean P−R*** (10^6)	***P−R Std. Dev.*** (10^5)
505	(4.5504, 5.0354)	4.7436	1.3098	(-0.0084, 2.8603×10^5)	1.5362	6.9586	(4.2937, 5.0333)	4.5900	1.4304
509	(4.5504, 5.0354)	4.7436	1.3098	(0, 2.8603×10^5)	1.5362	6.9586	(4.2937, 5.0333)	4.5900	1.4304
1017	(4.5504, 5.0354)	4.7436	1.3098	(-0.0073, 2.8603×10^5)	1.5362	6.9586	(4.2937, 5.0333)	4.5900	1.4304
1021	(4.5504, 5.0354)	4.7436	1.3098	(−0.0047, 2.8603×10^5)	1.5362	6.9586	(4.2937, 5.0333)	4.5900	1.4304
1025	(4.4309, 4.9771)	4.7282	1.1242	(8.6476×10^4, 2.7989×10^5)	1.6907	4.3278	(4.1556, 4.8598)	4.5591	1.3482

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EXAMPLE 5: ***New Market Entrance***

Suppose that company is planning to enter the Global market with Small Household Appliances product line. New market for this line has higher risk and represented by higher variance of product prices.

Parameters:

- k=2 (White Goods (WG), Small Household Appliances (SHA))
- m_1 =1,2 and m_2 =1 (“1”: National market (N), “2”: Global market (G))
- Product-Market Matrix (H)

$$\mathbf{H} = \begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix}$$

- Product Prices (SP_{ij}): (Average prices for each product line at each market)

$SP_{ij} \sim N(\mu_{SP_{ij}}, \sigma^2_{SP_{ij}})$, $\sigma^2_{SP_{ij}} = 0.10 \times \mu_{SP_{ij}}$ for i = 1, j = 1, 2 and i =2, j = 1,

$\sigma^2_{SP_{ij}} = 0.30 \times \mu_{SP_{ij}}$ for i =2, j = 2.

$\mu_{SP_{ij}}$ (TL)	j= 1 (N)	j= 2 (G)
i= 1(WG)	1 580	1 975
i =2 (SHA)	190	238

$\sigma^2_{SP_{ij}}$ (TL)	j= 1 (N)	j= 2 (G)
i= 1 (WG)	158	197.5
i =2 (SHA)	19	71.40

- Demand (d_{ij}):

$$d_{ij}(SP_{ij}) = b_{ij} - a_{ii,j} \times SP_{ij} + \varepsilon_{ij}, \quad \varepsilon_{ij} \sim N(0, \sigma^2_{\varepsilon_{ij}})$$

$$\sigma^2_{\varepsilon_{ij}} = 0.10 \times \mu_{d_{ij}}, \quad \mu_{d_{ij}} = g(SP_{ij}) = b_{ij} - a_{ii,j} \times SP_{ij}$$

b_{ij} (units) (intercept)	j= 1 (N)	j= 2 (G)
i= 1 (WG)	11 200	13 400
i =2 (SHA)	4 800	3 600

$a_{ii,j}$ (units) (elasticity)	j= 1 (N)	j= 2 (G)
i= 1 (WG)	5	3
i =2 (SHA)	4	3

- Production Cost (PC_i):

$$PC_i \sim N(\mu_{PC_i}, \sigma^2_{PC_i}) \text{ and } \sigma^2_{PC_i} = 0.10 \times \mu_{PC_i}$$

	i= 1 (WG)	i= 2 (SHA)
μ_{PC_i} (TL)	1 058	123
$\sigma^2_{PC_i}$ (TL)	105.8	12.3

- Lower bounds for decision variables x_{ij} :

l_{ij} (units) (lower bounds))	j= 1 (N)	j= 2 (G)
i= 1 (WG)	350	540
i =2 (SHA)	450	350

- Unit production capacities:

  $c_i = (c_1, c_2)$ = (0.000608, 0.00219) hrs.

- Total production capacities:

  $C_i = (C_1, C_2)$ = (8700, 8700) hrs.

<u>Levels of Parameters (Factors):</u>

(TL)	PC_1	PC_2	SP_{11}	SP_{12}	SP_{21}	SP_{22}
High (H)	1068.2859	126.5071	1592.5698	1989.0535	194.3589	246.4498
Low (L)	1047.7141	119.4929	1567.4302	1960.9465	185.6411	229.5502

$SP_{ij}(H) = \mu_{SP_{ij}} + \sigma_{SP_{ij}}$, $SP_{ij}(L) = \mu_{SP_{ij}} - \sigma_{SP_{ij}}$ and

$PC_i(H) = \mu_{PC_i} + \sigma_{PC_i}$, $PC_i(L) = \mu_{PC_i} - \sigma_{PC_i}$.

(Units)	SP_{11} (H)	SP_{11} (L)
d_{11} (H)	3255.1431	3381.1871
d_{11} (L)	3219.1589	3344.5109

(Units)	SP_{12} (H)	SP_{12} (L)
d_{12} (H)	7460.1027	7544.5779
d_{12} (L)	7405.5763	7489.7431

(Units)	SP_{21} (H)	SP_{21} (L)
d_{21} (H)	4042.6207	4077.5786
d_{21} (L)	4002.5081	4037.2926

(Units)	SP_{22} (H)	SP_{22} (L)
d_{22} (H)	2877.5641	2928.4121
d_{22} (L)	2843.7371	2894.2867

$d_{ij}(H) = g(SP_{ij}) + \sigma_{\varepsilon_{ij}}$, $d_{ij}(L) = g(SP_{ij}) - \sigma_{\varepsilon_{ij}}$ and $g(SP_{ij}) = b_{ij} - a_{ii,j} \times SP_{ij}$,

$\sigma^2_{\varepsilon_{ij}} = 0.10 \times g(SP_{ij})$.

Number of Structured Scenarios:

$$n = 2^{2\sum_{i=1}^{k} m_i + k} = 2^{2(m_1+m_2)+k} = 2^{2(2+2)+2} = 2^{10} = 1024$$

Best Solutions of Example 5 with respect to Solution Approaches:

Performance Measure	**Structured Scenarios**	**Deterministic Case**
Max. Regret	1.5261×10^5 (min-max regret solution)	1.7915×10^5 (extreme scenario solution)
Max. Regret SNR	− 228.4377 (regret SNR solution)	−231.2610 (extreme scenario solution)
Max. (P-R) SNR	320.2708 ((P-R) SNR solution)	320.2050 (extreme scenario solution)

Table 5.11: Results of Example 5 (New Market Entrance)

a) Best Solutions of Decision Variables

Solution Approach	Scenario #	x^*_{11} (10^3)	x^*_{12} (10^3)	x^*_{21} (10^3)	x^*_{22} (10^3)
Max-Min Regret	484, 500, 996,1012	3.2551	7.4601	4.0373	2.8776
Max. of Regret SNR	484, 500, 996,1012	3.2551	7.4601	4.0373	2.8776
Max. of (P-R) SNR	484, 500, 996,1012	3.2551	7.4601	4.0373	2.8776
Deterministic Case	1025	3.3000	7.4750	4.040	2.8860

b) Statistics Generated for the Best Solutions $(x_{11}^*, x_{12}^*, x_{21}^*, x_{22}^*)$

Scenario #	***Profit Range*** (10^6)	***Mean Profit*** (10^6)	***Profit Std. Dev.*** (10^5)	***Regret Range***	***Mean Regret*** (10^4)	***Regret Std. Dev.*** (10^4)	***P−R Range*** (10^6)	***Mean P−R*** (10^6)	***P−R Std. Dev.*** (10^5)
484	(8.8194, 9.4637)	9.0950	1.4865	$(-3.6322\times10^{-7}, 1.5261\times10^{5})$	8.3073	3.7872	(8.6734, 9.4633)	9.0119	1.6807
500	(8.8194, 9.4637)	9.0950	1.4865	$(0, 1.5261\times10^{5})$	8.3073	3.7872	(8.6734, 9.4633)	9.0119	1.6807
996	(8.8194, 9.4637)	9.0950	1.4865	$(-4.2841\times10^{-7}, 1.5261\times10^{5})$	8.3073	3.7872	(8.6734, 9.4633)	9.0119	1.6807
1012	(8.8194, 9.4637)	9.0950	1.4865	$(-1.0245\times10^{-7}, 1.5261\times10^{5})$	8.3073	3.7872	(8.6734, 9.4633)	9.0119	1.6807
1025	(8.8055, 9.3971)	9.0798	1.3976	$(3.6410\times10^{4}, 1.7915\times10^{4})$	9.8291	3.7328	(8.6466, 9.3371)	8.9815	1.5179

5.3 ANALYSIS OF THE RESULTS

In order to deal with the uncertainty, the scenarios were created according to the methodology explained in Chapter 4 (Table 5.2). The MATLAB code was used to run and get the experimental results. For each scenario generated by full factorial design of experiment, an optimal solution set is found through the deterministic product mix model (Table 5.3). Then the optimal set found for a scenario is tested for different scenarios. In short, each solution found by the deterministic model is evaluated under different predetermined scenario realizations. Next, objective function values for all optimal product sets and for all scenarios are found and located to a matrix (Table 5.4). Then, the maximum values of each scenario are determined in order to find the best solutions by using *Min-Max Regret* approach. Afterwards, every objective function value is subtracted from the maximum value of the corresponding scenario, and the new results are formed the regret matrix (Table 5.5). After that, the maximum of the regret values is found for each product set (row), and a column for maximum regrets is formed (Table 5.6). Meanwhile, for each product set, *Signal-to-Noise Ratios of Regrets* (SNR_R) and *Signal-to-Noise Ratios of Regret Free Profits* (SNR_{P-R}) are found in order to find the solutions to these approaches. Finally, SNR_R and SNR_{P-R} columns are formed (Table 5.6). As a result, the set(s) of the products

- with the smallest maximum regret,
- with the largest SNR_R, and
- with the largest SNR_{P-R}

are chosen as the best solution to the product mix problem under uncertainty. The results by three approaches can be either the same or different. These results are discussed below.

In analysis of the results, our major interest is to compare the results of deterministic and probabilistic approaches. In order to make this comparison, the mean values of the parameters of prices, costs and demand values are taken as deterministic. It is seen that the results obtained by three approaches are very close to each other most of the time. When the maximum regrets of the chosen product mixes are analyzed, it is observed that the maximum regret value of the product mix of the deterministic approach is greater than that of the product mix of the probabilistic approach by 1.13% to 17.8%. Among five example cases, two examples show different results regarding the min-max regret approach: In Example 2 and Example 4, min-max regret approach yields the solution of the deterministic case as the best solution. In such a case, one may also consider looking at the expected value of regret values to check the validity of the solution proposed by the min-max regret approach. If the expected regret value of deterministic case solution were smaller than that of the other chosen solutions, it would be possible to say that the solution of deterministic case was a better solution. However, when the regret data of the deterministic case is analyzed, it is seen that mean regret value of the deterministic case solution is greater than those of the other chosen product mix solutions. At the same time, mean profit value and mean regret free profit value of the deterministic case solution are smaller than those of the other chosen product mix solutions. This indicates that it is possible to obtain higher profit on the average with other chosen product mix solutions. Therefore, the acceptance of the solution indicated by the min-max regret approach would lead to an inferior decision because there are other solutions which provide higher profit values on the average. The mean regret values of the deterministic case solution are compared with those of the probabilistic approach solutions. The results of this analysis are shown in Table 5.12.

Table 5.12: Mean Regret Values of Deterministic versus Probabilistic Approach Solutions

Mean Regret	**Probabilistic** (10^4)	**Deterministic** (10^4)	$\left[(\bar{R}_d - \bar{R}_p)/\bar{R}_p\right] \times 100\,(*)$
Example-1	8.0180	9.5304	18.86%
Example-2	2.3358	2.6304	12.61%
Example-3	9.6724	11.2470	16.28%
Example-4	1.5362	1.6907	10.06%
Example-5	8.3073	9.8291	18.32%

(*) $\bar{R}_d$: Deterministic Solution's Mean Regret Value,

$\bar{R}_p$: Probabilistic Solution's Mean Regret Value

A similar analysis can be done for both mean of profit values and mean of regret free profit values. The results of this analysis are shown in Table 5.13.

Table 5.13: Mean Profit and Mean Regret Free Profit of Deterministic versus Probabilistic Approach Solutions

	Mean Profit			**Mean Regret Free Profit**		
	Probabilistic (10^6)	Deterministic (10^6)	% (*)	Probabilistic (10^6)	Deterministic (10^6)	% (*)
Example-1	8.7662	8.7511	0.17	8.6860	8.6558	0.35
Example-2	9.2521	9.2212	0.34	9.0199	8.9582	0.69
Example-3	8.9776	8.9618	0.18	8.8809	8.8494	0.36
Example-4	4.7436	4.7282	0.33	4.5900	4.5591	0.68
Example-5	9.0950	9.0798	0.17	9.0119	8.9815	0.34

(*) Percentage difference from deterministic case solution

It is seen that the probabilistic approach provides smaller mean regret values and larger mean profit and mean regret free profit values when they are compared with the deterministic approach. In addition to this, SNR results enable the system to find a solution set with small mean and variance. Thus, SNR_R is applied to the regret matrix, and SNR_{P-R} is applied to the Profit-Regret (P-R) matrix. It is seen that both SNR_R and SNR_{P-R} provide better results in the probabilistic approach when these measures are compared with the ones in the deterministic case. In all examples, larger profit values are attainable using the probabilistic approach. As a result, the probabilistic approach provides better results regarding both the mean and variance values of regret and profit and regret free profit as implied by improving the SNR values.

Although it was not observed in our numerical experiments results, there might be a case that a larger profit value could be attainable with a larger value of regret if SNR_R approach was used. To secure ourselves against such a case, SNR_{P-R} approach was introduced. The following graphical analyses are made to compare the probabilistic and deterministic approaches considering the regret free profits to which SNR_{P-R} approach is based.

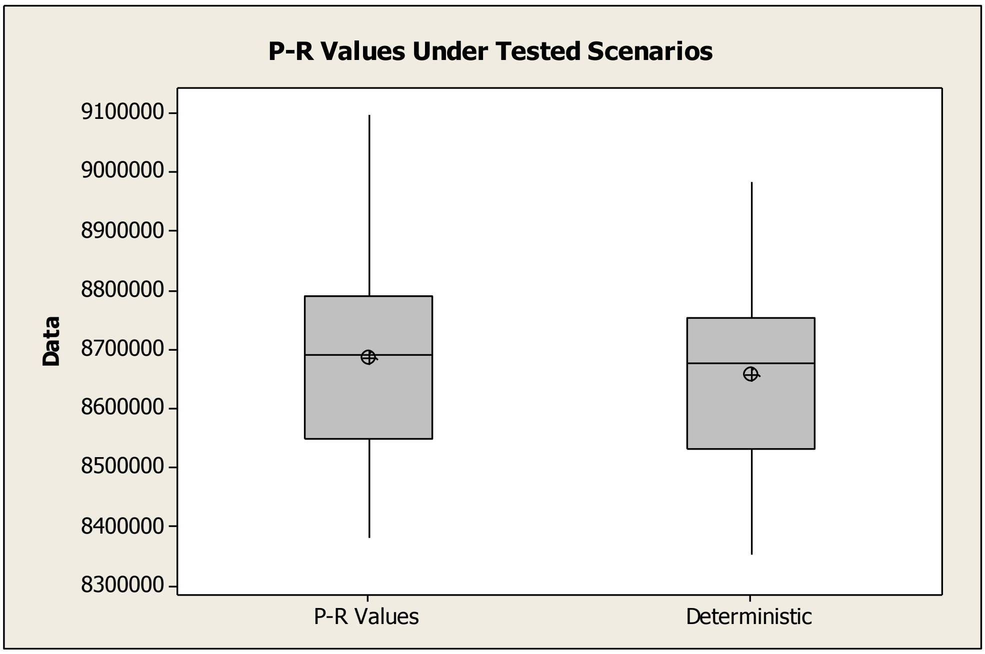

Figure 5.2: Box Plot of Regret Free Profits of Deterministic and Probabilistic Approaches (Example-1)

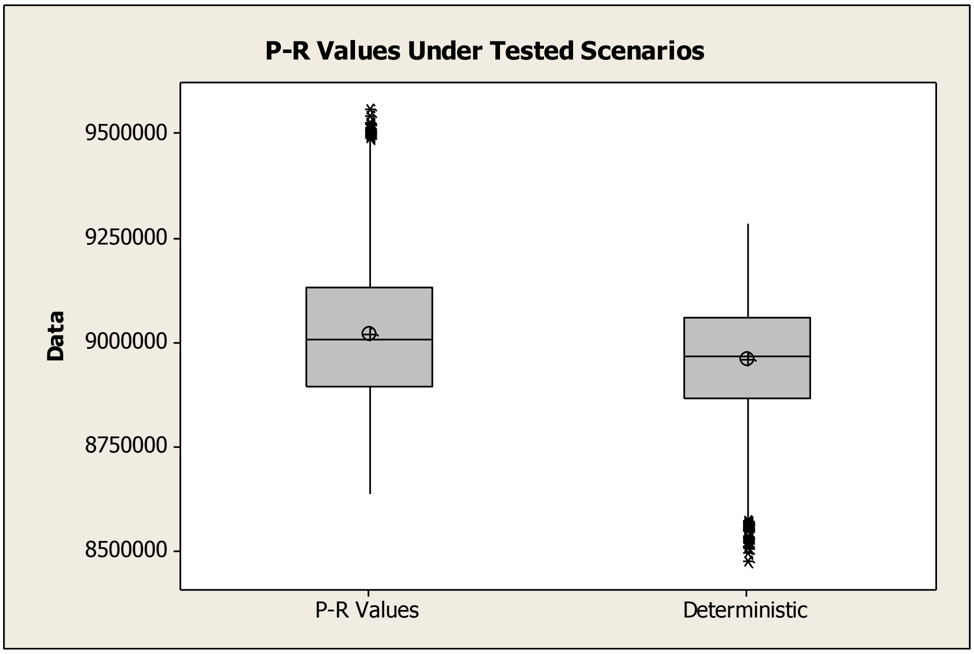

Figure 5.3: Box Plot of Regret Free Profits of Deterministic and Probabilistic Approaches (Example-2)

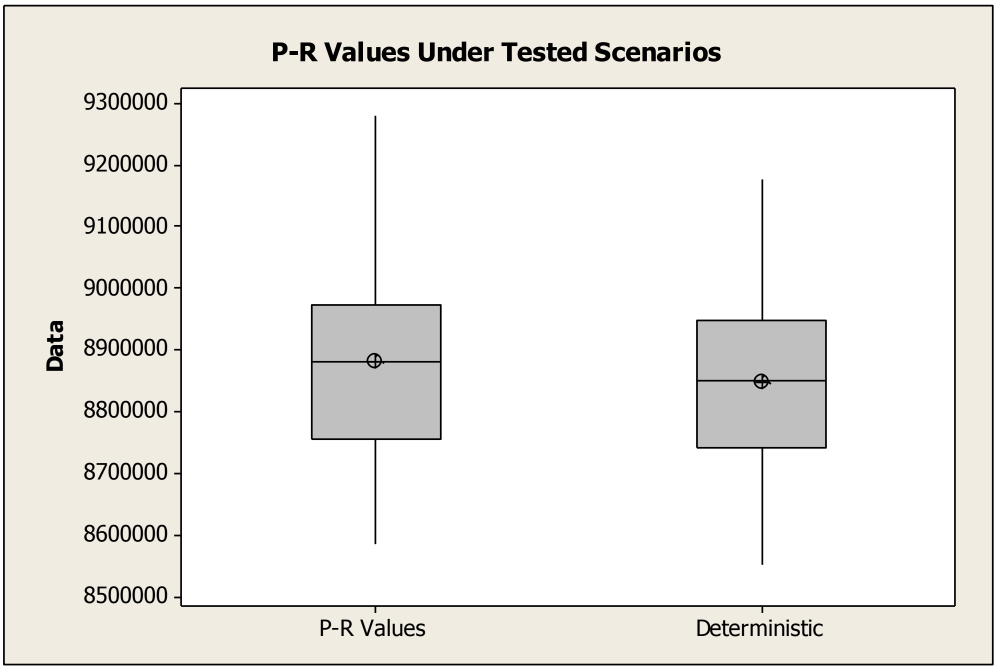

Figure 5.4: Box Plot of Regret Free Profits of Deterministic and Probabilistic Approaches (Example-3)

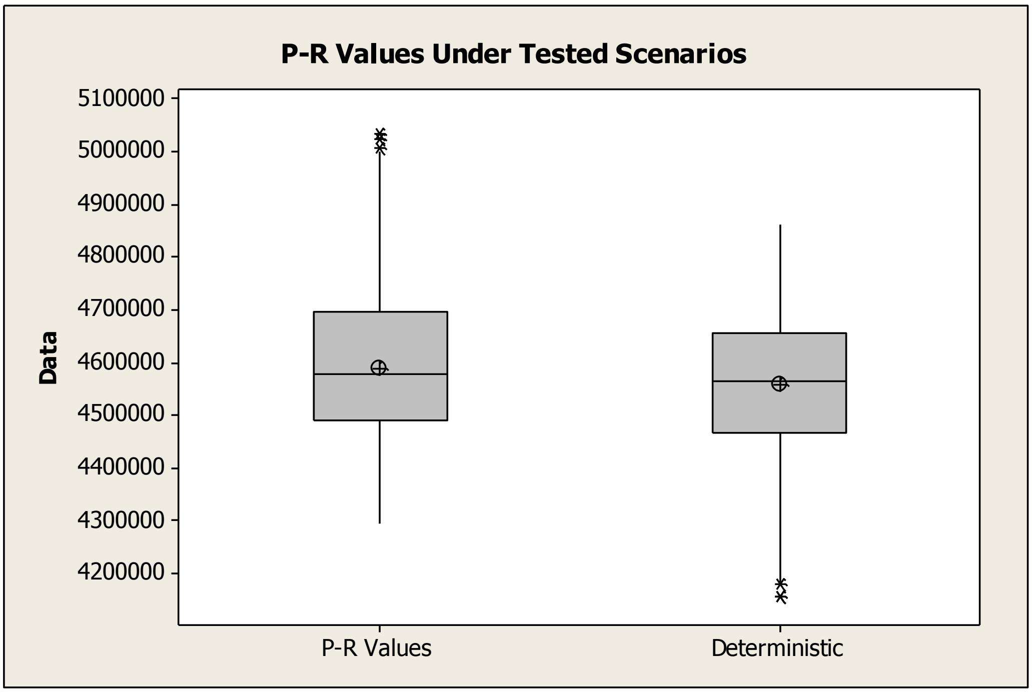

Figure 5.5: Box Plot of Regret Free Profits of Deterministic and Probabilistic Approaches (Example-4)

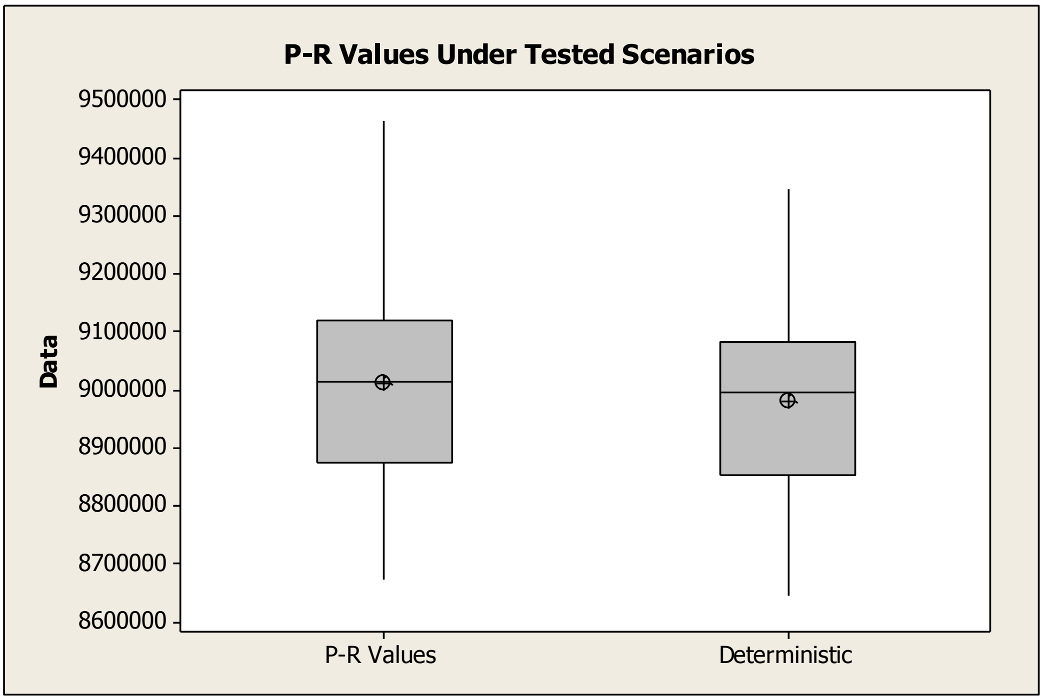

Figure 5.6: Box Plot of Regret Free Profits of Deterministic and Probabilistic Approaches (Example-5)

Box-plots are used to assess and compare the sample distributions. In our case, "P-R Values" represents the first sample distribution which is the regret free profit values of the chosen product mix under the other scenarios. The second sample distribution "Deterministic" consists of data of the regret free profit values obtained by the product mix of the deterministic case under the other scenarios. Firstly, it is seen that box-plots of all examples show that the mean values of the probabilistic P-R values are higher than the corresponding mean value of the deterministic case. Box-plots of Example 1, Example 3 and Example 5 show similar characteristics. The probabilistic P-R values and deterministic P-R values in those examples have both a slight negative skewness, since larger box areas are observed under the median in box-plots of these examples. Also, no outliers are present in these box-plots of the mentioned examples. However, the box-plots of Example 2 and Example 4 show totally different picture. In these box-plots, while probabilistic P-R values have positive skewness, deterministic P-R values have negative skewness. Besides, probabilistic P-R values consist of some unusual large observations and deterministic P-R values consist of some unusual small observations. It means that reverse situation exists regarding the regret values of those examples. In Example 2 and Example 4, the values of skewness statistic of the regret values of the chosen set of products by the probabilistic approach are (− 0.0348) and (−0.0378) respectively. On the other hand, skewness statistics of regret values of the deterministic case are 0.1297 and 0.3316 for Example 2 and Example 4 respectively. Remember that Example 4 is a descriptive case for volatile market conditions which reflects the environment with high degree of uncertainty. Higher uncertainty is represented by higher variances of the parameters of prices, costs and demands in this example. It is seen that skewness statistics of this example are relatively higher than the others. The results of Example 4 show that we have the possibility of obtaining higher regret free profits by probabilistic approach in high uncertainty cases than those obtained by the deterministic approach.

A further analysis can be done to check the normality of the regret free profit values of the chosen product mix solutions in the examples. For this purpose, the paired differences are obtained and their normality is tested (Figure 5.7). This analysis is presented below.

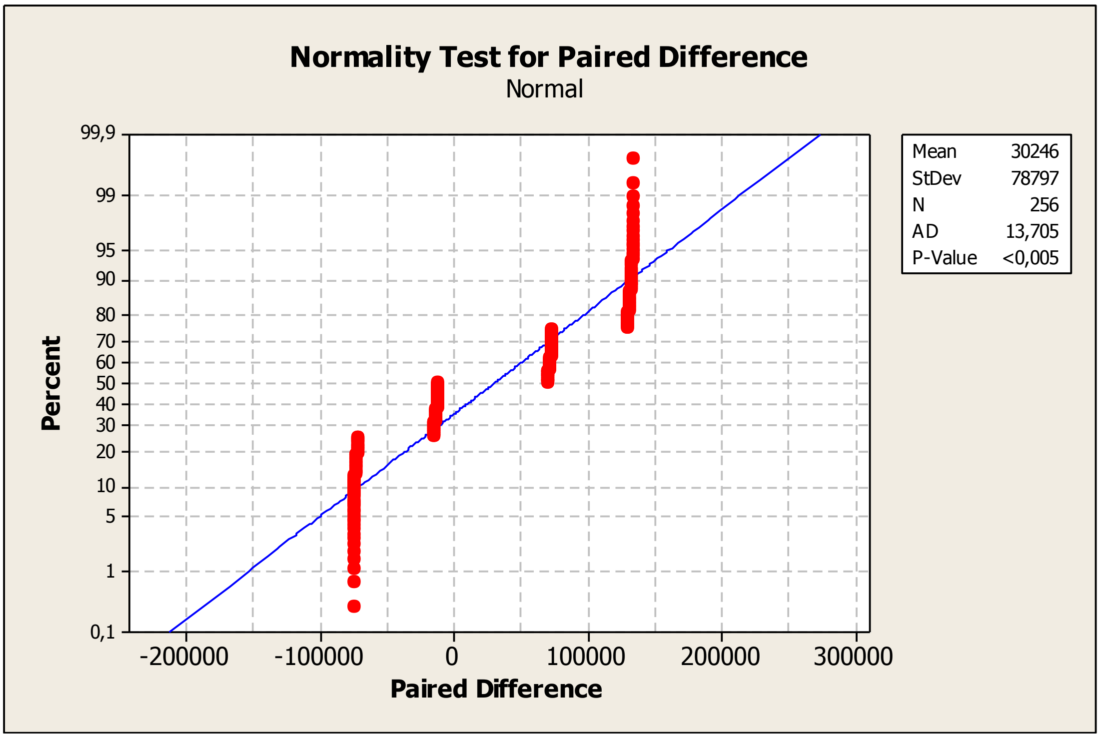

Figure 5.7: Normality Test of Regret Free Profits Differences (Example-1)

Normality test was made by MINITAB which was depicted in Figure 5.7. Normality test generates a normal probability plot and performs a hypothesis test to examine whether or not the observations of the sample distribution follow a normal distribution. The result of the normality test performed for paired differences (probabilistic-deterministic) of P-R values of the chosen product mix of Example 1 provides us strong evidence to reject the hypothesis of the normal distribution of paired differences of P-R values. Similar results for the other examples are presented below.

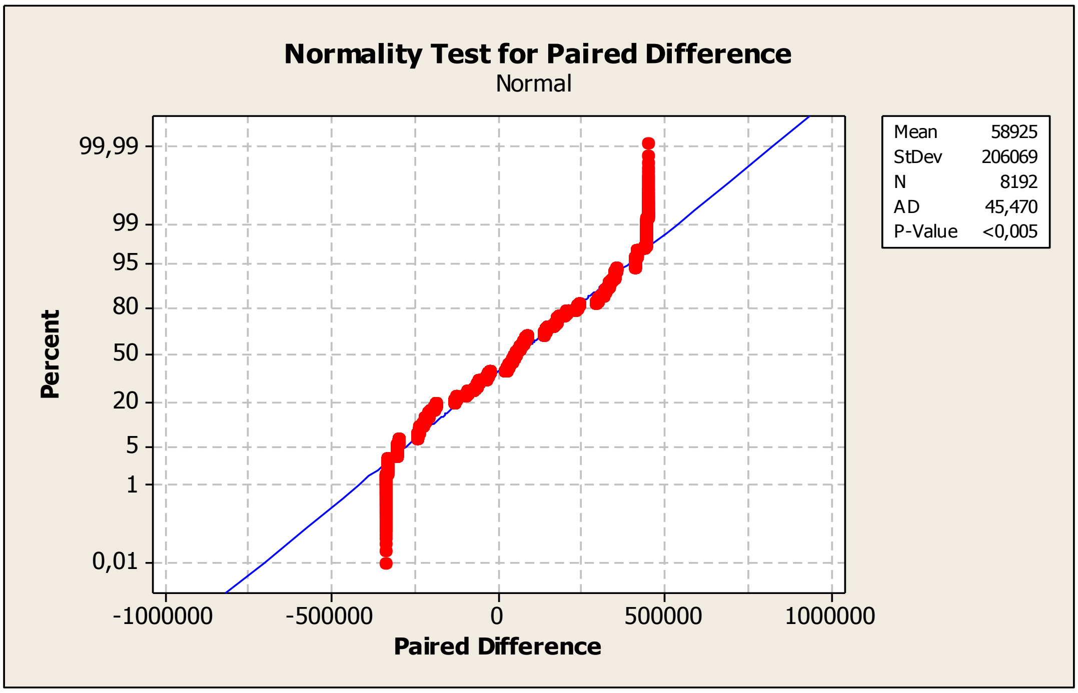

Figure 5.8: Normality Test of Regret Free Profits Differences (Example-2)

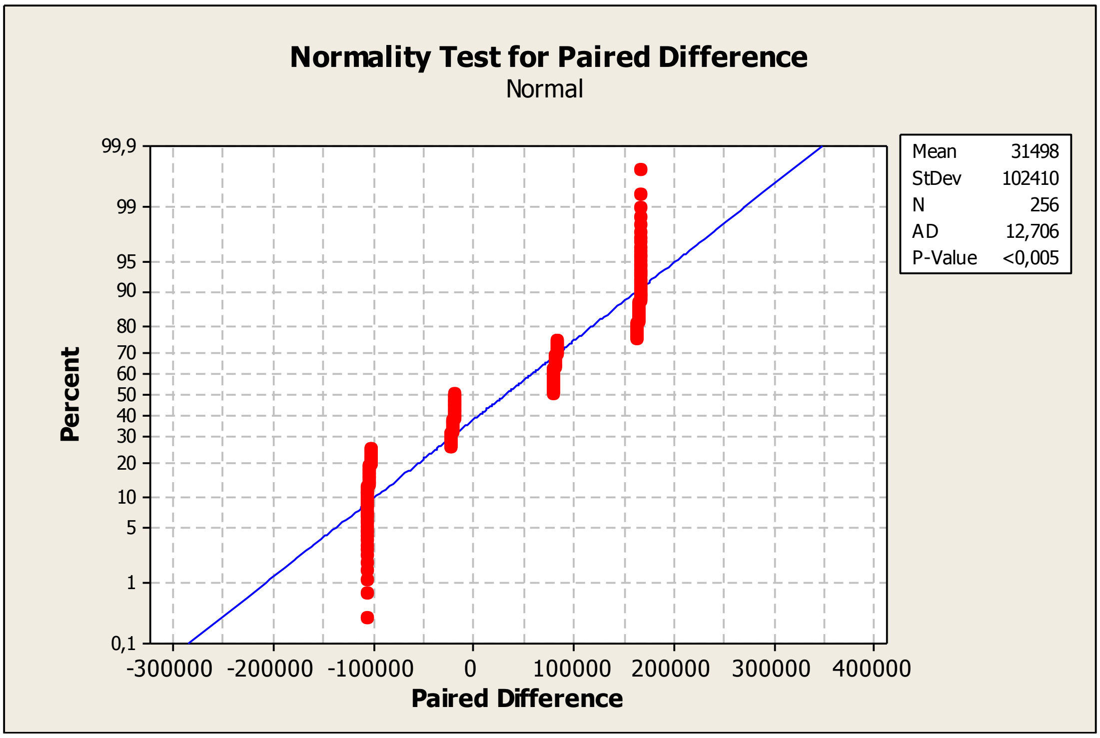

Figure 5.9: Normality Test of Regret Free Profits Differences (Example-3)

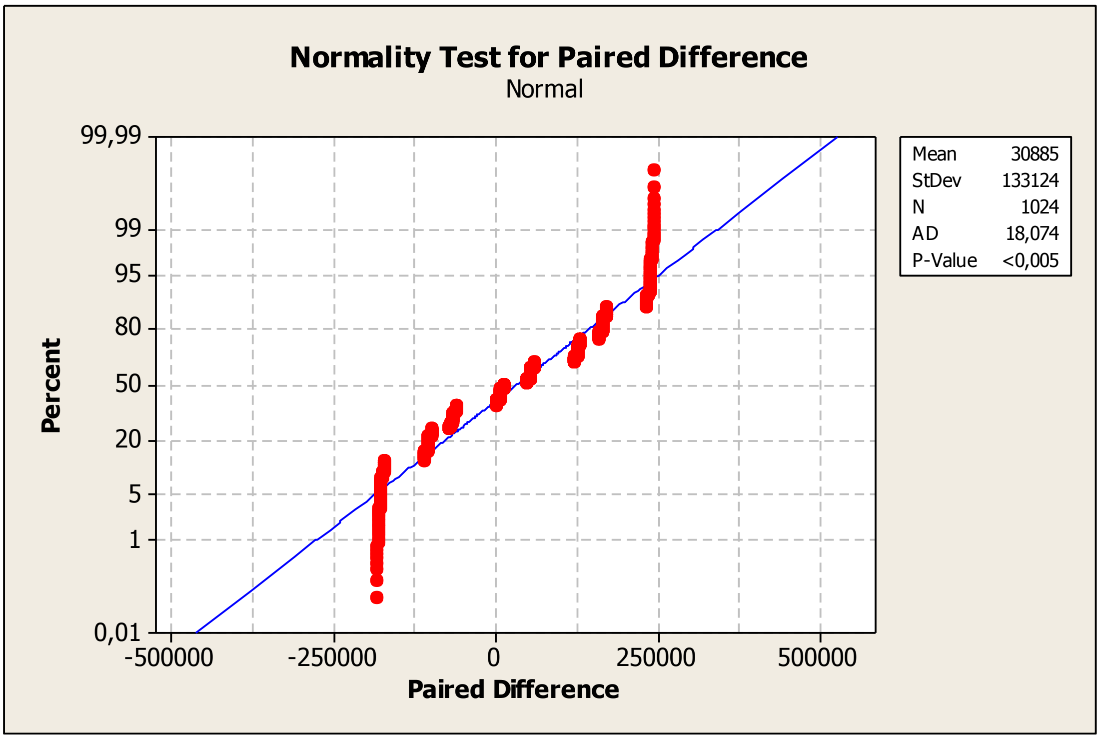

Figure 5.10: Normality Test of Regret Free Profits Differences (Example-4)

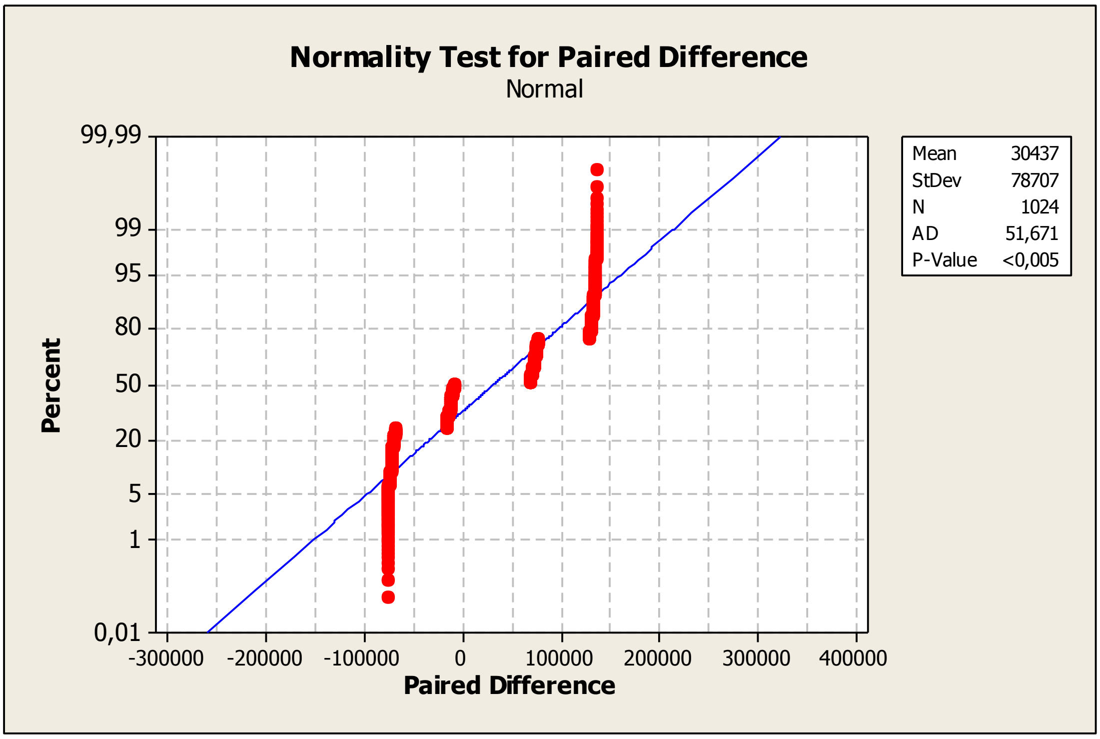

Figure 5.11: Normality Test of Regret Free Profits Differences (Example-5)

Since the normality assumption is not justified, some type of nonparametric inference for mean location of the differences is more appropriate. For this purpose, Wilcoxon signed-rank test can be applied which is not based on normality assumption.

Table 5.14: Output of Wilcoxon Signed Rank Test (Example-1)

Wilcoxon Signed Rank Test: Difference

```
Test of median = 0,000000 versus median > 0,000000

                 N for   Wilcoxon         Estimated
              N   Test  Statistic      P     Median
Difference  256    256    23104,0  0,000      30246
```

Table 5.15: Output of Wilcoxon Signed Rank Test (Example-2)

Wilcoxon Signed Rank Test: Difference

```
Test of median = 0,000000 versus median > 0,000000

                  N for    Wilcoxon         Estimated
               N   Test   Statistic      P     Median
Difference  8192   8192  21889536,0  0,000      58925
```

Table 5.16: Output of Wilcoxon Signed Rank Test (Example-3)

Wilcoxon Signed Rank Test: Difference

```
Test of median = 0,000000 versus median > 0,000000

                 N for   Wilcoxon         Estimated
              N   Test  Statistic      P     Median
Difference  256    256    20544,0  0,000      31498
```

Table 5.17: Output of Wilcoxon Signed Rank Test (Example-4)

Wilcoxon Signed Rank Test: Difference

```
Test of median = 0,000000 versus median > 0,000000

                  N for   Wilcoxon         Estimated
               N   Test  Statistic      P     Median
Difference  1024   1024   321856,0  0,000      30887
```

Table 5.18: Output of Wilcoxon Signed Rank Test (Example-5)

Wilcoxon Signed Rank Test: Difference

```
Test of median = 0,000000 versus median > 0,000000

                  N for   Wilcoxon         Estimated
               N   Test  Statistic      P     Median
Difference  1024   1024   366208,0  0,000      30437
```

In all examples, Wilcoxon Signed Rank test rejects the null hypothesis that the median of the differences is zero, with strong evidence which is reflected by large Wilcoxon statistic value and very small p-value. Therefore, the median of the differences between the probabilistic P-R values and the corresponding deterministic P-R values can be considered as greater than zero.

5.4 DISCUSSION

The methodology developed in this study has been implemented to the product mix problem at the strategic level of product management to handle the complexity imposed by uncertainty. Therefore, the main focus is to resolve this issue justifying the results provided by the implementation of the methodology. The probabilistic approach of the methodology involves generating several scenarios as the future realizations. Then, these scenarios are solved by means of a deterministic model. All these solutions of the scenarios are the candidate best solutions to the product mix problem. Then, these solutions are tested under different scenarios for assessment of the feasibility and robustness of the method. Finally, the best product mix is selected applying three alternative solution approaches. The concept of regret free profit (P-R) and SNR_{P-R} measure based on this concept is used heavily in analyzing the results and making the statistical inferences using this approach is found to be the most powerful approach. As a result, analysis of the results and the statistical inferences show that the probabilistic approach provides better results in terms of regret free profits. So, it is proven that the selected product mix by the probabilistic approach give the most consistently better results under uncertain environment.

In the examples studied, the consumer durables sector was considered. The only reason for this is the familiarity of this sector gained during the field study, which has been helpful in formulating the cases for the numerical examples. Implementation of the methodology developed in this study is possible in all sectors producing physical goods. For example, BMW Group has three main product lines which are BMW automobiles, Mini and Rolls Royce. So, BMW Group may use the methodology to find the best product mix of these lines in their markets which these lines are served. Mini line has Mini 1, Mini Cooper, and Mini 1 Cabrio families, and these families have several variants having different options. According to the different preference options of these families, candidate product sets can be constructed and deterministic model can be modified if necessary, and the methodology can be used to find the best family mix for Mini product line. Similarly, a medical device company may divide its product mix in the lines of hearing aids, reading glasses and motorized wheelchairs. Or, a cookware company might divide its entire set of products by type of metal such as the line of cast-iron products, line of aluminum products, and so forth. In short, for each company specific case, considering the purpose of the company, the product hierarchy is established, product-market structure is defined, and the best product mix is determined at the desired product level by using our methodology. It should be noted that the number of factors is limited in our problem case. Since the product mix problem is handled at the strategic level in our case, the number of products (line or family) and the number of markets are also limited. Table 5.19 shows the number of scenarios generated by two-level full factorial design of experiments in accordance with the number of factors considered in the experiments.

Table 5.19: Number of Factors versus Number of Scenarios

a) Number of products, k = 2

Case No.	m_1	m_2	$\sum_{i=1}^{k} m_i$	No. of Factors $n = 2\sum_{i=1}^{k} m_i + k$	No. of Scenarios 2^n
1	1	1	2	6	64
2	2	1	3	8	256
3	2	2	4	10	1,024
4	2	3	5	12	4,096
5	3	3	6	14	16,384
6	4	3	7	16	65,536
7	4	4	8	18	262,144
8	5	4	9	20	1,048,576
9	5	5	10	22	4,194,304
10	6	5	11	24	16,777,216

b) Number of products, k=3

Case No.	m_1	m_2	m_3	$\sum_{i=1}^{k} m_i$	No. of Factors $n = 2\sum_{i=1}^{k} m_i + k$	No. of Scenarios 2^n
1	1	1	1	3	9	512
2	2	1	1	4	11	2,048
3	2	2	1	5	13	8,192
4	2	2	2	6	15	32,768
5	3	2	2	7	17	131,072
6	3	3	2	8	19	524,288
7	3	3	3	9	21	2,097,152
8	4	3	3	10	23	8,388,608
9	4	4	3	11	25	33,554,432
10	4	4	4	12	27	134,217,728

The method, including probabilistic scenario generation and deterministic model, is constructed in MATLAB 7.10. So, MATLAB 7.10 linear programming solver is used to get the results. Numerical results obtained on Intel Core I-7, 8 GB RAM. The largest model size for the problem based on 13 factors is 8193 rows and 8192 columns. It takes around 3 minutes to solve and prepare the output matrices. When the factor number is increased, the memory capacity of MATLAB 7.10 becomes insufficient. In the examples presented here, products are aggregated at line and family levels in the sense that higher level product aggregation is not possible. Therefore, it can be stated that the model is efficient for the strategic level of product mix decision problem. However, if more detailed product schemes are needed to be studied, the variants of the model which are presented below can be used. Product breakdown, market disaggregation or single market variants of the model can be used to obtain the optimum product mix solution for detailed product schemes or market segments. For example, optimum mix of variants (models) of "Hot" family in a single market can be obtained iteratively by using the "product breakdown in a single market" variant of the model. Thus, optimum product mix solutions can be obtained at desired level of product aggregation at each market. We present three variants of the deterministic product mix model as follows:

Variant-1: Product-Mix Model with Shared Capacity

In our basic product mix model, capacity constraints show that product i cannot be allocated more than C_i hrs. assuming each product has a distinct facility (or allocated capacity) of production. While dealing with the mix of lines or families, the assumption of distinctly allocated capacities can be meaningful. However, if the problem requires finding the mix of variants in a family, the case where the total capacity is shared by the variants should be considered in the model. Therefore, the following constraint can be added to the model in which all products cannot be allocated more than C_{max} hrs (maximum capacity available).

Additional Constraint:

$$\sum_{i=1}^{k} c_i \sum_{j=1}^{m_i} x_{ij} \leq C_{\max}$$

Variant-2: Breakdown of Products with Product Mix Model

Specifically, basic product mix model can be used for budgeting purpose iteratively. In the first run, the optimum solution is found for the mix of lines. Then, the lines can be broken into families, and for each line, optimum mix of families can be found. At the second iteration, the results of the first run can be used as an additional constraint in order to guarantee the optimum total profit value for the company as follows:

Additional Constraint:

$$\sum_{i=1}^{k} \sum_{j \in M_i} P_{ij} \times x_{ij} \geq P_{op}^{*}$$

P_{op}^{*} : Optimum objective value of higher level of product determined in the previous iteration

Similarly, for each family, optimum mix of variants can be obtained combining both the first and second variants of the model.

Variant-3: Product Breakdown in a Single Market with Product Mix Model

Another special case can be considered for a single market case. In this case, the first iteration results obtained for the mix of lines can be detailed for the families or variants of a family by modifying the model as follows:

Additional Constraints:

$$\sum_{i=1}^{k} P_i \times x_i \geq P_{op}^{*}$$

$$\sum_{i=1}^{k} x_i = x_{op}^{*} \quad , \quad x_i = \sum_{j \in M_i} x_{ij}$$

P_i is the unit profit value ($SP_i - PC_i$) of product *i*, and x^{*}_{op} is the optimum value of total number of units of the higher level of product obtained in previous iteration.

In short, at the levels lower than the strategic level, full factorial design of experiments may cause to limit the number of factors. In our experiments, the maximum number of factors is 13 as mentioned above. If the number of factors is small to moderate (n≤10) (D'Errico and Zaino, 1988), the model can be used efficiently. For higher number of factors, the variants of the model can be used as explained above. Alternatively, there may be a need to consider fractional factorial experiments or Taguchi's orthogonal arrays instead of full design experiments to reduce the number of experiments or objective function evaluations. However, in such a case, since we are not able to see all combinations of the levels, a discrepancy may happen for the optimal product mix solution. For this reason, fractional factorial design can be supported by a multi-regression analysis and ANOVA test analysis.

The examples are descriptive cases formulated to get the numerical results. In these cases, different values of means and variances of the parameters are used. For example, volatile market conditions are represented by higher values of variances of the parameters. Similarly, different set of candidate products example is described using different means of prices and also unit production capacity is decreased by 15%, assuming that new product introduction changes the bundle of candidate products and decreases the production efficiency. This assumption is based on the findings of a very recent article (Gopal et al., 2013). In this article, it is stated that the new product introduction disrupts manufacturing operations which results in productivity losses. The average productivity loss is about 12-15% which is measured in terms of hrs./unit product. Gopal et al. (2013) point out the following remarks: It is interesting that product development books focus on profit impact of new product introduction to throughput improvement, but ignore the effect on plant productivity. On the other hand, it is understood that productivity loss escapes the attention of manufacturing focused books. It is also indicated that there are no rigorous assessments of the impact of new product launches on a plant's productivity. Several ways are identified to mitigate the loss of productivity. The most important one for us is "product mix flexibility". It is stated that product mix flexibility is critical for reducing the productivity loss. Product mix flexibility is a strategic tool under competition and mitigating demand uncertainty, which entails the ability to manufacture more than one product in a single manufacturing facility (Gopal et al., 2013). Therefore, it is more convenient to use the "Shared Capacity" variant of our deterministic model presented above. This model was not used in numerical results. The aim of using this example of productivity loss is just to make the reader informed about this important concept. The detailed study on the subject is left to the future research.

Finally, it is seen that rounding up or rounding down of the results obtained by LP-relaxation of the deterministic product mix model have negligible impact on the optimal value of the objective function. For example, the results of Example-1 show that the optimum product mix is 3255.1 units of WG in National market 7460.1 units in Global market and 4037.3 units of SHA in National market. The profit range is (8.5229-9.0983)$\times10^6$ TL. The price value of WG in National market is 1592.6 TL. and cost value of WG in this market is 1068.3 TL. for one of the scenario which gives the optimal results. In this case, it can be easily stated that rounding down the value of WG will not lead a significant impact on profit. Therefore, we may conclude that LP-relaxation of the knapsack model can be used to get fast and reliable results.

CHAPTER 6

CONCLUSIONS AND FUTURE RESEARCH

6.1 CONCLUSIONS

In many real life problems, uncertainty is the major complexity for the decision makers. A typical example to such a case is the product mix problem. Key parameters of the product mix problem are unknown to the decision maker at the time the decision has to be made. The product prices, costs of production and demands for products move by market dynamics such as unknown behaviors of the customers, changeable prices of suppliers, prices of competitors and new regulations imposed by the government. Therefore, the decision maker cannot be certain about the future realizations of financial performance of the company. In this study, we develop a methodology to aid the decision maker in product mix determination at the strategic level of product management under uncertainty.

We use simulation optimization approach to formulate the product mix problem under uncertainty. Our decision support system (DSS) model embodies two basic formal models:

- Deterministic Product Mix Model, and
- Probabilistic Model (simulation model).

The first model represents a *deterministic approach* and constructs the DSS that takes prices, demands and costs of the products as given and suggests the optimal product mix. So, it works as an optimization engine in our proposed DSS. The simulation model is constructed as a result of the *probabilistic approach*. In this approach the system is upgraded to another one which considers the uncertainty in the parameters. We develop a scenario-based scheme in the probabilistic approach by generating different scenarios focusing on the major inputs of the product mix model. Scenario generation method relies on systematic sampling obtained by a two-level full factorial design of experiment. In order to determine the levels of factors (parameters) discrete approximations of normally distributed random parameters of prices, costs and demands are used. A linear relationship is assumed between the prices of products and the level of demands by the law of demand. Then, optimal product mix solutions are found using the deterministic model repeatedly under various scenarios defined as possible realizations of the uncertain parameters. In the next stage, these optimal solutions are tested under the same set of scenarios and their performances are measured. The final stage requires the analysis of these results by using the various solution approaches to get the optimal product mix.

Analysis of the results and the statistical inferences show that the probabilistic approach provides better results in terms of objective function values. So, it is shown through examples that the selected product mixes by the probabilistic approach give the most consistently high profit results under uncertain environment.

Our primary goal in this study is to present an approach of dealing with uncertainty and the methodology developed for this purpose. Therefore, the product mix optimization model is kept as simple as possible in order to highlight the importance of the methodological approach. To the best of our knowledge, our methodology developed to aid the decision maker in product mix determination is a novel and original approach and it is the first study implemented for the product mix problem under uncertainty at the strategic product management level. Therefore, it represents the major contribution of this study. While the model developed in this study is mainly geared towards the product mix problem, the decision aid method developed here is general and can be used in many decision making problems involving uncertainty, such as investment planning, financial portfolio planning, capacity planning, etc.

As it is known, product mix problem is a very well-known problem in the literature. However, most of the literature handles the problem in the *production management* decision framework. We consider the problem in the framework of *product management*. To properly locate the product mix problem in the product management framework properly necessitates understanding the product management framework deeply. For this purpose, both a broad literature survey and a field study have been conducted. As a result, it has been realized that the product mix problem is one of the most important strategic decision making areas of product management framework. During this effort of understanding the product management framework, it is also realized that there is no comprehensive study dealing with the decision framework of product management from holistic perspective. Thus, using an integrative system approach, a product management system has also been proposed (Figure 3.7), and based on this proposal; some efforts have been spent to integrate the existing literature to extract and clarify the major decisions in product management and to present them in a structured and comprehensive way. The author believes that all these efforts represent some contribution to the existing literature of product management. The proposed decision framework of product management can be viewed as an initial attempt to fill the gap in the existing literature, so that this work can be improved further for the forthcoming studies in this area.

6.2 FUTURE RESEARCH

The following topics for the future research can be suggested regarding the strategic product mix problem under uncertainty:

1. ***Alternative Solution Approach to the DSS Model***

Multiple response surface optimization approach can be suggested as another appropriate one. For this purpose, first, empirical models of the mean and variance of the regret (or regret free profit) values are found by means of multiple linear regression;

$$E(regret) = f_1(x_1^*, ..., x_k^*)$$
$$V(regret) = f_2(x_1^*, ..., x_k^*)$$

Consequently, the following multiobjective optimization problem is solved:

Minimize $f_1(x_1^*, ..., x_k^*)$

Minimize $f_2(x_1^*, ..., x_k^*)$

subject to

$x_1^*, ..., x_k^*$

Here, a major problem is possibility of obtaining poor empirical models. In that case, this approach cannot be trusted to yield better results than the proposed one.

2. ***Extension of the Model with Price as a Decision Variable***

Pricing is another important decision making area in product management framework involving the consideration of uncertainty. In this case, a consumer utility function of the pair of (x, p_x) can be derived for each product at each market. Maximization of the utility for the consumers may be in conflict with maximizing the profits of the company. In such a case, a trade-off should be considered and formulated as a multi-objective problem. Deterministic model should be modified accordingly. The methodology can be applied with its main stages.

3. ***Extension of the Model for Line Addition to the Product Mix***

Line addition (capacity expansion) requires considering the establishment of a new plant or an investment in the existing facility to produce the products in the new line. Therefore, the deterministic model should be modified according to an investment planning model considering the initial investment cost, expected net inflows injected by the new product investment, salvage value of the investment over the forecasted life cycle of the new product(s), etc. A multi-period extension of the modified model can be more appropriate in which these inflows and outflows of the new product investment are modeled. In addition to this, a new bundle of candidate products should be considered with different mean values and variances of the prices, costs and demands.

4. ***Product Breakdown and Market Disaggregation Extension of the Model***

The product breakdown extension of the model can be useful for traditional budgeting activities of the company. For this purpose, this extension of the model, which is presented in Chapter 4, can be used iteratively at the expense of some efficiency loss. For example, first, the line mix is determined. After getting the optimum results for the line mix at the first iteration, each line can be broken down into the families of corresponding lines. At the second iteration, using the optimum results obtained in the first iteration as an additional constraint, the optimum results of the family mix are obtained for each line. Then, similarly, families are broken into the variants and by using the optimum results obtained for the mix of families as additional constraints, the optimum mix of variants are found for each family.

The constraints added iteratively are the minimum profit requirements of the lines and families accordingly.

However, if the number of factors is too high, the fractional factorial design of experiment can be suggested instead of full factorial design of experiment. In this case, the levels of the factors should be determined so as to match as many moments as possible of the continuous and discrete approximating distributions.

5. *The Problem of Determining the Set of Candidate Products*

Determining the set of candidate products is an important decision making problem in product management framework which involves sub-decisions and parallel decisions in different levels of management in the company. Set of candidate products is assumed as pre-determined information and therefore it is a given input in our model. The solution to this problem may require using the combination of several decision tools. Figure 6.1 depicts a suggested solution framework where the use of combination of several decision tools is shown as an example. More research is needed to develop a methodology for determining the candidate set of products.

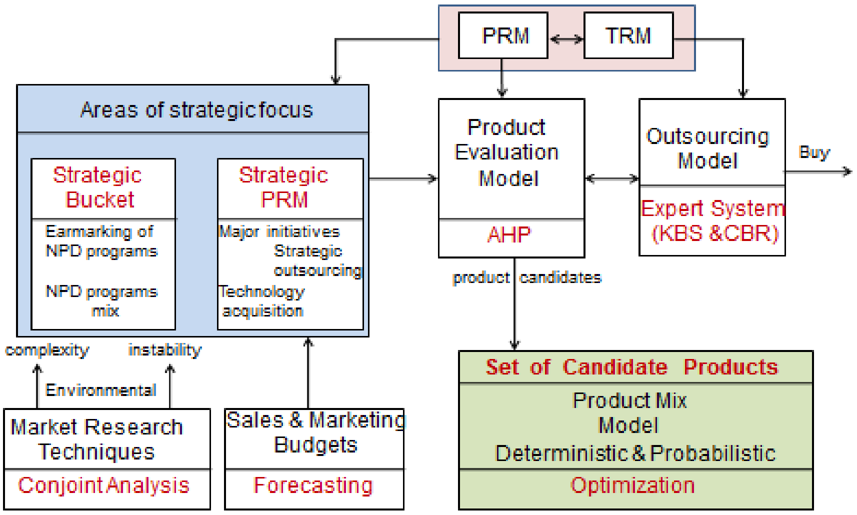

Figure 6.1: Generation of Set of Candidate Products (Use of Tools & Techniques)

6. *Product Dependency Extension of the Model*

The relationships among the products bring additional complexity to the product mix problem. If substitutable products and complementary products are considered in the problem, dependency occurs in the random parameters of the model. In this case, for each product, we need to consider both pairwise interactions for the factors of price, demand and cost of the product itself, and the cross price sensitivities of demands of other products simultaneously. Therefore, the number of factors will be much higher than that of the product independency case.

7. Multi-Objective - Multi-Candidate Set Extension of the Model

Global companies may consider different goals in different markets for its products. For example, Company D considers the maximization of market share in Global market, while it is a profit maximizing firm in the National market. Therefore, although the traditional product mix problem is solved with the profit maximization objective, upon the company's different goals in different markets, the model can be modified. In this case, for each market, different candidate set identification may be required.

8. The Possibility of Different Production Costs at Different Markets

Market indifference is assumed for production costs of products in our study. However, a global firm may have production facilities in different market places to produce the same product. For example, Company D has dish washer factory in both Turkey and China and these products are sold in these locations. In that case, the production cost of producing one unit of dish washer may be different in these locations. In such a case, production cost should be considered not only for each product but also for each market which causes to consider higher number of factors in the experiments. Besides, the deterministic model should be modified accordingly.

9. Consideration of Manufacturing Efficiency Loss caused by New Product Introduction to the Set of Candidate Products

As discussed in section 5.4, new product introduction distrupts manufacturing operations which results in productivity losses. The productivity loss caused by new product introduction was roughly described in our numerical examples (see Example 3) to make the reader informed about this important concept. Therefore, the loss of productivity should be studied and detailed further in product mix model which may require making some modifications considering product mix flexibility, capacity sharing among products (variants), the impact on production cost and profit and so on.

10. Implementation of Product Mix Model for Service Sector

The methodology developed in this research study is general and applicable in many decision making problems involving uncertainty. Depending on the problem case under consideration the deterministic part of the approach may require some modifications. In this research, product mix model as the deterministic part of the approach is constructed considering the physical goods produced in manufacturing sector. The same model can be modified for service sector considering different measurement and definitions of the parameters in the model. For example, the product lines of a hotel producing services in the hospitality sector can be considered as the rooms, food and beverage service, business assistance service, etc. The total number of accomodations of the rooms in terms of day/night can be taken as the total capacity for the rooms. The families for the rooms can be considered as "single", "double", "suite", "presidential suit" etc. The seasonal variations in demand can be important for this sector, therefore piecewise linear functional relationship may be more appropriate for defining price-demand relation in probabilistic part of the approach.

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APPENDIX A

PRODUCT MANAGEMENT GLOSSARY

It was realized during the literature survey that there are many perspectives to product management as a professional discipline and a management approach. The definitions and interpretations vary significantly among these perspectives. It is therefore useful to have a set of clear definitions that help establish a common understanding. This glossary presents term definitions that are integrated of the definitions provided in Steinhardt (2010) and Haines (2009). It can be stated that Haines (2009) provides professional terminology which shapes corporate processes. On the other hand, Steinhardt (2010) presents the definitions from marketing point of view. In this research study, a few definitions are proposed considering the integrated literature review. These definitions are remarked by (*) in this Appendix. Additionally, if a term is defined differently by the authors mentioned above, (S) and (H) letters are used to indicate the references Steinhardt (2010) and Haines (2009) respectively.

Term	**Definition**
Activity-based costing	A technique that logically allocates overhead to products based on actual usage of factory facilities or machinery.
Architecture	See *product architecture*
Allowances(Pricing)	A conditional refund only in form of a deduction from the list price in exchange for customer action. Allowances are often accomplished in two forms: Trade-in (Pricing)- An item of property given in part payment upon purchase. Rebate (Pricing)- Customer receives reimbursement for a portion of the purchase price , in exchange for customer information.
Attainable market share	The market share you could potentially, or realistically achieve (attain) in volume and/or revenue.
Attribute	A characteristic of a product that can include a color, design, style, form, shape or feature.
Bait pricing	Pricing that aims to attract customers with low prices with intent to sell higher priced items.
Barrier to entry	A condition that exists in a market that makes it difficult for another business to establish a foothold. A barrier can include intense competition, governmental regulation, a shortage of skilled labor, or other obstacles.
Base price	Initial price of a product before any alteration.

Benchmark	A study that compares the actual or observed performance of a business activity, process, method, or function to a standard of competence.
Benefits	Product features that are desirable to the customer (S). Something of value as perceived by a customer (H).
Beta test (or trial)	Testing of a product by a friendly customer or customers who are willing to use the product as intended so that any issues or problems can be uncovered and resolved.
Brand	An identity made of symbols and ideas, which portray a specific offering from a known source (S). A brand represents the shared or combined set of perceptions formed in the minds of a market segment about a company and/or a product (H).
Business case	Examination of a potential market opportunity on a product level (S). It is a formal document used to justify investments in new products, product enhancements, and marketing expenditures (H).
Business competence	Set of professional skills and knowledge that relate directly to performing product management.
Business development	Actions that improve the performance of the enterprise, its access to markets, and its ability to compete by creating strategic relationships with logistical, content and technological partners.
Business plan	Examination of a potential business opportunity on a company level.
Business products	Products intended for resale, for use in producing other products, or for providing services in an organization.
Business strategy	Decisions that support being a leader, follower or innovator in a specific line of business.
Business- to- business	The transaction of goods or services between businesses (B2B) (S). A business model where a company (a business) sells its products to other businesses (H).
Business- to- consumer	The transaction of goods or services between business and private individuals (B2C) (S). A business model where a company (a business) sells its products to consumers (H).
Buyer	The entity that decides to obtain the product (S). A customer type in a business who becomes the ultimate purchaser of a product (H).
Cannibalization	When products from a product portfolio are sold in the market together, and one product draws sales away from the other. In this case, one product is said to cannibalize the potential sales of the other product. Overall, this may have a negative impact on the portfolio.

Captive product(Pricing tactic)	An imbalanced price ratio between product's components which are sold separately. The main system component is underpriced and the consumables or support services are overpriced. The "Captive Product" pricing tactic can be quickly and easily accomplished via product system decoupling.
Client	The entity that is the receiver of goods or services.
Company core competency	A company's unique ability to deliver value, while differentiating itself from the competition.
Competitive advantage	A depiction that the company or its products are each doing something better than their competition in a way that could benefit the customer (S). The relative advantage that one product or product line has over those products offered by other companies (H).
Complementary products	Products in a product portfolio that are sold together in the market, where one product's existence may induce the sale of the other product (the complement).
Conditional license	Expiring ownership and usage rights to a product. Can be renewable and non-renewable.
Consumer	An individual or household that buy and use goods and services created by industries (S). Typically used in defining an individual or household that will benefit from using a product or service (H).
Consumer problem	A marketplace situation in which consumer needs remain unsatisfied (B2C). The solution is a whole product.
Consumer products	Products intended for use by household consumers for non-business purposes. Consumer Products are used for personal gain.
Corporate branding	The process of building and maintaining a brand at the institutional level.
Corporate marketing	An outbound activity aimed at generating awareness and differentiation to the company.
Corporate mission statement	A formal statement that a company makes about their reason for existing and briefly describes the company's general business direction of the value customers should expect to receive.
Corporate vision statement	A message that summarizes the company's purpose and intent and describes how, in the future, its products and activities shall affect the world.
Customer	The entity (consumer or company) that takes (financial) responsibility for purchasing the product. Often the realm to which the buyer and user belong.
Customers' expectations	The hopes for deriving benefits from the product and establishing a rewarding relationship with the vendor.

Demand(Economics)	Quantity of a product that will be bought in the market at various prices for a specified period.
Demand(Marketing)	Wants for a specific products coupled by an ability to pay for them.
Demand-based pricing (Pricing Tactic)	Rapidly adjust prices per customer according to market characteristics.
Discrimination (Pricing Tactic)	Charging different market segments with different prices for same product. There are several levels of discrimination.
Distribution channel map	A drawing or visual diagram used to portray the movement of goods through a company's distribution channels.
Diversification (Pricing Tactic)	Creating product variants with distributed price points.
Durability(Product)	How long the product maintains a level of performance without degradation.
Dynamic pricing (Pricing Tactic)	Rapidly adjust prices per customer according to customer characteristics.
Feature	A product capability or attribute that fulfills a specific customer or market need and provides an appropriate benefit.
Focus group	A small group of invited individuals (possibly current or prospective customers) who are guided by a moderator to discuss or evaluate a product or product concept.
Goods	Tangible products we can possess. Segmented to durable and non-durable.
Holistic	An expression applied to looking at an organization or a process completely and systematically.
Inbound marketing	The efforts devoted to securing data and information from a variety of sources so that it can be used to guide marketing plan and programs.
Industry	A group companies which produce and sell a particular product type (S). A set of organizations or companies who focus their selling and marketing efforts on meeting the needs of similar market segments (H).
Innovation	The introduction of a product that is new or substantially improved. Innovation is the process of converting and commercializing an invention into a product (S). Refers to the solving of a customer or market problem in a way that is more unique than anything else that exists in the market. The solution can include either or incremental change to a product or service (H).
Invention	An idea which represents a revolutionary or evolutionary change. Invention is an idea that improves an existing solution or offers a

	conceptually new solution to a problem.
Licensing	A method of providing rights to usage and ownership to a product, for a specified price and/or term.
Line extension	A product that is added to an existing product line either as a newer version or derivative of a current product.
Market attractiveness	The appeal of a market area based on the customer types in that market area or market segment. Furthermore, an attractive market can be identified by the ease of access (limited competitive activity).
Market focus	A strategic orientation of an organization or product team that holistically considers the dimensions of the industry, the dynamics of the competitive environment, and customers' needs in determining the appropriate product portfolio investments.
Market penetration	The degree to which a product is being sold in a given market area. Higher penetration means that more people in a currently pursued market area are purchasing the product, or that the product is being sold in other market areas.
Market opportunity	A lucrative, lasting and sizeable market problem.
Market plan	A description of the long-term goals and messages delivered to the target market relative to a particular company or product.
Market problem	A "consumer", "product" or "technology" problem in the target market.
Market requirement	An aggregate unit of information which represents with sufficient detail the functionality that is sought to address a specific facet of a particular market problem.
Market segmentation	A division of the overall market for a product, into groups of common characteristics (S). Identification of customer types based on specific categories such as common needs or similar buying behaviors (H).
Market share	The amount of market demand that can be captured by a product or product line. Market share is expressed as a percentage of the total addressable market.
Market strategy	Decisions that define target markets, set marketing objectives, and outline how to build a corporate competitive advantage.
Market-driven	A product delivery strategy that is based on producing and delivering products that the market needs.
Marketing	An instructive business domain that serves to inform and educate target markets about the value and competitive advantage of a company and its products.
Marketing mix	A combination of product, price, place (distribution), and promotion activities that are applied to a particular target market (S).

	A combined set of strategic or tactical tools-often referred to as the “four Ps”. The mix elements include the product itself, its pricing, the promotional programs that support the product, and the place (meaning distribution channel) (H).
Marketing plan	A description of the selection and application of marketing mixes in the target market.
Marketing program	A short-term marketplace effort designed to obtain a specific marketing goal.
Marketing strategy	The decisions that determine how to achieve marketing’s goal in a particular target market, through the selection and application of marketing mixes.
Offshoring	A special case of outsourcing in which business operations or overhead activities are moved to other countries to reduce costs. Sometimes referred to euphemistically as globalization of operations.
Opportunity	An idea or a concept derived from a variety of methods such as strategy formulation from market research activities, or ideation.
Organizational culture	The collective set of attitudes, activities, and behaviors that, collectively, tend to give an organization its personality.
Outbound marketing	Encompasses the work activities carried out to create programs that communicate messages or position products to customers and analysts, using advertising, public relations activities, and other events.
Penetration(Pricing Tactic)	Briefly charging a relatively low price upon product launch.
Platform	The underlying foundations, technology frameworks, base architectures, and interfaces upon which products are built.
Positioning	The customer’s unique psychological placement of the relative qualities of a product or company with respect to its competitors.
Price	A specification of what a seller wants in exchange for granting right of ownership or use to a product (S). The amount of money charged for a product; one of four Ps of the marketing mix (H).
Price discounts	Deductions from the list price.
Price elasticity of demand	Percentage change in quantity demanded that occurs in response to a percentage change in price.
Pricing strategies	The primary method to pricing that relies on a particular pricing decision factor.
Pricing tactics	Pricing actions which are dependent on the particular life cycle stage of the product that is being priced.
Product	Any offering that satisfies needs. Represents a collection of tangible and intangible assets (S). Something that is offered for

	sale, either tangible or intangible (H).
Product architecture	The product's fundamental structure or platform that enables the product to achieve its desired functionality.
Product attribute	A real characteristic or property of the product.
Product branding	The process of building and maintaining a brand at the product level.
Product bundling	An aggregate of products sold collectively at a price that is lower than the sum of their prices. The price of the set of products is lower than the total of individual products.
Product category or class	A term synonymous to "product line" in the context of competing products.
Product customization	The process of adding special features or components to an existing platform, product line, or product to meet newly discovered needs of a target market or market segment, or of an individual customer.
Product family	A set of derived products that share the same technological foundation. Members of a product family are called "product variants".
Product feature	A product capability that satisfies a specific user/buyer need.
Product group	A set of products coupled or packaged together to form a new unified offering. Members of a product group are called "product members".
Product life cycle	A term to describe a product, from its conception to its discontinuance and ultimate market withdrawal.
Product line	A set of products that are technologically different yet provide similar functionality that serves the same target market needs (S). A grouping of products focused on similar markets or on solving a particular type of problem (H).
Product management	An occupational domain which contains two professional disciplines: product planning and product marketing. An organizational life-cycle function which deals with mainly development of new products/technology and markets, and/or improve existing products/technologies and extend product lines in order to create profitable portfolio (mix) of products satisfying the customers (*).
Product marketing	Outbound activities aimed at generating product awareness, differentiation and demand.
Product mix	An entire set of products offered by a company. Collection of product units, product lines, and product groups (S). The combination of all products sold within a given portfolio. Very often, the term *product mix* is used for budgeting or portfolio tracking because it describes how many of each product are to be sold or actually sold (H).

Product planning	The ongoing process of identifying and articulating market requirements that define a product's feature.
Product portfolio	A product line in which the products are properly diversified and balanced along the timeline and stages of the product life cycle model (S). Several products or product lines may be grouped into a related collection called a product portfolio (H). The set of products investments, i.e., the products under development (*).
Product problem	An industry situation in which product requirements' are unmet (B2B). The solution is a product component.
Product roadmap	A high level schedule of future product releases with brief descriptions of market requirements and features for those releases.
Product strategy	Decisions that build and enhance products to fit market needs, and outline how to build a product competitive advantage.
Product unit	An individual product that may be offered separately from any other product.
Sales-driven	A product delivery strategy that is based on producing and delivering products that a customer wants.
Scenario	A succession of uses cases (S). A specific sequence of hypothetical events and contingencies, used for planning and forecasting purposes. A scenario can be thought of as a possible story about the future (H).
Strategy	A coordinated set of long-term decisions that help achieve corporate objectives (S). A strategy is a series of planned actions and objectives designed to achieve a specified future outcome (H).
Supply	Quantity of a product that will be offered to the market by suppliers at various prices for a specific period.
Tactical activities	Assignments, usually self-contained and specific that fulfill short-term business needs.
Tactics	A set of actions taken to fulfill a strategy.
Target market	The group or groups of customers selected by a firm to sell to (S). The grouping of target customer types (by geography, demographic, or other segment definition), who exhibit a common set of needs (H).
Technical specification	A highly detailed description of the solution's design, attributes and standards.
Technology problem	Challenges in applied science. The solution is scientific research.
Technology-driven	A product delivery strategy that is based on producing and

	delivering products that we conceive.
User	The entity that interacts with the product.
Value	The worth derived by the customer from owning and using the product.
Voice of customer(VOC)	The process for eliciting needs from customers. It embodies a market-driven approach that involves spending time with current and future customers to determine past, present and future market problems that customers need to solve in order to meet their business goals and objectives (S). A technique that captures customer needs either through explicit or direct interactions with customers using surveys, focus groups, or observations as made on a visit to a customer's location (H).
Want	A request for specific objects that might satisfy the need.

APPENDIX B

QUESTIONNAIRE USED IN THE FIELD STUDY

C.1 COVER LETTER

Sayın Yetkili,

ODTÜ Endüstri Mühendisliği Yöneylem Araştırması programında "Etkin bir Ürün Yönetimi için Karar-Destek Sistemi" başlıklı doktora tezi çalışmamı yapmaktayım. Literatürde belirtildiği üzere, Ürün Yönetimi, son elli yıldır akademik çalışma platformunda yer almış bir konu olmakla birlikte, halen çözüm bekleyen çok boyutlu bir karar verme problemi olma özelliğini korumaktadır. Özellikle teknolojik değişimlerin çok hızlı yaşandığı günümüzün zor piyasa koşullarında **Ürün Yönetimi Problemi** olarak adlandırabileceğimiz bu konunun firmalar için stratejik öneme sahip olduğu anlaşılmaktadır. Tezimin mevcut aşamasında, piyasada Ürün Yönetimi kararlarının nasıl alındığına ilişkin bir "Saha Çalışması" yapmam gerekmektedir. Saha çalışmasından hedeflenen, literatürde yer alan teorik bilgiler ile piyasadan edinilen bilgiler arasındaki farklılıkları görmek ve probleme yönelik çözüm arayışlarını, **piyasanın gerçek ihtiyaçlarını saptayarak** oluşturmaktır. Diğer bir deyişle, bu problem ile içiçe yaşayan yöneticilerin deneyimledikleri karar verme sürecinin literatür ile ne şekilde örtüştüğünü belirlemeye yönelik bir fark analizi ("gap analysis") yapmaktır. Literatüre göre, bu kararlar kapsamında firmalar her gelecek planlama dönemi için yeni veya eski ürünlerinden hangilerini ve ne miktarlarda üretecekleri veya müşterilerine sunacakları konusunda stratejik değerlendirmeler yapmaktadır. Bu değerlendirmelerde rol oynayan önemli faktörlerlerdeki farklılıklar, karar vericiler ve organizasyonel farklılıklar, izlenilen yaklaşımlar, yöntemlerdeki farklılıklar, kısıtlar, terminoloji farklılıkları ve benzeri konularda siz değerli yöneticilerin görüşlerini almak üzere firmanızı ziyaret etmek istemekteyim.

Bu çalışma, tezimin bundan sonraki aşamaları için bir hareket noktası niteliğini taşımaktadır. Bu nedenle, tarafınızca uygun görüleceğini ümit ettiğim bu karşılıklı görüşme, yaptığım çalışmanın başarısına çok önemli katkılarda bulunacaktır. Şahsınız ve katkısı olacağını düşündüğünüz diğer katılımcılarla yapılacak bu görüşmenin yaklaşık bir saat sürebileceğini tahmin etmekteyiz. Konuşulacak konuların kapsamını belirten soru/konu listesi ekte bilgilerinize sunulmuştur. Tümüyle bilimsel amaçlar için edinilen firmanıza ait tüm bilgilerin gizliliğine kesinlikle riayet edilecektir. Buna rağmen, üçüncü şahıslarla paylaşmayı uygun bulmadığınız bir konu olur ise buna saygı duyacağımızı belirtmek isterim. Yıl sonunda, yapmış olduğum "Saha Çalışması" raporundan, arzu ettiğiniz takdirde, size de bir kopya sunmak isterim.

Yoğun iş temponuz içinde kısıtlı ve değerli zamanınızı ayırdığınız için, ve ayrıca verdiğiniz katkı ve destekden dolayı şimdiden teşekkürlerimi sunarım.

Saygılarımla,

C.2 QUESTIONNAIRE EXPLANATIONS

ANKETE İLİŞKİN AÇIKLAMALAR:

1. Yazmanız gereken bölümlerde yer kısıtlı gelirse ayrı bir sayfaya soru numarasını belirterek yazabilirsiniz.
2. Soru **A-3, B-2, C-2, C-4, D-2, E** için firmanıza ait basılı doküman verilebilir. (Yıllık Faaliyet Raporu vb.)
3. Görüşünüzün sorulduğu ve düz cümle ile yer alan ifadelerde gördüğünüz (0--- 100) gösterge çizelgesinde;

   "0" : "Kesinlikle katılmıyorum"

   "100" : "Tümüyle katılıyorum"

   anlamını taşımaktadır. Bu aralıkta yer alan tüm değerleri kullanabilirsiniz.
4. **BÖLÜM-2, Soru 2-5**' de bu gösterge çizelgesini size göre **en önemli faktör için "100", hiçbir önemi olmayan faktör için "0"** değerini kullanarak cevaplandırınız.

C.3 QUESTIONNAIRE

ANKET FORMU **Tarih:**

YANITLAYAN

Adı, Soyadı :

Ünvanı :

Departman :

BÖLÜM 1

ŞİRKET PROFİLİ BİLGİLERİ

A.GENEL

A.1 Firma adı, Unvanı:

A.2 Kuruluş Yılı:

A.3 Ortaklık Yapısı:

B. STRATEJİK KONULAR

B.1 Firmanızın varoluş nedenini açıklayan ve bir cümle ile ifade edebileceğiniz birincil amacı nedir?

(Örnek: Firmamız, istihdama katkıda bulunarak, müşterilerine en üst kalitede ve doğa dostu ürünler sunmayı amaçlamaktadır.)

B.2 Firmanızın temel ilkeleri nelerdir?

(Örnek: Kısa vadeli kazançlar uğruna etik değerlerimizden ödün vermeyiz.)

B.3 Firmanızın mevcut stratejisi nedir?

(Örnek: Önümüzdeki beş yıl içinde toplam gelirimizin %50'si yeni ürünlerden gelecektir.)

C. SEKTÖR/PAZAR/ÜRÜN BİLGİLERİ

C.1 Firmanın faaliyet gösterdiği sektör:

C.2 Pazar Yapısı (Firmanız ve Rakipleriniz):

(Bugün itibariyle)

PAZARI PAYLAŞANLAR	Pazar Payı (%)

C.3 Firmanızın Üretimi:

a) Stoka üretim

b) Siparişe dayalı üretim

c) Diğer (Açıklayınız)

C.4 Başlıca Ürünleriniz:

Ürün adı	Yıllık Üretim Miktar ( )	Yıllık Satış Miktar ( )	Pazar Yaşı (*)	Ürün Geliştirme Süresi (**)

(*) Pazara sunulduğu tarihten bugüne kadar geçen süre
(**) Fikir, tasarım, test, üretim için geçen süre

D. ORGANİZASYON

D.1 Firmanızda "Ürün Yönetimi Departmanı" var mıdır?

Evet ☐ Hayır ☐

D.2 Organizasyon Şeması

E. BÜYÜKLÜK GÖSTERGELERİ

	2005	**2006**	**2007**	**2008**	**2009 (*)**
Yıllık Ciro					
Pazar Payı (%)					
AR-GE Yatırımı (Ciro içindeki payı)					
Karlılık (Ciroya oran)					
Toplam Çalışan Sayısı					

(*)Yılsonu tahmini

2.1 Firmanızın Ürün Yönetimi hangi faaliyetleri kapsar?

a) Ürün Yönetiminde ürün planlaması yapıyoruz. **(0 … 100)**

b) Ürün Yönetimimiz ürünün pazarlanması faaliyetlerini kapsar. **(0 … 100)**

c) Diğer (Açıklayınız) **(0 … 100)**

2.2 Firmanızın Ürün Yönetiminde amaçlar/hedefler nelerdir?

a) Pazar payını artırmak **(0 … 100)**

b) Pazara rakiplerimizden önce ürün sunmak **(0 … 100)**

c) Ürün maliyetlerini düşürmek **(0 … 100)**

d) Karlılığı artırmak **(0 … 100)**

e) Diğer (Açıklayınız) **(0 … 100)**

2.3 Firmanızın Ürün Yönetiminde alınan kararlar nelerdir?

a) Gelecek dönemlerde yeni ürün geliştirilmesi, ya da mevcut ürünlerde iyileştirme/modifikasyon yapılması kararı **(0 … 100)**

b) Mevcut Pazar ya da yeni Pazar/Segment kararı **(0 … 100)**

c) Fiyatlandırma kararı **(0 … 100)**

d) Ürünün firma içinde üretilmesi ya da dışarıdan satın alınması kararı **(0 … 100)**

e) Üretim için hangi teknolojinin kullanılacağı kararı **(0 … 100)**

f) AR-GE projelerinin seçilmesi, önceliklerinin saptanması **(0 … 100)**

g) Yeni ürünün ne zaman imalata girmesi gerektiği kararı **(0 … 100)**

h) Yeni ürünün ne zaman piyasaya sunulacağı kararı **(0 … 100)**

i) AR-GE projelerine, proje bazında ayrılması gereken mali kaynakların saptanması kararı **(0 … 100)**

j) Diğer (Açıklayınız) **(0 … 100)**

2.4 Firmanızın organizasyon yapısı içinde Ürün Yönetimine ilişkin kararlar hangi yönetim kademesinde alınıyor?

a) Tüm kararları Yönetim Kurulu alır ve uygulamaya koyar **(0 … 100)**

b) Pazarlama Ve Satış Bölümü kararları tespit eder ve Yönetim Kurulunu onayına sunar **(0 … 100)**

c) AR-GE, Pazarlama/Satış ve İmalat Bölümleri yetkilileri ekip olarak karar verirler ve Yönetim Kurulu onayına sunarlar **(0 … 100)**

d) Ürün Yönetimi departmanı liderliğinde, AR-GE, Pazarlama ve İmalat bölümleri ekip olarak kararları oluştururlar ve Yönetim Kurulunun onayına sunarlar **(0 … 100)**

e) Diğer (Açıklayınız) **(0 … 100)**

2.5 Ürün Yönetimi kararlarınızı etkileyen başlıca faktörler nelerdir?

Faktör	A Ç I K L A M A	(0 … 100)
Pazar	Pazar yapısı, ürünün Pazar pozisyonu, talep, pazarın cazibesi, vb.	
Müşteriler	Müşteri istekleri, müşteri memnuniyeti, vb.	
Rakipler	Rekabetin yoğunluğu, Pazar payı değişkenliği, yeni ürünler, vb.	
Teknoloji	Teknolojik değişim hızı, fırsatlar, teknolojik değişimin türü	
Tedarikçiler	İlişkiler, pazarlık gücü, sadakat	
Distribütörler	Satış ağı, pazarlık gücü, satış gücü	
Stratejik Planlama	Uzun dönem perspektif, stratejik amaçlar, ürün stratejisi	
Organizasyon	Üst yönetim desteği, ekip çalışması, iyi iletişim, esnek yapı	
Enformasyon	Data toplama, bilgi üretme, analiz	
Öz Değerler	Kompetan yönetim, kaliteli personel, bilimsellik, AR-GE, repütasyon, marka değeri	
Kaynaklar	Mali kaynaklar, teknolojik yeterlilik, keşif kabiliyeti	
Makro/Çevresel Faktörler	Politik, yasal, çevreyi koruma, enerji tüketimi, vb. dış etkiler	
Diğer (Açıklayınız)		

2.6 Ürünlerimizin Pazar içindeki pozisyonu aşağıdaki kararlarımız için önemlidir.

a) Fiyatlandırma **(0 … 100)**

b) Yeni ürüne geçiş kararı **(0 … 100)**

c) Mevcut ürünleri iyileştirme kararı **(0 … 100)**

d) Pazarlama stratejilerinde değişiklik **(0 … 100)**

e) Diğer (Açıklayınız) **(0 … 100)**

2.7 Pazar talebi tahminlerini hangi sıklıkla yapıyorsunuz?

a) Siparişe dayalı üretim yaptığımız için ihtiyaç duymuyoruz. **(0 … 100)**
b) Aylık tahminlerde bulunuyoruz. **(0 … 100)**
c) Üçer aylık dönemlerde yapıyoruz. **(0 … 100)**
d) Yılda iki kez yapıyoruz. **(0 … 100)**
e) Yıllık yapıyoruz. **(0 … 100)**
f) Diğer (Açıklayınız) **(0 … 100)**

2.8 Müşterilerimizin istekleri/ihtiyaçları/tercihleri ile ilgili bilgiler düzenli olarak topluyoruz. **(0 … 100)**

2.9 Şirketimizin amaç ve politikaları, müşterilerimizin memnuniyeti üzerine tesis edilmiştir. **(0 … 100)**

2.10 Müşteri memnuniyeti seviyesini düzenli olarak değerlendirerek, iyileştirmeye yönelik kararlarımızı derhal alıyoruz. **(0 … 100)**

2.11 Önemli müşterilerimiz/müşteri gruplarımızla kuvvetli ilişkiler kurmaya ve korumaya gayret ediyoruz. **(0 … 100)**

2.12 Pazarımızda farklı ihtiyaçları olan farklı grup ve segmentlerin varlığını idrak ederek, kendimizi buna göre adapte ediyoruz. **(0 … 100)**

2.13 Rakiplerimizin faaliyetleri hakkında düzenli olarak bilgi topluyoruz. **(0 … 100)**

2.14 Rakiplerimizin pazara sunumlarını takip edebilmek için düzenli olarak "Benchmarking" tatbik ediyoruz. **(0 … 100)**

2.15 Önem verdiğimiz rakiplerimizin ataklarına hızlı cevap verebiliyoruz. **(0 … 100)**

2.16 Müşterilerimizin, rakiplerimizde önem verdiği konular hakkında kendimizi farklılaştırmaya çok önem veriyoruz. **(0 … 100)**

2.17 AR-GE projelerimizi,

a) Rakiplerimizin teknolojik faaliyetlerine göre saptıyoruz. **(0 … 100)**
b) Pazardaki teknolojik değişim hızına göre saptıyoruz. **(0 … 100)**
c) Teknolojik değişimin radikal mi yoksa mevcutta iyileştirme mi olduğuna bakarak saptıyoruz.
(0 … 100)
d) Müşterilerden gelen isteklere cevap verecek şekilde saptıyoruz. **(0 … 100)**
e) Diğer (Açıklayınız) **(0 … 100)**

2.18 En büyük önceliğimiz, kısa dönemdeki karlılık değil, uzun vadedeki pazar payımızı artırmaktır. **(0 … 100)**

2.19 İç bünyeye yönelik verimliliği artırmaktan çok, pazar performansımızı artırmaya önem veriyoruz. **(0 … 100)**

2.20 Kararlarımızda kısa vadeli kazançları değil, uzun vadeli faydaları önemseriz. **(0 … 100)**

2.21 Müşterilerle ilgili bilgiler, organizasyon içinde sirküle edilir ve paylaşılır. **(0 … 100)**

2.22 Organizasyonda farklı departmanlarda müşterilerin ihtiyaçlarına hizmet etmek için etkin bir şekilde birlikte çalışılır. **(0 … 100)**

2.23 Müşteri hizmetlerinin etkinliği için departmanlar arası gerilim ve çekişmeye izin verilmez. **(0 … 100)**

2.24 Organizasyonumuz katı hiyerarşi ile kısıtlanmadan, fırsatları yakalayarak deperlendirebilecek esnekliğe sahiptir. **(0 … 100)**

2.25 Çalışanlarımızın tümü, müşteri memnuniyeti için üslendikleri rolün bilincindedir. **(0 … 100)**

2.26 Çalışanı ödüllendirme sistemi pazar performansı ve müşteri memnuniyetine uygun kurulmuştur. **(0 … 100)**

2.27 Üst yönetim, her zaman müşteri memnuniyetine ilişkin konulara öncelik verir. **(0 … 100)**

2.28 Tedarikçilerle olan ilişkilerimiz pazarda bizi avantajlı konumda tutmaktadır. **(0 … 100)**

2.29 Tedarikçilerle olan pazarlık gücümüz, rakiplerimize kıyasla bize üstünlük sağlar. **(0 … 100)**

2.30 Satış gücümüz, pazardaki en büyük kozumuzdur. **(0 … 100)**

2.31 Distribütörler/Perakendeciler satış gücümüzün en önemli parçasıdır. **(0 … 100)**

2.32 Kararlarınızı alırken hangi bilgilere ihtiyaç duyuyorsunuz?

a) Tüketici istekleri **(0 … 100)**
b) Rakiplerin faaliyetleri **(0 … 100)**
c) Talep tahminleri/Pazar araştırmaları **(0 … 100)**
d) Genel ekonomik veriler **(0 … 100)**
e) Maliyetler **(0 … 100)**
f) Kullanılabilir mali kaynaklar **(0 … 100)**
g) Diğer (Açıklayınız) **(0 … 100)**

2.33 Kararlarınızda kullandığınız bilgileri türetirken hangi teknikleri ve araçları kullanıyorsunuz?

a) "Beyin fırtınası" (Brainstorming) **(0 … 100)**
b) Tüketici analizleri **(0 … 100)**
c) "Benchmarking" **(0 … 100)**
d) Teknoloji tahminleri **(0 … 100)**
e) Trend analizleri **(0 … 100)**
f) Patent analizleri **(0 … 100)**
g) Regresyon **(0 … 100)**
h) Diğer (Açıklayınız) **(0 … 100)**

2.34 Kararlarınızı alırken göz önüne aldığınız kısıtlar nelerdir?

a) Mali kaynakların sınırları **(0 … 100)**
b) Teknolojik yeterlilik **(0 … 100)**
c) İnsan kaynakları **(0 … 100)**
d) Bilimsel bilgi ve analiz gücü **(0 … 100)**
e) AR-GE imkanları **(0 … 100)**
f) Yasal zorunluluklar **(0 … 100)**
g) Diğer (Açıklayınız) **(0 … 100)**

2.35 Aşağıdaki diyagramda, ürün yönetimi kararlarını etkileyebilecek makro-çevresel faktörler gösterilmiştir. Firmanızda ürün yönetimi kararlarınızı etkileyen bu kategorideki faktörleri **(0-100)** aralığında derecelendiriniz.

1. Politik (0 … 100)

- ✓ Dış ticaret politikası
- ✓ Vergi politikası
- ✓ Politik istikrar
- ✓ Sosyal refah projeleri

4. Sosyo-kültürel (0 … 100)

- ✓ Demografik nüfus
- ✓ Gelir dağılımı
- ✓ Sosyal hareketlilik
- ✓ Yaşam tarzı değişiklikleri
- ✓ İşve eğlence davranışları
- ✓ Tüketici trendleri
- ✓ Eğitim düzeyi

2. Yasal (0 … 100)

- ✓ Rekabet piyasası kanunları
- ✓ İşçi yasaları
- ✓ Ürün güvenliği yasası
- ✓ Kamu sağlığı ve güvencesi yasası

5. Makro-teknolojik (0 … 100)

- ✓ Hükümetin kendi yaptığı araştırmalar
- ✓ Hükümet ve endüstrinin teknolojik eforları
- ✓ Keşifler
- ✓ Teknoloji transfer hızı

3. Ekonomik (0 … 100)

- ✓ Dalgalanmalar
- ✓ Büyüme trendi
- ✓ Faiz oranları
- ✓ Piyasanın para arzı
- ✓ Enflasyon
- ✓ İşsizlik
- ✓ Harcanabilir gelir

6. Çevresel (0 … 100)

- ✓ Çevreyi koruma yasası
- ✓ Geri kullanım/dönüşüm
- ✓ Enerji ve doğal kaynaklar tüketimi

BÖLÜM 3: GENELLEME

3.1 Ürün yönetimi üç yıl ya da sonrası dönemleri kapsayan uzun vadeli planlama ve stratejik kararlar almayı gerektirir. **(0 … 100)**

3.2 Etkin ve başarılı bir ürün yönetiminden beklenen, doğru zamanda doğru ürünlerle piyasada olmak ve kaynakları en doğru şekilde kullanmaktır. **(0 … 100)**

3.3 Ürün yönetiminde ilk hareket noktası,

a) Tüketici istekleri/talepleridir. **(0 … 100)**

b) AR-GE'nin geliştirdiği projelerdir. **(0 … 100)**

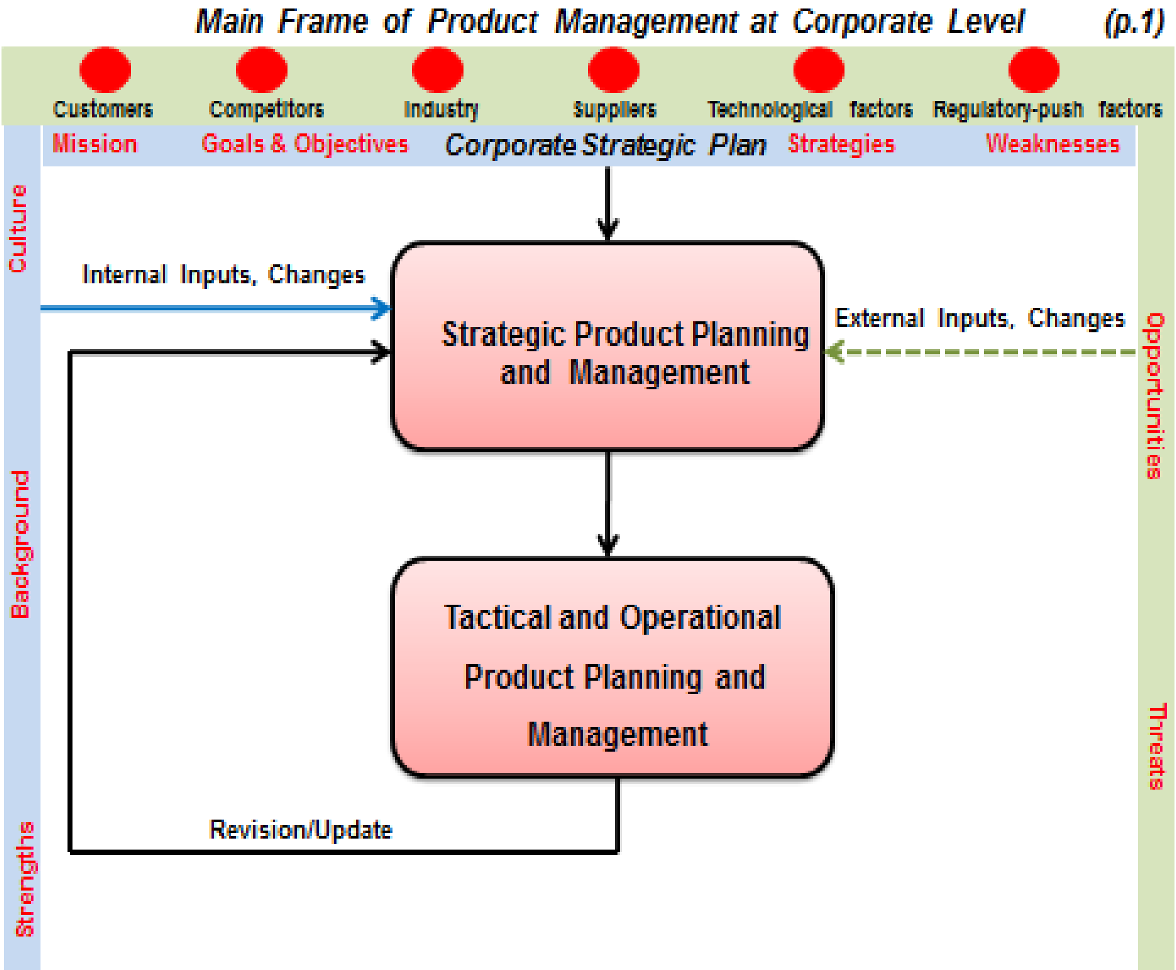
3.3 Ürün yönetiminde sizi en çok zorlayan karar problemi hangisidir?

3.4 Sizce ideal/etkin ürün yönetimi nasıl olmalıdır?

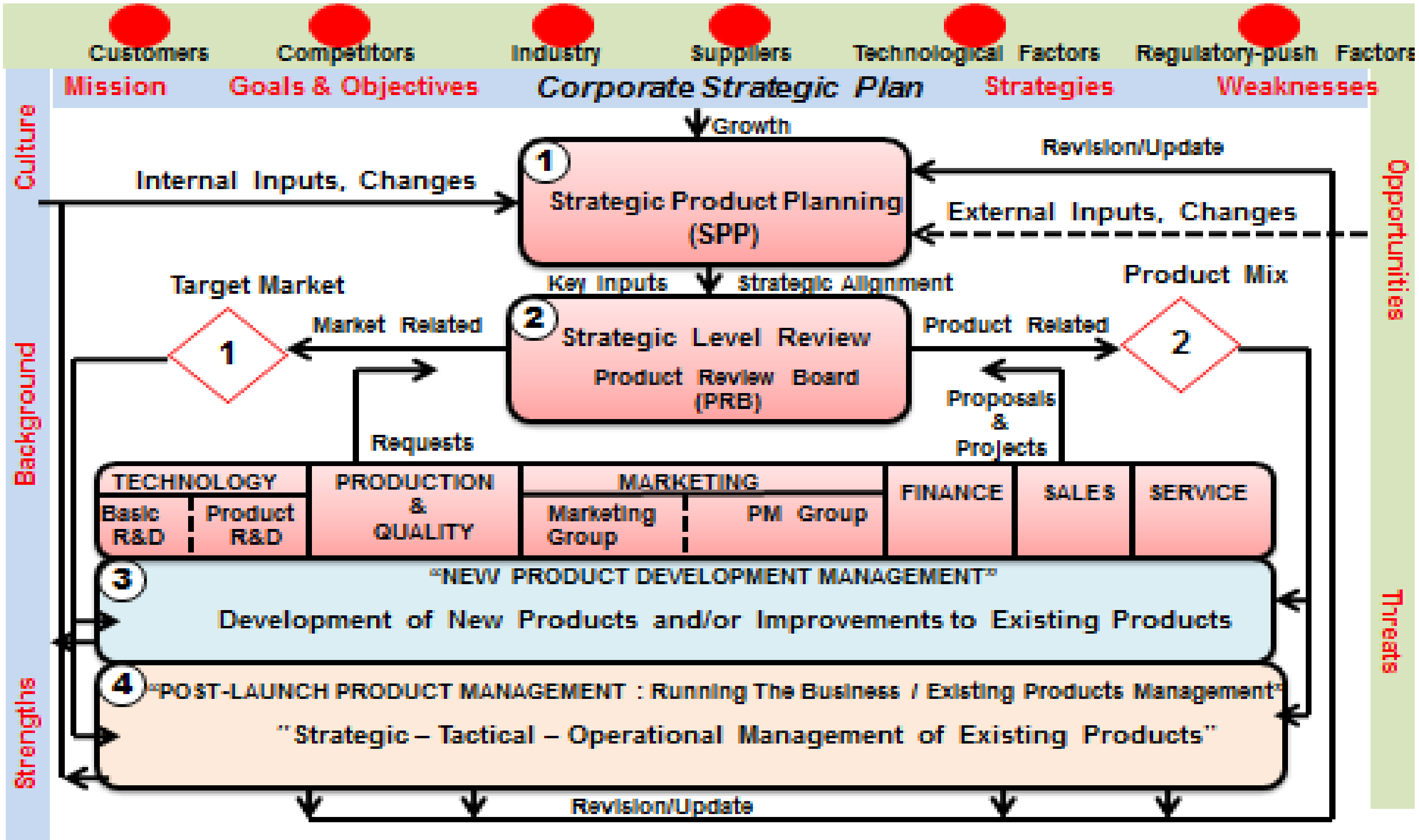
T E Ş E K K Ü R L E R

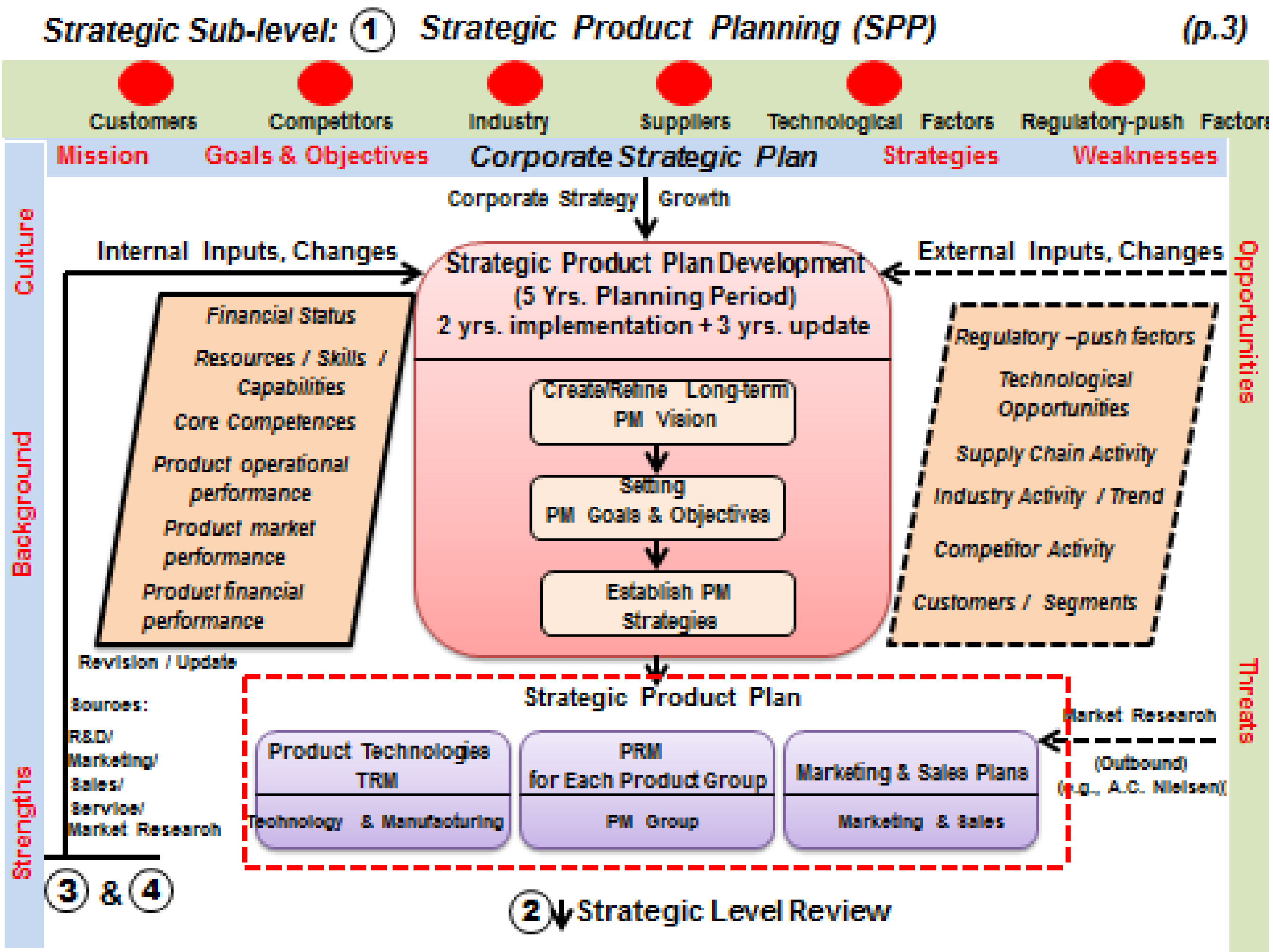
APPENDIX C

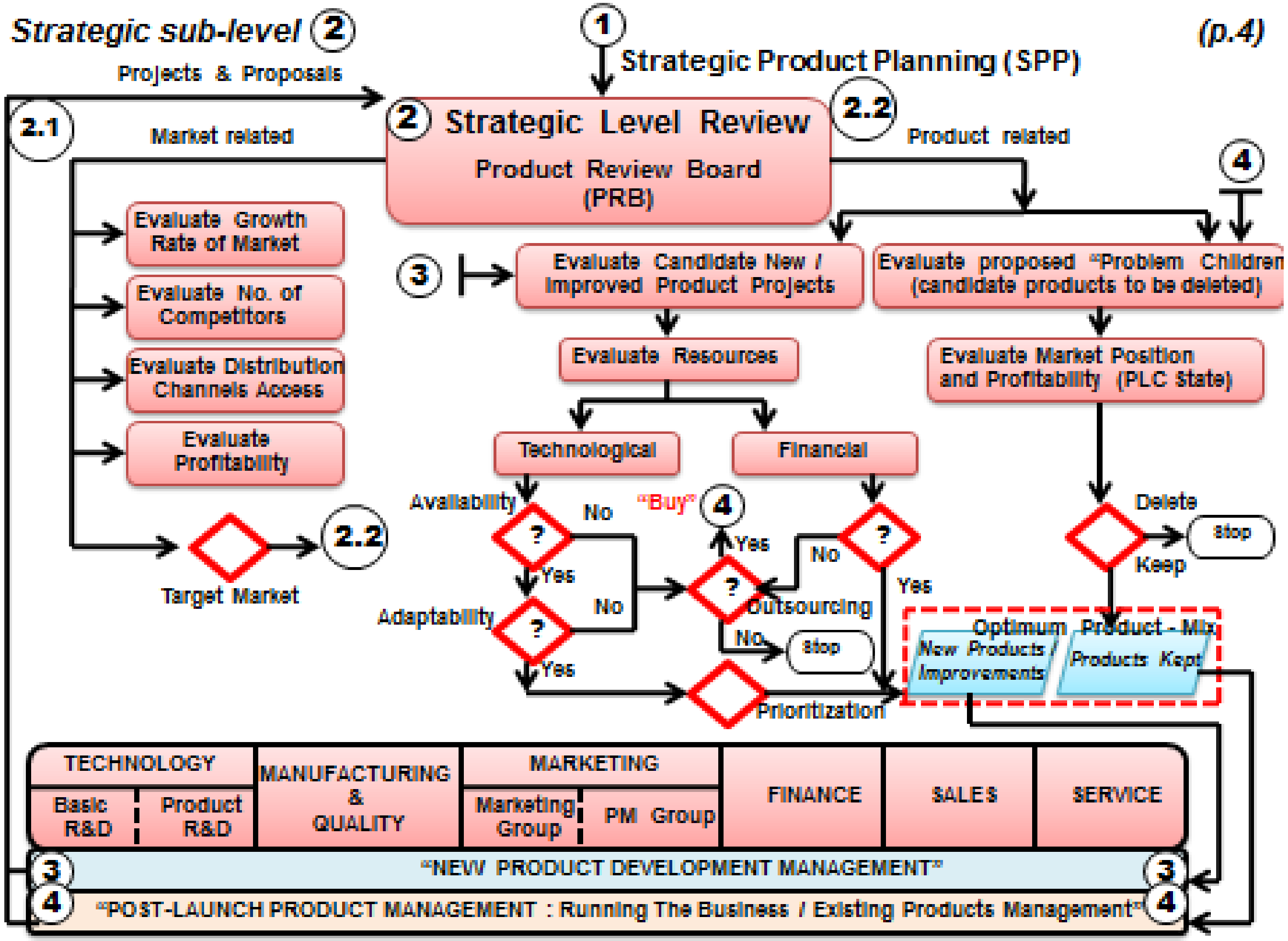
FLOWCHART OF PRODUCT MANAGEMENT FRAMEWORK (FLOW MODEL)



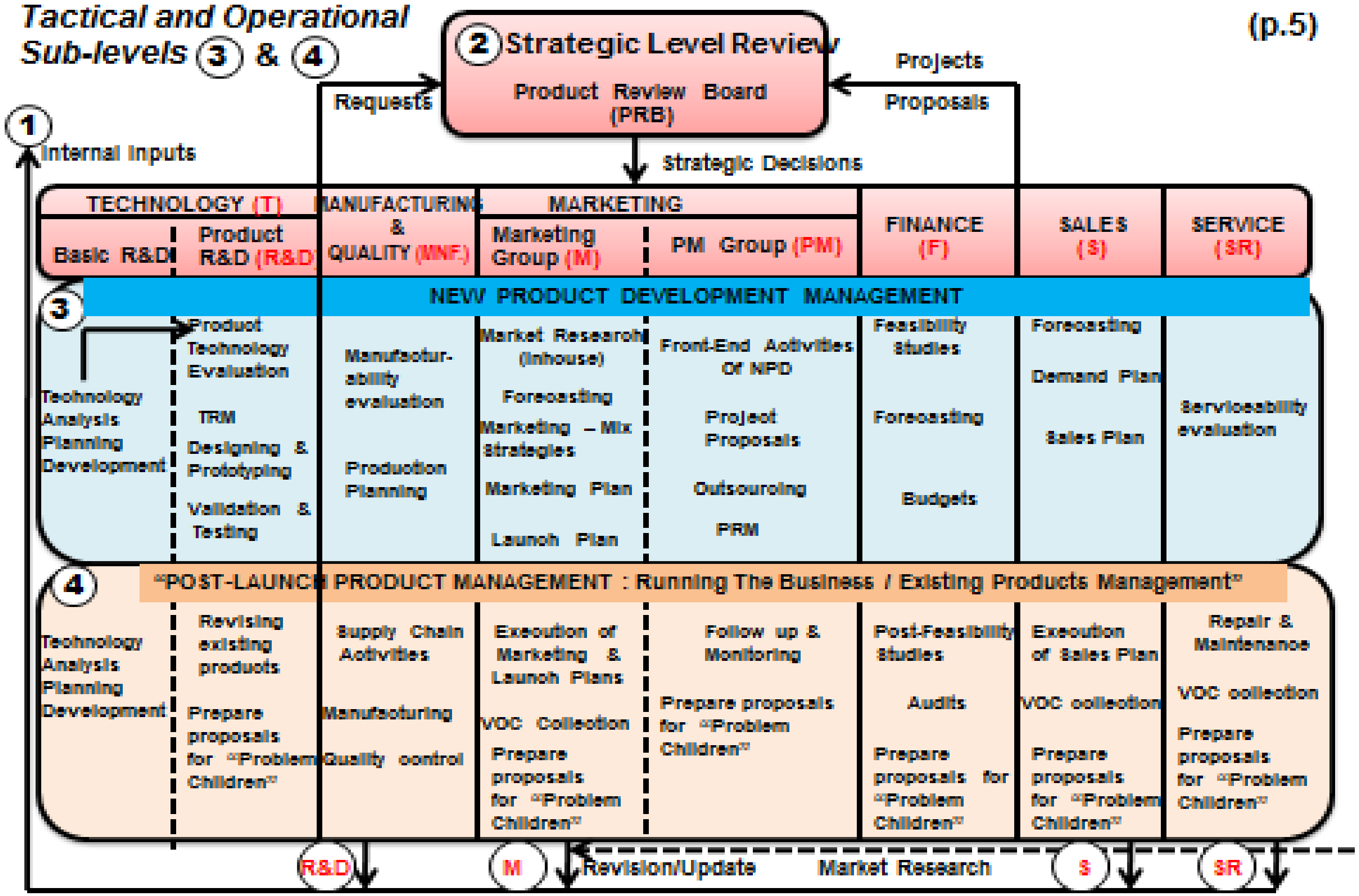
Levels of Major Activities and Decisions in Product Management (p.2)

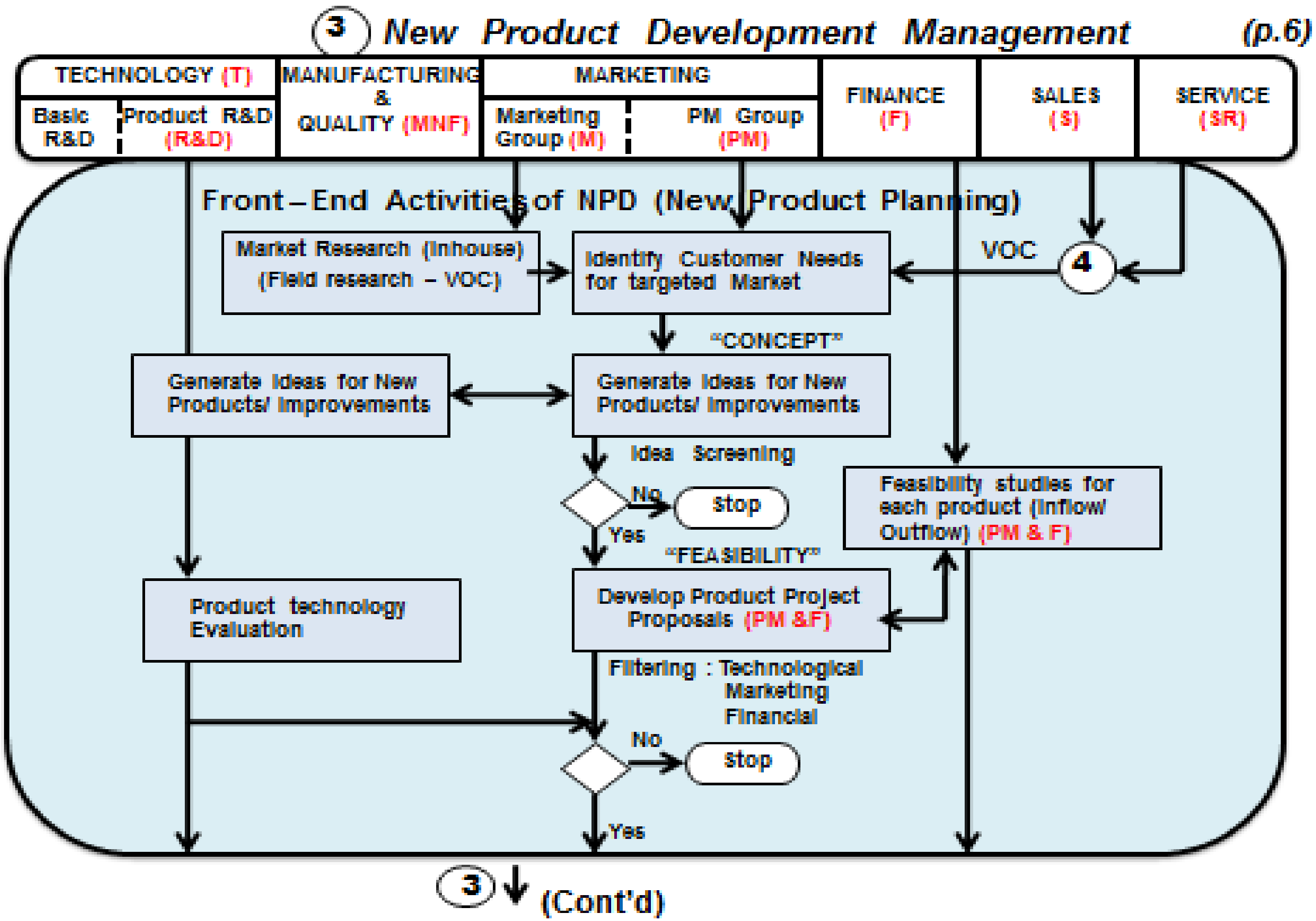


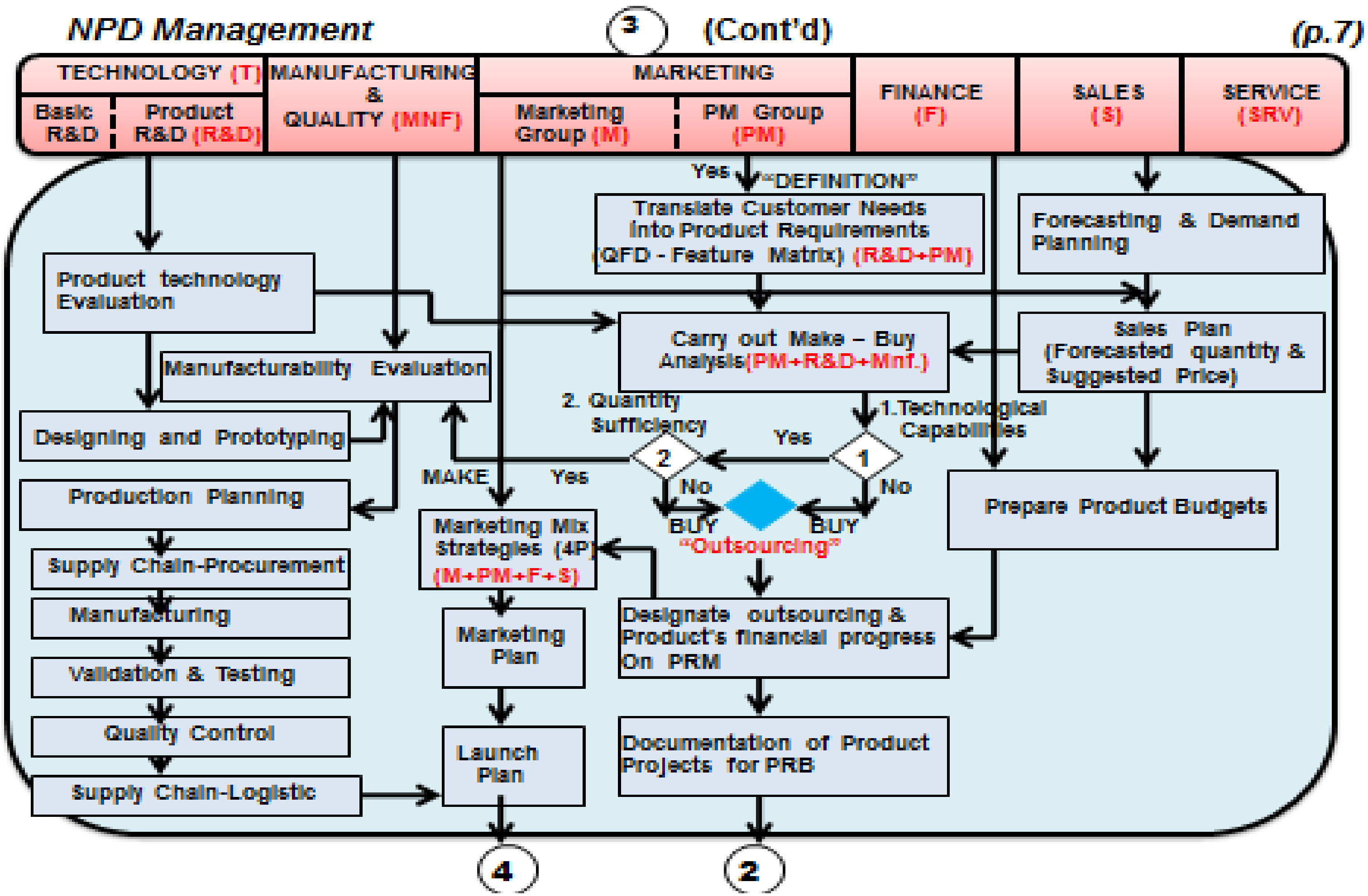

Strategic Sub-level: 1 Strategic Product Planning (SPP)
(p.3)
Customers
Competitors
Industry
Suppliers
Technological Factors
Regulatory-push Factors
Mission
Goals & Objectives
Corporate Strategic Plan
Strategies
Weaknesses
Culture
Background
Strengths
Opportunities
Threats
Corporate Strategy
Growth
Internal Inputs, Changes
External Inputs, Changes
Strategic Product Plan Development
(5 Yrs. Planning Period)
2 yrs. implementation + 3 yrs. update
Create/Refine Long-term PM Vision
Setting PM Goals & Objectives
Establish PM Strategies
Financial Status
Resources / Skills / Capabilities
Core Competences
Product operational performance
Product market performance
Product financial performance
Regulatory –push factors
Technological Opportunities
Supply Chain Activity
Industry Activity / Trend
Competitor Activity
Customers / Segments
Revision / Update
Sources:
R&D/
Marketing/
Sales/
Service/
Market Research
Strategic Product Plan
Product Technologies TRM
Technology & Manufacturing
PRM for Each Product Group
PM Group
Marketing & Sales Plans
Marketing & Sales
Market Research
(Outbound)
(e.g., A.C. Nielsen)
3 & 4
2 Strategic Level Review



Strategic sub-level 2
(p.4)
1
Strategic Product Planning (SPP)
Projects & Proposals
2.1
Market related
2 Strategic Level Review
Product Review Board (PRB)
2.2
Product related
4
Evaluate Growth Rate of Market
Evaluate No. of Competitors
Evaluate Distribution Channels Access
Evaluate Profitability
Target Market
2.2
3
Evaluate Candidate New / Improved Product Projects
Evaluate proposed "Problem Children" (candidate products to be deleted)
Evaluate Resources
Evaluate Market Position and Profitability (PLC State)
Technological
Financial
Availability
Adaptability
No
Yes
"Buy"
4
Outsourcing
Stop
Prioritization
Delete
Keep
Optimum Product - Mix
New Products / Improvements
Products Kept
TECHNOLOGY
Basic R&D
Product R&D
MANUFACTURING & QUALITY
MARKETING
Marketing Group
PM Group
FINANCE
SALES
SERVICE
3 "NEW PRODUCT DEVELOPMENT MANAGEMENT" 3
4 "POST-LAUNCH PRODUCT MANAGEMENT : Running The Business / Existing Products Management" 4


Tactical and Operational Sub-levels 3 & 4
(p.5)
2 Strategic Level Review
Product Review Board (PRB)
Requests
Projects
Proposals
1 Internal Inputs
Strategic Decisions
TECHNOLOGY (T)
Basic R&D
Product R&D (R&D)
MANUFACTURING & QUALITY (MNF.)
MARKETING
Marketing Group (M)
PM Group (PM)
FINANCE (F)
SALES (S)
SERVICE (SR)
3 NEW PRODUCT DEVELOPMENT MANAGEMENT
Technology Analysis Planning Development
Product Technology Evaluation
TRM
Designing & Prototyping
Validation & Testing
Manufactur-ability evaluation
Production Planning
Market Research (inhouse)
Forecasting
Marketing – Mix strategies
Marketing Plan
Launch Plan
Front-End Activities Of NPD
Project Proposals
Outsourcing
PRM
Feasibility studies
Forecasting
Budgets
Forecasting
Demand Plan
Sales Plan
Serviceability evaluation
4 "POST-LAUNCH PRODUCT MANAGEMENT : Running The Business / Existing Products Management"
Technology Analysis Planning Development
Revising existing products
Prepare proposals for "Problem Children"
Supply Chain Activities
Manufacturing
Quality control
Execution of Marketing & Launch Plans
VOC Collection
Prepare proposals for "Problem Children"
Follow up & Monitoring
Prepare proposals for "Problem Children"
Post-Feasibility studies
Audits
Prepare proposals for "Problem Children"
Execution of Sales Plan
VOC collection
Prepare proposals for "Problem Children"
Repair & Maintenance
VOC collection
Prepare proposals for "Problem Children"
R&D
M
Revision/Update
Market Research
S
SR


3
New Product Development Management
(p.6)
TECHNOLOGY (T)
Basic R&D
Product R&D (R&D)
MANUFACTURING & QUALITY (MNF)
MARKETING
Marketing Group (M)
PM Group (PM)
FINANCE (F)
SALES (S)
SERVICE (SR)
Front – End Activities of NPD (New Product Planning)
Market Research (Inhouse) (Field research – VOC)
Identify Customer Needs for targeted Market
VOC
4
"CONCEPT"
Generate Ideas for New Products/ Improvements
Generate Ideas for New Products/ Improvements
Idea Screening
No
Stop
Yes
"FEASIBILITY"
Feasibility studies for each product (Inflow/ Outflow) (PM & F)
Product technology Evaluation
Develop Product Project Proposals (PM &F)
Filtering : Technological Marketing Financial
No
Stop
Yes
3
(Cont'd)



NPD Management
3
(Cont'd)
(p.7)
TECHNOLOGY (T)
Basic R&D
Product R&D (R&D)
MANUFACTURING & QUALITY (MNF)
MARKETING
Marketing Group (M)
PM Group (PM)
FINANCE (F)
SALES (S)
SERVICE (SRV)
Yes
"DEFINITION"
Translate Customer Needs into Product Requirements (QFD - Feature Matrix) (R&D+PM)
Forecasting & Demand Planning
Product technology Evaluation
Carry out Make – Buy Analysis(PM+R&D+Mnf.)
Sales Plan (Forecasted quantity & Suggested Price)
Manufacturability Evaluation
Designing and Prototyping
2. Quantity Sufficiency
1.Technological Capabilities
Yes
2
1
MAKE
Yes
No
No
Production Planning
BUY
BUY
"Outsourcing"
Prepare Product Budgets
Marketing Mix Strategies (4P) (M+PM+F+S)
Supply Chain-Procurement
Manufacturing
Marketing Plan
Designate outsourcing & Product's financial progress On PRM
Validation & Testing
Quality Control
Launch Plan
Documentation of Product Projects for PRB
Supply Chain-Logistic
4
2

APPENDIX D

MATLAB 7.0 – CODE

```
function Victory = CombinedExpFinal1
 % INPUT DEFINITIONS
P = xlsread('Parameters1-Com'); %Fixed Inputs
k = P(1); %number of products
ep = P(2); %coefficient
interest = P(3);
varep = P(4);
noe = P(5);
Exp = xlsread('Experiments3');% should be in Scenario matrix format
K = xlsread('Parameters2-Com'); %Product dependent inputs-array inputs
meancost = K(1,:);
varcost = K(2,:);
sigmacost = sqrt(varcost);
unitcap = K(3,:);
totcap = K(4,:);
meanp = xlsread('meanp');
varp = xlsread('varp');
sigmap = sqrt(varp);
intercept = xlsread('intercept');
elasticity = xlsread('elasticity');
lowbound = xlsread('lowbound');
marketmat = xlsread('marketmat');
Scenario =
scenario(k,ep,meancost,sigmacost,meanp,sigmap,intercept,elasticity,marketmat
,varep);
ComScenario = cat(1,Scenario,Exp);
Optimization =
optimization(k,ComScenario,lowbound,marketmat,unitcap,totcap,interest,noe);
Victory = 35;

% STRUCTURED SCENARIO GENERATION
function Scenario =
scenario(k,ep,meancost,sigmacost,meanp,sigmap,intercept,elasticity,marketmat
,varep)
m = sum(marketmat,2);
summ = sum(m);
n = 2*summ + k;
Scenario = ff2n(n);
xlswrite('ComResults',Scenario,'First');

for j = 1:k
    col = 1;
    if j == 1
        col = 1;
    else
        for l = 1:j-1
            col = col + 2*m(l) + 1;
        end
    end

for i = 1:2^n
        if Scenario(i,col) == 1
            Scenario(i,col) = meancost(j) + ep * sigmacost(j);
        else
            Scenario(i,col) = meancost(j) - ep * sigmacost(j);
```

```
        end
    end
end

xlswrite('ComResults',Scenario,'Second');


for j = 1:k
    col = 1;
    if j == 1
        col = 1;
    else
        for l = 1:j-1
            col = col + 2*m(l) + 1;
        end
    end
    indices = find(marketmat(j,:));
    for l = 0:m(j)-1
        for i = 1:2^n
            if Scenario(i,col + 2*l + 1) == 1
                Scenario(i,col + 2*l + 1) = meanp(j,indices(l+1)) + ep *
sigmap(j,indices(l+1));
            else
                Scenario(i,col + 2*l + 1) = meanp(j,indices(l+1)) - ep *
sigmap(j,indices(l+1));
            end

        end
    end

end



xlswrite('ComResults',Scenario,'Third');

for j = 1:k
    col = 1;
    if j == 1
        col = 1;
    else
        for l = 1:j-1
            col = col + 2*m(l) + 1;
        end
    end
    indices = find(marketmat(j,:));
    for l = 0:m(j)-1
        for i = 1:2^n
            temp = intercept(j,indices(l+1)) - elasticity(j,indices(l+1)) *
Scenario(i,col + 2*l + 1);
            if Scenario(i,col + 2*l + 2) == 1
                Scenario(i,col + 2*l + 2) = temp + sqrt(varep * temp);
            else
                Scenario(i,col + 2*l + 2) = temp - sqrt(varep * temp);
            end
        end

    end
end

savefile = 'ComScenario.mat';
save(savefile, 'Scenario');
%xlswrite('ComResults',Scenario,'Forth');
```

```
% OPTIMIZATION
function Optimization =
optimization(k,ComScenario,lowbound,marketmat,unitcap,totcap,interest,noe)
m = sum(marketmat,2);
summ = sum(m);
n = 2*summ + k;
obj = zeros(2^n+noe,summ);
cost = zeros(2^n+noe,summ);
bound = zeros(2^n+noe,summ);
constraint = zeros(k,summ);
for j = 1:k
    col = 1;
    if j == 1
        col = 1;
    else
        for l = 1:j-1
            col = col + 2*m(l) + 1;
        end
    end
    column = 1;
    if j == 1
        column = 1;
    else
        for l = 1:j-1
            column = column + m(l);
        end
    end
    for l = 0:m(j)-1
        constraint(j,column+l) = 1 * unitcap(j);
        for i = 1:2^n+noe
            obj(i,column+l) = ComScenario(i,col + 2*l + 1) -
ComScenario(i,col);
            cost(i,column+l) = ComScenario(i,col);
            bound(i,column+l) = ComScenario(i,col + 2*l + 2);
        end
    end
end
%display(ComScenario)
A = constraint;
b = totcap';

%xlswrite('ComResults',obj,'Fifth');
%xlswrite('ComResults',bound,'Sixth');
Optimization = zeros(2^n+noe,summ+1);
Solution = zeros(2^n+noe,summ);
demand = zeros(2^n+noe,summ);
for i = 1:2^n
    upbound = max(lowbound,bound(i,:)');
    demand(i,:) = max(lowbound,bound(i,:)');
    f = -1 * obj(i,:)';
    [x,fval] = linprog(f,A,b,[],[],lowbound,upbound);
    Optimization(i,:) = [x',-1 * fval];
    Solution(i,:) = x';
end


 for i = 2^n+1:2^n+noe
        upbound = bound(i,:)';
        f = -1 * obj(i,:)';
        [x,fval] = linprog(f,A,b,[],[],lowbound,upbound);
        Optimization(i,:) = [x',-1 * fval];
        Solution(i,:) = x';
 end
```

```
xlswrite('ComResults',Optimization,'Result');

% TESTING THE SOLUTIONS UNDER ALL STRUCTURED SCENARIOS-Objective Function

Rmatrix = zeros(2^n+noe,2^n);
for i = 1:2^n+noe
    for j = 1:2^n
        Rmatrix(i,j) = (Solution(i,:) - max(Solution(i,:) - demand(j,:), 0)
) * obj(j,:)' - interest * max(Solution(i,:) - demand(j,:), 0) * cost(j,:)'
;
    end
end
%xlswrite('ComResults',Rmatrix,'Rmatrix');

Profitmin = min(Rmatrix,[],2);
Profitmax = max(Rmatrix,[],2);
Profitmean = mean(Rmatrix,2);
Profitstd = std(Rmatrix,1,2);

Profitdata = zeros(2^n+noe,4);
Profitdata(:,1)= Profitmin;
Profitdata(:,2)= Profitmax;
Profitdata(:,3)= Profitmean;
Profitdata(:,4)= Profitstd;

savefile = 'ComProfit.mat';
save(savefile,'Profitdata');

% REGRET MATRIX CONSTRUCTION
Regretmat = zeros(2^n,2^n);
for i = 1:2^n
    for j=1:2^n
          Regretmat(i,j) = Rmatrix(j,j) - Rmatrix(i,j);
    end
end


for i = 2^n+1:2^n+noe
    for j=1:2^n
        Regretmat(i,j) =  Optimization(j,summ+1) - Rmatrix(i,j);
   end
end


%xlswrite('ComResults',Regretmat,'Regretmat');

% REGRET FREE PROFIT
Pdistance = zeros (2^n+noe,2^n);
for i = 1:2^n+noe
    Pdistance (i,:) = Rmatrix (i,:)- Regretmat (i,:);
end
%xlswrite('ComResults',Pdistance,'Pdistance');

Pdistancemin = min(Pdistance,[],2);
Pdistancemax = max(Pdistance,[],2);
Pdistancemean = mean(Pdistance,2);
Pdistancestd = std(Pdistance,1,2);
Pdistanceskew = skewness(Pdistance,1,2);

Pdistancesq = Pdistance .* Pdistance;
Reciprocal = zeros (2^n+noe,2^n);
for i = 1:2^n+noe
```

```
    for j = 1:2^n
        Reciprocal(i,j) = 1/Pdistancesq(i,j);
   end
end
Reciprocalmean = mean (Reciprocal,2);
Pdistancesnr = -10 *log(Reciprocalmean);

FreeProfitdata = zeros(2^n+noe,6);
FreeProfitdata(:,1) = Pdistancemin;
FreeProfitdata(:,2) = Pdistancemax;
FreeProfitdata(:,3) = Pdistancemean;
FreeProfitdata(:,4) = Pdistancestd;
FreeProfitdata(:,5) = Pdistancesnr;
FreeProfitdata(:,6) = Pdistanceskew;

savefile='ComFreeProfit.mat';
save(savefile,'FreeProfitdata');

Regretmin = min(Regretmat,[],2);
Regretmax = max(Regretmat,[],2);
Regretmean = mean(Regretmat,2);
Regretstd = std(Regretmat,1,2);
Regretmeansq = Regretmean .* Regretmean;
Regretstdsq = Regretstd .* Regretstd;
Regretsnr = -10 * log(Regretmeansq + Regretstdsq);
Regretskew = skewness(Regretmat,1,2);

Regretdata = zeros(2^n+noe,6);
Regretdata(:,1) = Regretmin;
Regretdata(:,2) = Regretmax;
Regretdata(:,3) = Regretmean;
Regretdata(:,4) = Regretstd;
Regretdata(:,5) = Regretsnr;
Regretdata(:,6) = Regretskew;

xlswrite('ComResults',Regretdata,'Regretdata');

Regretmaxmin = min(Regretmax);
Maxregretsnr = max(Regretsnr);
MaxPdistancesnr = max(Pdistancesnr);

display (Regretmaxmin)
display (Maxregretsnr)
display (MaxPdistancesnr)

%xlswrite('ComResults',Regretmaxmin,'Regretmaxmin');
savefile = 'ComOptimization.mat';
save(savefile, 'Optimization', 'Rmatrix',
'Regretmat','Pdistance','Regretdata',
'Regretmaxmin','Maxregretsnr','MaxPdistancesnr');
```

APPENDIX E

OUTPUT EXAMPLE

Table E-1: Scenario Matrix (Example 1)

PC_1	SP_{11}	d_{11}	SP_{12}	d_{12}	PC_2	SP_{21}	d_{21}
1047,71	1567,43	3344,51	1960,94	7489,74	119,492	185,641	4037,29
1047,71	1567,43	3344,51	1960,94	7489,74	119,492	185,641	4077,57
1047,71	1567,43	3344,51	1960,94	7489,74	119,492	194,358	4002,50
1047,71	1567,43	3344,51	1960,94	7489,74	119,492	194,358	4042,62
1047,71	1567,43	3344,51	1960,94	7489,74	126,507	185,641	4037,29
1047,71	1567,43	3344,51	1960,94	7489,74	126,507	185,641	4077,57
1047,71	1567,43	3344,51	1960,94	7489,74	126,507	194,358	4002,50
1047,71	1567,43	3344,51	1960,94	7489,74	126,507	194,358	4042,62
1047,71	1567,43	3344,51	1960,94	7544,57	119,492	185,641	4037,29
1047,71	1567,43	3344,51	1960,94	7544,57	119,492	185,641	4077,57
1047,71	1567,43	3344,51	1960,94	7544,57	119,492	194,358	4002,50
1047,71	1567,43	3344,51	1960,94	7544,57	119,492	194,358	4042,62
1047,71	1567,43	3344,51	1960,94	7544,57	126,507	185,641	4037,29
1047,71	1567,43	3344,51	1960,94	7544,57	126,507	185,641	4077,57
1047,71	1567,43	3344,51	1960,94	7544,57	126,507	194,358	4002,50
1047,71	1567,43	3344,51	1960,94	7544,57	126,507	194,358	4042,62
1047,71	1567,43	3344,51	1989,05	7405,57	119,492	185,641	4037,29
1047,71	1567,43	3344,51	1989,05	7405,57	119,492	185,641	4077,57
1047,71	1567,43	3344,51	1989,05	7405,57	119,492	194,358	4002,50
1047,71	1567,43	3344,51	1989,05	7405,57	119,492	194,358	4042,62
1047,71	1567,43	3344,51	1989,05	7405,57	126,507	185,641	4037,29
1047,71	1567,43	3344,51	1989,05	7405,57	126,507	185,641	4077,57
1047,71	1567,43	3344,51	1989,05	7405,57	126,507	194,358	4002,50
1047,71	1567,43	3344,51	1989,05	7405,57	126,507	194,358	4042,62
1047,71	1567,43	3344,51	1989,05	7460,10	119,492	185,641	4037,29
1047,71	1567,43	3344,51	1989,05	7460,10	119,492	185,641	4077,57
1047,71	1567,43	3344,51	1989,05	7460,10	119,492	194,358	4002,50
1047,71	1567,43	3344,51	1989,05	7460,10	119,492	194,358	4042,62
1047,71	1567,43	3344,51	1989,05	7460,10	126,507	185,641	4037,29
1047,71	1567,43	3344,51	1989,05	7460,10	126,507	185,641	4077,57
1047,71	1567,43	3344,51	1989,05	7460,10	126,507	194,358	4002,50
1047,71	1567,43	3344,51	1989,05	7460,10	126,507	194,358	4042,62
1047,71	1567,43	3381,18	1960,94	7489,74	119,492	185,641	4037,29

1047,71	1567,43	3381,18	1960,94	7489,74	119,492	185,641	4077,57
1047,71	1567,43	3381,18	1960,94	7489,74	119,492	194,358	4002,50
1047,71	1567,43	3381,18	1960,94	7489,74	119,492	194,358	4042,62
1047,71	1567,43	3381,18	1960,94	7489,74	126,507	185,641	4037,29
1047,71	1567,43	3381,18	1960,94	7489,74	126,507	185,641	4077,57
1047,71	1567,43	3381,18	1960,94	7489,74	126,507	194,358	4002,50
1047,71	1567,43	3381,18	1960,94	7489,74	126,507	194,358	4042,62
1047,71	1567,43	3381,18	1960,94	7544,57	119,492	185,641	4037,29
1047,71	1567,43	3381,18	1960,94	7544,57	119,492	185,641	4077,57
1047,71	1567,43	3381,18	1960,94	7544,57	119,492	194,358	4002,50
1047,71	1567,43	3381,18	1960,94	7544,57	119,492	194,358	4042,62
1047,71	1567,43	3381,18	1960,94	7544,57	126,507	185,641	4037,29
1047,71	1567,43	3381,18	1960,94	7544,57	126,507	185,641	4077,57
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1047,71	1567,43	3381,18	1960,94	7544,57	126,507	194,358	4042,62
1047,71	1567,43	3381,18	1989,05	7405,57	119,492	185,641	4037,29
1047,71	1567,43	3381,18	1989,05	7405,57	119,492	185,641	4077,57
1047,71	1567,43	3381,18	1989,05	7405,57	119,492	194,358	4002,50
1047,71	1567,43	3381,18	1989,05	7405,57	119,492	194,358	4042,62
1047,71	1567,43	3381,18	1989,05	7405,57	126,507	185,641	4037,29
1047,71	1567,43	3381,18	1989,05	7405,57	126,507	185,641	4077,57
1047,71	1567,43	3381,18	1989,05	7405,57	126,507	194,358	4002,50
1047,71	1567,43	3381,18	1989,05	7405,57	126,507	194,358	4042,62
1047,71	1567,43	3381,18	1989,05	7460,10	119,492	185,641	4037,29
1047,71	1567,43	3381,18	1989,05	7460,10	119,492	185,641	4077,57
1047,71	1567,43	3381,18	1989,05	7460,10	119,492	194,358	4002,50
1047,71	1567,43	3381,18	1989,05	7460,10	119,492	194,358	4042,62
1047,71	1567,43	3381,18	1989,05	7460,10	126,507	185,641	4037,29
1047,71	1567,43	3381,18	1989,05	7460,10	126,507	185,641	4077,57
1047,71	1567,43	3381,18	1989,05	7460,10	126,507	194,358	4002,50
1047,71	1567,43	3381,18	1989,05	7460,10	126,507	194,358	4042,62
1047,71	1592,57	3219,15	1960,94	7489,74	119,492	185,641	4037,29
1047,71	1592,57	3219,15	1960,94	7489,74	119,492	185,641	4077,57
1047,71	1592,57	3219,15	1960,94	7489,74	119,492	194,358	4002,50
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1047,71	1592,57	3219,15	1960,94	7489,74	126,507	194,358	4042,62
1047,71	1592,57	3219,15	1960,94	7544,57	119,492	185,641	4037,29
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1047,71	1592,57	3219,15	1960,94	7544,57	126,507	194,358	4002,50
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1047,71	1592,57	3219,15	1989,05	7405,57	119,492	194,358	4002,50
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1047,71	1592,57	3219,15	1989,05	7460,10	119,492	185,641	4037,29
1047,71	1592,57	3219,15	1989,05	7460,10	119,492	185,641	4077,57
1047,71	1592,57	3219,15	1989,05	7460,10	119,492	194,358	4002,50
1047,71	1592,57	3219,15,	1989,05	7460,10	119,492	194,358	4042,62
1047,71	1592,57	3219,15	1989,05	7460,10	126,507	185,641	4037,29
1047,71	1592,57	3219,15	1989,05	7460,10	126,507	185,641	4077,57
1047,71	1592,57	3219,15	1989,05	7460,10	126,507	194,358	4002,50
1047,71	1592,57	3219,15	1989,05	7460,10	126,507	194,358	4042,62
1047,71	1592,57	3255,14	1960,94	7489,74	119,492	185,641	4037,29
1047,71	1592,57	3255,14	1960,94	7489,74	119,492	185,641	4077,57
1047,71	1592,57	3255,14	1960,94	7489,74	119,492	194,358	4002,50
1047,71	1592,57	3255,14	1960,94	7489,74	119,492	194,358	4042,62
1047,71	1592,57	3255,14	1960,94	7489,74	126,507	185,641	4037,29
1047,71	1592,57	3255,14	1960,94	7489,74	126,507	185,641	4077,57
1047,71	1592,57	3255,14	1960,94	7489,74	126,507	194,358	4002,50
1047,71	1592,57	3255,14	1960,94	7489,74	126,507	194,358	4042,62
1047,71	1592,57	3255,14	1960,94	7544,57	119,492	185,641	4037,29
1047,71	1592,57	3255,14	1960,94	7544,57	119,492	185,641	4077,57
1047,71	1592,57	3255,14	1960,94	7544,57	119,492	194,358	4002,50
1047,71	1592,57	3255,14	1960,94	7544,57	119,492	194,358	4042,62
1047,71	1592,57	3255,14	1960,94	7544,57	126,507	185,641	4037,29
1047,71	1592,57	3255,14	1960,94	7544,57	126,507	185,641	4077,57
1047,71	1592,57	3255,14	1960,94	7544,57	126,507	194,358	4002,50
1047,71	1592,57	3255,14	1960,94	7544,57	126,507	194,358	4042,62
1047,71	1592,57	3255,14	1989,05	7405,57	119,492	185,641	4037,29
1047,71	1592,57	3255,14	1989,05	7405,57	119,492	185,641	4077,57
1047,71	1592,57	3255,14	1989,05	7405,57	119,492	194,358	4002,50
1047,71	1592,57	3255,14	1989,05	7405,57	119,492	194,358	4042,62
1047,71	1592,57	3255,14	1989,05	7405,57	126,507	185,641	4037,29
1047,71	1592,57	3255,14	1989,05	7405,57	126,507	185,641	4077,57
1047,71	1592,57	3255,14	1989,05	7405,57	126,507	194,358	4002,50

1047,71	1592,57	3255,14	1989,05	7405,57	126,507	194,358	4042,62
1047,71	1592,57	3255,14	1989,05	7460,10	119,492	185,641	4037,29
1047,71	1592,57	3255,14	1989,05	7460,10	119,492	185,641	4077,57
1047,71	1592,57	3255,14	1989,05	7460,10	119,492	194,358	4002,50
1047,71	1592,57	3255,14	1989,05	7460,10	119,492	194,358	4042,62
1047,71	1592,57	3255,14	1989,05	7460,10	126,507	185,641	4037,29
1047,71	1592,57	3255,14	1989,05	7460,10	126,507	185,641	4077,57
1047,71	1592,57	3255,14	1989,05	7460,10	126,507	194,358	4002,50
1047,71	1592,57	3255,14	1989,05	7460,10	126,507	194,358	4042,62
1068,28	1567,43	3344,51	1960,94	7489,74	119,492	185,641	4037,29
1068,28	1567,43	3344,51	1960,94	7489,74	119,492	185,641	4077,57
1068,28	1567,43	3344,51	1960,94	7489,74	119,492	194,358	4002,50
1068,28	1567,43	3344,51	1960,94	7489,74	119,492	194,358	4042,62
1068,28	1567,43	3344,51	1960,94	7489,74	126,507	185,641	4037,29
1068,28	1567,43	3344,51	1960,94	7489,74	126,507	185,641	4077,57
1068,28	1567,43	3344,51	1960,94	7489,74	126,507	194,358	4002,50
1068,28	1567,43	3344,51	1960,94	7489,74	126,507	194,358	4042,62
1068,28	1567,43	3344,51	1960,94	7544,57	119,492	185,641	4037,29
1068,28	1567,43	3344,51	1960,94	7544,57	119,492	185,641	4077,57
1068,28	1567,43	3344,51	1960,94	7544,57	119,492	194,358	4002,50
1068,28	1567,43	3344,51	1960,94	7544,57	119,492	194,358	4042,62
1068,28	1567,43	3344,51	1960,94	7544,57	126,507	185,641	4037,29
1068,28	1567,43	3344,51	1960,94	7544,57	126,507	185,641	4077,57
1068,28	1567,43	3344,51	1960,94	7544,57	126,507	194,358	4002,50
1068,28	1567,43	3344,51	1960,94	7544,57	126,507	194,358	4042,62
1068,28	1567,43	3344,51	1989,05	7405,57	119,492	185,641	4037,29
1068,28	1567,43	3344,51	1989,05	7405,57	119,492	185,641	4077,57
1068,28	1567,43	3344,51	1989,05	7405,57	119,492	194,358	4002,50
1068,28	1567,43	3344,51	1989,05	7405,57	119,492	194,358	4042,62
1068,28	1567,43	3344,51	1989,05	7405,57	126,507	185,641	4037,29
1068,28	1567,43	3344,51	1989,05	7405,57	126,507	185,641	4077,57
1068,28	1567,43	3344,51	1989,05	7405,57	126,507	194,358	4002,50
1068,28	1567,43	3344,51	1989,05	7405,57	126,507	194,358	4042,62
1068,28	1567,43	3344,51	1989,05	7460,10	119,492	185,641	4037,29
1068,28	1567,43	3344,51	1989,05	7460,10	119,492	185,641	4077,57
1068,28	1567,43	3344,51	1989,05	7460,10	119,492	194,358	4002,50
1068,28	1567,43	3344,51	1989,05	7460,10	119,492	194,358	4042,62
1068,28	1567,43	3344,51	1989,05	7460,10	126,507	185,641	4037,29
1068,28	1567,43	3344,51	1989,05	7460,10	126,507	185,641	4077,57
1068,28	1567,43	3344,51	1989,05	7460,10	126,507	194,358	4002,50
1068,28	1567,43	3344,51	1989,05	7460,10	126,507	194,358	4042,62
1068,28	1567,43	3381,18	1960,94	7489,74	119,492	185,641	4037,29
1068,28	1567,43	3381,18	1960,94	7489,74	119,492	185,641	4077,57

1068,28	1567,43	3381,18	1960,94	7489,74	119,492	194,358	4002,50
1068,28	1567,43	3381,18	1960,94	7489,74	119,492	194,358	4042,62
1068,28	1567,43	3381,18	1960,94	7489,74	126,507	185,641	4037,29
1068,28	1567,43	3381,18	1960,94	7489,74	126,507	185,641	4077,57
1068,28	1567,43	3381,18	1960,94	7489,74	126,507	194,358	4002,50
1068,28	1567,43	3381,18	1960,94	7489,74	126,507	194,358	4042,62
1068,28	1567,43	3381,18	1960,94	7544,57	119,492	185,641	4037,29
1068,28	1567,43	3381,18	1960,94	7544,57	119,492	185,641	4077,57
1068,28	1567,43	3381,18	1960,94	7544,57	119,492	194,358	4002,50
1068,28	1567,43	3381,18	1960,94	7544,57	119,492	194,358	4042,62
1068,28	1567,43	3381,18	1960,94	7544,57	126,507	185,641	4037,29
1068,28	1567,43	3381,18	1960,94	7544,57	126,507	185,641	4077,57
1068,28	1567,43	3381,18	1960,94	7544,57	126,507	194,358	4002,50
1068,28	1567,43	3381,18	1960,94	7544,57	126,507	194,358	4042,62
1068,28	1567,43	3381,18	1989,05	7405,57	119,492	185,641	4037,29
1068,28	1567,43	3381,18	1989,05	7405,57	119,492	185,641	4077,57
1068,28	1567,43	3381,18	1989,05	7405,57	119,492	194,358	4002,50
1068,28	1567,43	3381,18	1989,05	7405,57	119,492	194,358	4042,62
1068,28	1567,43	3381,18	1989,05	7405,57	126,507	185,641	4037,29
1068,28	1567,43	3381,18	1989,05	7405,57	126,507	185,641	4077,57
1068,28	1567,43	3381,18	1989,05	7405,57	126,507	194,358	4002,50
1068,28	1567,43	3381,18	1989,05	7405,57	126,507	194,358	4042,62
1068,28	1567,43	3381,18	1989,05	7460,10	119,492	185,641	4037,29
1068,28	1567,43	3381,18	1989,05	7460,10	119,492	185,641	4077,57
1068,28	1567,43	3381,18	1989,05	7460,10	119,492	194,358	4002,50
1068,28	1567,43	3381,18	1989,05	7460,10	119,492	194,358	4042,62
1068,28	1567,43	3381,18	1989,05	7460,10	126,507	185,641	4037,29
1068,28	1567,43	3381,18	1989,05	7460,10	126,507	185,641	4077,57
1068,28	1567,43	3381,18	1989,05	7460,10	126,507	194,358	4002,50
1068,28	1567,43	3381,18	1989,05	7460,10	126,507	194,358	4042,62
1068,28	1592,57	3219,15	1960,94	7489,74	119,492	185,641	4037,29
1068,28	1592,57	3219,15	1960,94	7489,74	119,492	185,641	4077,57
1068,28	1592,57	3219,15	1960,94	7489,74	119,492	194,358	4002,50
1068,28	1592,57	3219,15	1960,94	7489,74	119,492	194,358	4042,62
1068,28	1592,57	3219,15	1960,94	7489,74	126,507	185,641	4037,29
1068,28	1592,57	3219,15	1960,94	7489,74	126,507	185,641	4077,57
1068,28	1592,57	3219,15	1960,94	7489,74	126,507	194,358	4002,50
1068,28	1592,57	3219,15	1960,94	7489,74	126,507	194,358	4042,62
1068,28	1592,57	3219,15	1960,94	7544,57	119,492	185,641	4037,29
1068,28	1592,57	3219,15	1960,94	7544,57	119,492	185,641	4077,57
1068,28	1592,57	3219,15	1960,94	7544,57	119,492	194,358	4002,50
1068,28	1592,57	3219,15	1960,94	7544,57	119,492	194,358	4042,62
1068,28	1592,57	3219,15	1960,94	7544,57	126,507	185,641	4037,29

1068,28	1592,57	3219,15	1960,94	7544,57	126,507	185,641	4077,57
1068,28	1592,57	3219,15	1960,94	7544,57	126,507	194,358	4002,50
1068,28	1592,57	3219,15	1960,94	7544,57	126,507	194,358	4042,62
1068,28	1592,57	3219,15	1989,05	7405,57	119,492	185,641	4037,29
1068,28	1592,57	3219,15	1989,05	7405,57	119,492	185,641	4077,57
1068,28	1592,57	3219,15	1989,05	7405,57	119,492	194,358	4002,50
1068,28	1592,57	3219,15	1989,05	7405,57	119,492	194,358	4042,62
1068,28	1592,57	3219,15	1989,05	7405,57	126,507	185,641	4037,29
1068,28	1592,57	3219,15	1989,05	7405,57	126,507	185,641	4077,57
1068,28	1592,57	3219,15	1989,05	7405,57	126,507	194,358	4002,50
1068,28	1592,57	3219,15	1989,05	7405,57	126,507	194,358	4042,62
1068,28	1592,57	3219,15	1989,05	7460,10	119,492	185,641	4037,29
1068,28	1592,57	3219,15	1989,05	7460,10	119,492	185,641	4077,57
1068,28	1592,57	3219,15	1989,05	7460,10	119,492	194,358	4002,50
1068,28	1592,57	3219,15	1989,05	7460,10	119,492	194,358	4042,62
1068,28	1592,57	3219,15	1989,05	7460,10	126,507	185,641	4037,29
1068,28	1592,57	3219,15	1989,05	7460,10	126,507	185,641	4077,57
1068,28	1592,57	3219,15	1989,05	7460,10	126,507	194,358	4002,50
1068,28	1592,57	3219,15	1989,05	7460,10	126,507	194,358	4042,62
1068,28	1592,57	3255,14	1960,94	7489,74	119,492	185,641	4037,29
1068,28	1592,57	3255,14	1960,94	7489,74	119,492	185,641	4077,57
1068,28	1592,57	3255,14	1960,94	7489,74	119,492	194,358	4002,50
1068,28	1592,57	3255,14	1960,94	7489,74	119,492	194,358	4042,62
1068,28	1592,57	3255,14	1960,94	7489,74	126,507	185,641	4037,29
1068,28	1592,57	3255,14	1960,94	7489,74	126,507	185,641	4077,57
1068,28	1592,57	3255,14	1960,94	7489,74	126,507	194,358	4002,50
1068,28	1592,57	3255,14	1960,94	7489,74	126,507	194,358	4042,62
1068,28	1592,57	3255,14	1960,94	7544,57	119,492	185,641	4037,29
1068,28	1592,57	3255,14	1960,94	7544,57	119,492	185,641	4077,57
1068,28	1592,57	3255,14	1960,94	7544,57	119,492	194,358	4002,50
1068,28	1592,57	3255,14	1960,94	7544,57	119,492	194,358	4042,62
1068,28	1592,57	3255,14	1960,94	7544,57	126,507	185,641	4037,29
1068,28	1592,57	3255,14	1960,94	7544,57	126,507	185,641	4077,57
1068,28	1592,57	3255,14	1960,94	7544,57	126,507	194,358	4002,50
1068,28	1592,57	3255,14	1960,94	7544,57	126,507	194,358	4042,62
1068,28	1592,57	3255,14	1989,05	7405,57	119,492	185,641	4037,29
1068,28	1592,57	3255,14	1989,05	7405,57	119,492	185,641	4077,57
1068,28	1592,57	3255,14	1989,05	7405,57	119,492	194,358	4002,50
1068,28	1592,57	3255,14	1989,05	7405,57	119,492	194,358	4042,62
1068,28	1592,57	3255,14	1989,05	7405,57	126,507	185,641	4037,29
1068,28	1592,57	3255,14	1989,05	7405,57	126,507	185,641	4077,57
1068,28	1592,57	3255,14	1989,05	7405,57	126,507	194,358	4002,50
1068,28	1592,57	3255,14	1989,05	7405,57	126,507	194,358	4042,62

1068,28	1592,57	3255,14	1989,05	7460,10	119,492	185,641	4037,29
1068,28	1592,57	3255,14	1989,05	7460,10	119,492	185,641	4077,57
1068,28	1592,57	3255,14	1989,05	7460,10	119,492	194,358	4002,50
1068,28	1592,57	3255,14	1989,05	7460,10	119,492	194,358	4042,62
1068,28	1592,57	3255,14	1989,05	7460,10	126,507	185,641	4037,29
1068,28	1592,57	3255,14	1989,05	7460,10	126,507	185,641	4077,57
1068,28	1592,57	3255,14	1989,05	7460,10	126,507	194,358	4002,50
1068,28	1592,57	3255,14	1989,05	7460,10	126,507	194,358	4042,62

Table E-2: Optimal Solutions under Each Scenario (Example 1)

x_{11}^*	x_{12}^*	x_{21}^*	$P_{op.}^*$
3344,511	7489,743	4037,293	8845132
3344,511	7489,743	4077,579	8847797
3344,511	7489,743	4002,508	8877724
3344,511	7489,743	4042,621	8880727
3344,511	7489,743	4037,293	8816814
3344,511	7489,743	4077,579	8819196
3344,511	7489,743	4002,508	8849650
3344,511	7489,743	4042,621	8852371
3344,511	7544,578	4037,293	8895209
3344,511	7544,578	4077,579	8897874
3344,511	7544,578	4002,508	8927801
3344,511	7544,578	4042,621	8930804
3344,511	7544,578	4037,293	8866891
3344,511	7544,578	4077,579	8869273
3344,511	7544,578	4002,508	8899727
3344,511	7544,578	4042,621	8902448
3344,511	7405,576	4037,293	8976417
3344,511	7405,576	4077,579	8979082
3344,511	7405,576	4002,508	9009009
3344,511	7405,576	4042,621	9012012
3344,511	7405,576	4037,293	8948098
3344,511	7405,576	4077,579	8950480
3344,511	7405,576	4002,508	8980934
3344,511	7405,576	4042,621	8983656
3344,511	7460,103	4037,293	9027745
3344,511	7460,103	4077,579	9030409
3344,511	7460,103	4002,508	9060337
3344,511	7460,103	4042,621	9063340
3344,511	7460,103	4037,293	8999426

3344,511	7460,103	4077,579	9001808
3344,511	7460,103	4002,508	9032262
3344,511	7460,103	4042,621	9034984
3381,187	7489,743	4037,293	8864193
3381,187	7489,743	4077,579	8866858
3381,187	7489,743	4002,508	8896786
3381,187	7489,743	4042,621	8899789
3381,187	7489,743	4037,293	8835875
3381,187	7489,743	4077,579	8838257
3381,187	7489,743	4002,508	8868711
3381,187	7489,743	4042,621	8871433
3381,187	7544,578	4037,293	8914270
3381,187	7544,578	4077,579	8916935
3381,187	7544,578	4002,508	8946863
3381,187	7544,578	4042,621	8949866
3381,187	7544,578	4037,293	8885952
3381,187	7544,578	4077,579	8888334
3381,187	7544,578	4002,508	8918788
3381,187	7544,578	4042,621	8921510
3381,187	7405,576	4037,293	8995478
3381,187	7405,576	4077,579	8998143
3381,187	7405,576	4002,508	9028070
3381,187	7405,576	4042,621	9031073
3381,187	7405,576	4037,293	8967159
3381,187	7405,576	4077,579	8969541
3381,187	7405,576	4002,508	8999995
3381,187	7405,576	4042,621	9002717
3381,187	7460,103	4037,293	9046806
3381,187	7460,103	4077,579	9049471
3381,187	7460,103	4002,508	9079398
3381,187	7460,103	4042,621	9082401
3381,187	7460,103	4037,293	9018487
3381,187	7460,103	4077,579	9020869
3381,187	7460,103	4002,508	9051323
3381,187	7460,103	4042,621	9054045
3219,159	7489,743	4037,293	8860913
3219,159	7489,743	4077,579	8863578
3219,159	7489,743	4002,508	8893505
3219,159	7489,743	4042,621	8896508
3219,159	7489,743	4037,293	8832595
3219,159	7489,743	4077,579	8834977
3219,159	7489,743	4002,508	8865431
3219,159	7489,743	4042,621	8868152

3219,159	7544,578	4037,293	8910990
3219,159	7544,578	4077,579	8913655
3219,159	7544,578	4002,508	8943582
3219,159	7544,578	4042,621	8946585
3219,159	7544,578	4037,293	8882672
3219,159	7544,578	4077,579	8885054
3219,159	7544,578	4002,508	8915508
3219,159	7544,578	4042,621	8918229
3219,159	7405,576	4037,293	8992198
3219,159	7405,576	4077,579	8994862
3219,159	7405,576	4002,508	9024790
3219,159	7405,576	4042,621	9027793
3219,159	7405,576	4037,293	8963879
3219,159	7405,576	4077,579	8966261
3219,159	7405,576	4002,508	8996715
3219,159	7405,576	4042,621	8999437
3219,159	7460,103	4037,293	9043525
3219,159	7460,103	4077,579	9046190
3219,159	7460,103	4002,508	9076118
3219,159	7460,103	4042,621	9079121
3219,159	7460,103	4037,293	9015207
3219,159	7460,103	4077,579	9017589
3219,159	7460,103	4002,508	9048043
3219,159	7460,103	4042,621	9050765
3255,143	7489,743	4037,293	8880519
3255,143	7489,743	4077,579	8883184
3255,143	7489,743	4002,508	8913111
3255,143	7489,743	4042,621	8916115
3255,143	7489,743	4037,293	8852201
3255,143	7489,743	4077,579	8854583
3255,143	7489,743	4002,508	8885037
3255,143	7489,743	4042,621	8887759
3255,143	7544,578	4037,293	8930596
3255,143	7544,578	4077,579	8933261
3255,143	7544,578	4002,508	8963188
3255,143	7544,578	4042,621	8966192
3255,143	7544,578	4037,293	8902278
3255,143	7544,578	4077,579	8904660
3255,143	7544,578	4002,508	8935114
3255,143	7544,578	4042,621	8937836
3255,143	7405,576	4037,293	9011804
3255,143	7405,576	4077,579	9014469
3255,143	7405,576	4002,508	9044396

3255,143	7405,576	4042,621	9047399
3255,143	7405,576	4037,293	8983485
3255,143	7405,576	4077,579	8985867
3255,143	7405,576	4002,508	9016321
3255,143	7405,576	4042,621	9019043
3255,143	7460,103	4037,293	9063132
3255,143	7460,103	4077,579	9065797
3255,143	7460,103	4002,508	9095724
3255,143	7460,103	4042,621	9098727
3255,143	7460,103	4037,293	9034813
3255,143	7460,103	4077,579	9037195
3255,143	7460,103	4002,508	9067649
3255,143	7460,103	4042,621	9070371
3344,511	7489,743	4037,293	8622252
3344,511	7489,743	4077,579	8624917
3344,511	7489,743	4002,508	8654844
3344,511	7489,743	4042,621	8657847
3344,511	7489,743	4037,293	8593933
3344,511	7489,743	4077,579	8596316
3344,511	7489,743	4002,508	8626769
3344,511	7489,743	4042,621	8629491
3344,511	7544,578	4037,293	8671201
3344,511	7544,578	4077,579	8673866
3344,511	7544,578	4002,508	8703793
3344,511	7544,578	4042,621	8706796
3344,511	7544,578	4037,293	8642882
3344,511	7544,578	4077,579	8645264
3344,511	7544,578	4002,508	8675718
3344,511	7544,578	4042,621	8678440
3344,511	7405,576	4037,293	8755268
3344,511	7405,576	4077,579	8757933
3344,511	7405,576	4002,508	8787860
3344,511	7405,576	4042,621	8790863
3344,511	7405,576	4037,293	8726949
3344,511	7405,576	4077,579	8729331
3344,511	7405,576	4002,508	8759785
3344,511	7405,576	4042,621	8762507
3344,511	7460,103	4037,293	8805474
3344,511	7460,103	4077,579	8808139
3344,511	7460,103	4002,508	8838066
3344,511	7460,103	4042,621	8841069
3344,511	7460,103	4037,293	8777155
3344,511	7460,103	4077,579	8779538

3344,511	7460,103	4002,508	8809991
3344,511	7460,103	4042,621	8812713
3381,187	7489,743	4037,293	8640559
3381,187	7489,743	4077,579	8643223
3381,187	7489,743	4002,508	8673151
3381,187	7489,743	4042,621	8676154
3381,187	7489,743	4037,293	8612240
3381,187	7489,743	4077,579	8614622
3381,187	7489,743	4002,508	8645076
3381,187	7489,743	4042,621	8647798
3381,187	7544,578	4037,293	8689508
3381,187	7544,578	4077,579	8692172
3381,187	7544,578	4002,508	8722100
3381,187	7544,578	4042,621	8725103
3381,187	7544,578	4037,293	8661189
3381,187	7544,578	4077,579	8663571
3381,187	7544,578	4002,508	8694025
3381,187	7544,578	4042,621	8696747
3381,187	7405,576	4037,293	8773574
3381,187	7405,576	4077,579	8776239
3381,187	7405,576	4002,508	8806167
3381,187	7405,576	4042,621	8809170
3381,187	7405,576	4037,293	8745256
3381,187	7405,576	4077,579	8747638
3381,187	7405,576	4002,508	8778092
3381,187	7405,576	4042,621	8780814
3381,187	7460,103	4037,293	8823781
3381,187	7460,103	4077,579	8826445
3381,187	7460,103	4002,508	8856373
3381,187	7460,103	4042,621	8859376
3381,187	7460,103	4037,293	8795462
3381,187	7460,103	4077,579	8797844
3381,187	7460,103	4002,508	8828298
3381,187	7460,103	4042,621	8831020
3219,159	7489,743	4037,293	8640612
3219,159	7489,743	4077,579	8643276
3219,159	7489,743	4002,508	8673204
3219,159	7489,743	4042,621	8676207
3219,159	7489,743	4037,293	8612293
3219,159	7489,743	4077,579	8614675
3219,159	7489,743	4002,508	8645129
3219,159	7489,743	4042,621	8647851
3219,159	7544,578	4037,293	8689560

3219,159	7544,578	4077,579	8692225
3219,159	7544,578	4002,508	8722153
3219,159	7544,578	4042,621	8725156
3219,159	7544,578	4037,293	8661242
3219,159	7544,578	4077,579	8663624
3219,159	7544,578	4002,508	8694078
3219,159	7544,578	4042,621	8696800
3219,159	7405,576	4037,293	8773627
3219,159	7405,576	4077,579	8776292
3219,159	7405,576	4002,508	8806220
3219,159	7405,576	4042,621	8809223
3219,159	7405,576	4037,293	8745309
3219,159	7405,576	4077,579	8747691
3219,159	7405,576	4002,508	8778145
3219,159	7405,576	4042,621	8780867
3219,159	7460,103	4037,293	8823834
3219,159	7460,103	4077,579	8826498
3219,159	7460,103	4002,508	8856426
3219,159	7460,103	4042,621	8859429
3219,159	7460,103	4037,293	8795515
3219,159	7460,103	4077,579	8797897
3219,159	7460,103	4002,508	8828351
3219,159	7460,103	4042,621	8831073
3255,143	7489,743	4037,293	8659477
3255,143	7489,743	4077,579	8662142
3255,143	7489,743	4002,508	8692070
3255,143	7489,743	4042,621	8695073
3255,143	7489,743	4037,293	8631159
3255,143	7489,743	4077,579	8633541
3255,143	7489,743	4002,508	8663995
3255,143	7489,743	4042,621	8666717
3255,143	7544,578	4037,293	8708426
3255,143	7544,578	4077,579	8711091
3255,143	7544,578	4002,508	8741019
3255,143	7544,578	4042,621	8744022
3255,143	7544,578	4037,293	8680108
3255,143	7544,578	4077,579	8682490
3255,143	7544,578	4002,508	8712944
3255,143	7544,578	4042,621	8715666
3255,143	7405,576	4037,293	8792493
3255,143	7405,576	4077,579	8795158
3255,143	7405,576	4002,508	8825085
3255,143	7405,576	4042,621	8828089

3255,143	7405,576	4037,293	8764175
3255,143	7405,576	4077,579	8766557
3255,143	7405,576	4002,508	8797011
3255,143	7405,576	4042,621	8799732
3255,143	7460,103	4037,293	8842700
3255,143	7460,103	4077,579	8845364
3255,143	7460,103	4002,508	8875292
3255,143	7460,103	4042,621	8878295
3255,143	7460,103	4037,293	8814381
3255,143	7460,103	4077,579	8816763
3255,143	7460,103	4002,508	8847217
3255,143	7460,103	4042,621	8849939
3300	7475	4040	8847855

Table E-3: Regret Data (Example 1)

Min. Regret	*Max. Regret*	*Regret Mean*	*Regret Std. Dev.*	*Regret SNR*	*Skewness*	*P-R SNR*
-3,00E-07	239637,6	110138,4	66358,96	-235,287	0,118895	319,394
-3,07E-07	244989	113142,6	66423,53	-235,689	0,118541	319,380
-1,62E-07	239982,9	110725,3	66355,88	-235,365	0,118902	319,391
-1,66E-07	240345,4	110303,9	66364,33	-235,309	0,118877	319,393
0	239637,6	110138,4	66358,96	-235,287	0,118895	319,394
0	244989	113142,6	66423,53	-235,689	0,118541	319,380
0	239982,9	110725,3	66355,88	-235,365	0,118902	319,391
0	240345,4	110303,9	66364,33	-235,309	0,118877	319,393
-2,96E-07	301145,9	143447,2	79911,81	-240,177	0,050031	319,237
-3,09E-07	306497,3	146451,4	79965,44	-240,498	0,049926	319,223
-1,62E-07	301491,2	144034,1	79909,26	-240,24	0,05003	319,234
-1,68E-07	301853,7	143612,7	79916,27	-240,195	0,050028	319,236
0	301145,9	143447,2	79911,81	-240,177	0,050031	319,237

0	306497,3	146451,4	79965,44	-240,498	0,049926	319,223
0	301491,2	144034,1	79909,26	-240,24	0,05003	319,234
0	301853,7	143612,7	79916,27	-240,195	0,050028	319,236
-3,28E-07	269461	129222,1	72918,38	-238,15	0,061791	319,299
-3,37E-07	274812,3	132226,3	72977,15	-238,504	0,061636	319,285
-1,83E-07	269806,2	129809	72915,58	-238,219	0,06179	319,296
-1,84E-07	270168,7	129387,7	72923,27	-238,17	0,061786	319,298
0	269461	129222,1	72918,38	-238,15	0,061791	319,299
0	274812,3	132226,3	72977,15	-238,504	0,061636	319,285
0	269806,2	129809	72915,58	-238,219	0,06179	319,296
0	270168,7	129387,7	72923,27	-238,17	0,061786	319,298
-3,26E-07	220635,5	107056,5	64390,71	-234,71	0,078652	319,405
-3,37E-07	225986,8	110060,7	64457,25	-235,125	0,0784	319,392
-1,83E-07	220980,7	107643,4	64387,54	-234,79	0,078653	319,403
-1,84E-07	221343,2	107222	64396,24	-234,733	0,078643	319,405
0	220635,5	107056,5	64390,71	-234,71	0,078652	319,405
0	225986,8	110060,7	64457,25	-235,125	0,0784	319,392
0	220980,7	107643,4	64387,54	-234,79	0,078653	319,403
0	221343,2	107222	64396,24	-234,733	0,078643	319,405
-2,98E-07	280777,3	136025	80136,8	-239,391	0,014691	319,270
-3,09E-07	286128,6	139029,3	80190,28	-239,721	0,014657	319,256
-1,62E-07	281122,6	136611,9	80134,26	-239,455	0,014686	319,267
-1,64E-07	281485	136190,6	80141,25	-239,41	0,014694	319,269
0	280777,3	136025	80136,8	-239,391	0,014691	319,270
0	286128,6	139029,3	80190,28	-239,721	0,014657	319,256

0	281122,6	136611,9	80134,26	-239,455	0,014686	319,267
0	281485	136190,6	80141,25	-239,41	0,014694	319,269
-2,96E-07	342285,6	169333,8	91677,43	-243,363	-0,00202	319,112
-3,07E-07	347636,9	172338,1	91724,18	-243,638	-0,00202	319,098
-1,62E-07	342630,9	169920,7	91675,21	-243,417	-0,00202	319,109
-1,64E-07	342993,3	169499,4	91681,32	-243,378	-0,00202	319,111
0	342285,6	169333,8	91677,43	-243,363	-0,00202	319,112
0	347636,9	172338,1	91724,18	-243,638	-0,00202	319,098
0	342630,9	169920,7	91675,21	-243,417	-0,00202	319,109
0	342993,3	169499,4	91681,32	-243,378	-0,00202	319,111
-3,28E-07	310448,7	155108,8	85643,43	-241,699	-0,00537	319,174
-3,33E-07	315800	158113	85693,47	-241,997	-0,00536	319,160
-1,81E-07	310794	155695,7	85641,04	-241,756	-0,00537	319,171
-1,84E-07	311156,5	155274,4	85647,59	-241,715	-0,00536	319,173
0	310448,7	155108,8	85643,43	-241,699	-0,00537	319,174
0	315800	158113	85693,47	-241,997	-0,00536	319,160
0	310794	155695,7	85641,04	-241,756	-0,00537	319,171
0	311156,5	155274,4	85647,59	-241,715	-0,00536	319,173
-3,28E-07	261775,1	132943,1	78513,15	-238,946	-0,01289	319,282
-3,37E-07	267126,4	135947,4	78567,73	-239,282	-0,01287	319,268
-1,79E-07	262120,4	133530	78510,55	-239,011	-0,0129	319,279
-1,84E-07	262482,9	133108,7	78517,69	-238,964	-0,01289	319,281
0	261775,1	132943,1	78513,15	-238,946	-0,01289	319,282
0	267126,4	135947,4	78567,73	-239,282	-0,01287	319,268
0	262120,4	133530	78510,55	-239,011	-0,0129	319,279

0	262482,9	133108,7	78517,69	-238,964	-0,01289	319,281
-3,20E-07	181420,8	87243,33	47326,86	-230,109	0,081177	319,503
-3,30E-07	186772,2	90247,57	47417,36	-230,644	0,080692	319,489
-1,77E-07	181766,1	87830,24	47322,55	-230,212	0,081172	319,500
-1,81E-07	182128,6	87408,9	47334,4	-230,139	0,081167	319,502
0	181420,8	87243,33	47326,86	-230,109	0,081177	319,503
0	186772,2	90247,57	47417,36	-230,644	0,080692	319,489
0	181766,1	87830,24	47322,55	-230,212	0,081172	319,500
0	182128,6	87408,9	47334,4	-230,139	0,081167	319,502
-3,20E-07	241744,7	120552,1	64966,73	-236,546	-0,00358	319,347
-3,28E-07	247096	123556,4	65032,69	-236,934	-0,00358	319,333
-1,77E-07	242090	121139,1	64963,59	-236,622	-0,00359	319,344
-1,79E-07	242452,4	120717,7	64972,22	-236,568	-0,00357	319,346
0	241744,7	120552,1	64966,73	-236,546	-0,00358	319,347
0	247096	123556,4	65032,69	-236,934	-0,00358	319,333
0	242090	121139,1	64963,59	-236,622	-0,00359	319,344
0	242452,4	120717,7	64972,22	-236,568	-0,00357	319,346
-3,48E-07	215769,8	106327,1	56175,87	-233,947	-0,00903	319,408
-3,59E-07	221121,2	109331,3	56252,14	-234,391	-0,00901	319,394
-1,94E-07	216115,1	106914	56172,24	-234,033	-0,00905	319,405
-1,97E-07	216477,6	106492,7	56182,22	-233,972	-0,00901	319,407
0	215769,8	106327,1	56175,87	-233,947	-0,00903	319,408
0	221121,2	109331,3	56252,14	-234,391	-0,00901	319,394
0	216115,1	106914	56172,24	-234,033	-0,00905	319,405
0	216477,6	106492,7	56182,22	-233,972	-0,00901	319,407

-3,50E-07	165974,5	84161,44	44534,33	-229,278	-0,05572	319,514
-3,61E-07	171325,8	87165,68	44630,49	-229,84	-0,05538	319,500
-1,92E-07	166319,8	84748,35	44529,74	-229,387	-0,05577	319,511
-1,97E-07	166682,3	84327,02	44542,34	-229,31	-0,05565	319,513
0	165974,5	84161,44	44534,33	-229,278	-0,05572	319,514
0	171325,8	87165,68	44630,49	-229,84	-0,05538	319,500
0	166319,8	84748,35	44529,74	-229,387	-0,05577	319,511
0	166682,3	84327,02	44542,34	-229,31	-0,05565	319,513
-3,20E-07	162719,3	83262,31	41066,8	-228,772	0,009356	319,522
-3,30E-07	168070,6	86266,55	41171,06	-229,356	0,009253	319,508
-1,75E-07	163064,6	83849,22	41061,83	-228,885	0,009317	319,519
-1,79E-07	163427,1	83427,88	41075,48	-228,805	0,009393	319,521
0	162719,3	83262,31	41066,8	-228,772	0,009356	319,522
0	168070,6	86266,55	41171,06	-229,356	0,009253	319,508
0	163064,6	83849,22	41061,83	-228,885	0,009317	319,519
0	163427,1	83427,88	41075,48	-228,805	0,009393	319,521
-3,22E-07	223452,7	116571,1	60562,08	-235,715	-0,03984	319,366
-3,28E-07	228804	119575,4	60632,83	-236,122	-0,03972	319,352
-1,73E-07	223798	117158	60558,71	-235,794	-0,03986	319,363
-1,79E-07	224160,4	116736,7	60567,97	-235,737	-0,03982	319,365
0	223452,7	116571,1	60562,08	-235,715	-0,03984	319,366
0	228804	119575,4	60632,83	-236,122	-0,03972	319,352
0	223798	117158	60558,71	-235,794	-0,03986	319,363
0	224160,4	116736,7	60567,97	-235,737	-0,03982	319,365
-3,48E-07	197068,3	102346,1	51007,05	-232,941	-0,07306	319,427

-3,61E-07	202419,6	105350,3	51091,03	-233,413	-0,07272	319,413
-1,94E-07	197413,6	102933	51003,05	-233,032	-0,0731	319,424
-1,97E-07	197776,1	102511,6	51014,04	-232,967	-0,07301	319,426
0	197068,3	102346,1	51007,05	-232,941	-0,07306	319,427
0	202419,6	105350,3	51091,03	-233,413	-0,07272	319,413
0	197413,6	102933	51003,05	-233,032	-0,0731	319,424
0	197776,1	102511,6	51014,04	-232,967	-0,07301	319,426
-3,48E-07	147273	80180,42	37811,67	-227,849	-0,23919	319,533
-3,59E-07	152624,3	83184,66	37924,88	-228,465	-0,2371	319,519
-1,92E-07	147618,2	80767,33	37806,27	-227,968	-0,23935	319,531
-1,97E-07	147980,7	80346	37821,1	-227,883	-0,23896	319,533
0	147273	80180,42	37811,67	-227,849	-0,23919	319,533
0	152624,3	83184,66	37924,88	-228,465	-0,2371	319,519
0	147618,2	80767,33	37806,27	-227,968	-0,23935	319,531
0	147980,7	80346	37821,1	-227,883	-0,23896	319,533
-3,52E-07	239637,6	110138,4	66358,96	-235,287	0,118895	319,394
-3,63E-07	244989	113142,6	66423,53	-235,689	0,118541	319,380
-1,97E-07	239982,9	110725,3	66355,88	-235,365	0,118902	319,391
-1,99E-07	240345,4	110303,9	66364,33	-235,309	0,118877	319,393
-8,94E-08	239637,6	110138,4	66358,96	-235,287	0,118895	319,394
-9,13E-08	244989	113142,6	66423,53	-235,689	0,118541	319,380
-5,22E-08	239982,9	110725,3	66355,88	-235,365	0,118902	319,391
-5,22E-08	240345,4	110303,9	66364,33	-235,309	0,118877	319,393
-3,50E-07	301145,9	143447,2	79911,81	-240,177	0,050031	319,237
-3,61E-07	306497,3	146451,4	79965,44	-240,498	0,049926	319,223

-1,96E-07	301491,2	144034,1	79909,26	-240,24	0,05003	319,234
-2,01E-07	301853,7	143612,7	79916,27	-240,195	0,050028	319,236
-8,38E-08	301145,9	143447,2	79911,81	-240,177	0,050031	319,237
-8,75E-08	306497,3	146451,4	79965,44	-240,498	0,049926	319,223
-5,22E-08	301491,2	144034,1	79909,26	-240,24	0,05003	319,234
-5,40E-08	301853,7	143612,7	79916,27	-240,195	0,050028	319,236
-3,86E-07	269461	129222,1	72918,38	-238,15	0,061791	319,299
-3,99E-07	274812,3	132226,3	72977,15	-238,504	0,061636	319,285
-2,16E-07	269806,2	129809	72915,58	-238,219	0,06179	319,296
-2,20E-07	270168,7	129387,7	72923,27	-238,17	0,061786	319,298
-9,13E-08	269461	129222,1	72918,38	-238,15	0,061791	319,299
-9,31E-08	274812,3	132226,3	72977,15	-238,504	0,061636	319,285
-5,59E-08	269806,2	129809	72915,58	-238,219	0,06179	319,296
-5,59E-08	270168,7	129387,7	72923,27	-238,17	0,061786	319,298
-3,86E-07	220635,5	107056,5	64390,71	-234,71	0,078652	319,405
-3,99E-07	225986,8	110060,7	64457,25	-235,125	0,0784	319,392
-2,18E-07	220980,7	107643,4	64387,54	-234,79	0,078653	319,403
-2,22E-07	221343,2	107222	64396,24	-234,733	0,078643	319,405
-9,31E-08	220635,5	107056,5	64390,71	-234,71	0,078652	319,405
-9,50E-08	225986,8	110060,7	64457,25	-235,125	0,0784	319,392
-5,96E-08	220980,7	107643,4	64387,54	-234,79	0,078653	319,403
-5,77E-08	221343,2	107222	64396,24	-234,733	0,078643	319,405
-3,52E-07	280777,3	136025	80136,8	-239,391	0,014691	319,270
-3,61E-07	286128,6	139029,3	80190,28	-239,721	0,014657	319,256
-1,96E-07	281122,6	136611,9	80134,26	-239,455	0,014686	319,267

-1,99E-07	281485	136190,6	80141,25	-239,41	0,014694	319,269
-8,57E-08	280777,3	136025	80136,8	-239,391	0,014691	319,270
-8,94E-08	286128,6	139029,3	80190,28	-239,721	0,014657	319,256
-5,40E-08	281122,6	136611,9	80134,26	-239,455	0,014686	319,267
-5,22E-08	281485	136190,6	80141,25	-239,41	0,014694	319,269
-3,54E-07	342285,6	169333,8	91677,43	-243,363	-0,00202	319,112
-3,59E-07	347636,9	172338,1	91724,18	-243,638	-0,00202	319,098
-1,96E-07	342630,9	169920,7	91675,21	-243,417	-0,00202	319,109
-1,97E-07	342993,3	169499,4	91681,32	-243,378	-0,00202	319,111
-8,75E-08	342285,6	169333,8	91677,43	-243,363	-0,00202	319,112
-8,94E-08	347636,9	172338,1	91724,18	-243,638	-0,00202	319,098
-5,22E-08	342630,9	169920,7	91675,21	-243,417	-0,00202	319,109
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-3,86E-07	310448,7	155108,8	85643,43	-241,699	-0,00537	319,174
-3,95E-07	315800	158113	85693,47	-241,997	-0,00536	319,160
-2,16E-07	310794	155695,7	85641,04	-241,756	-0,00537	319,171
-2,22E-07	311156,5	155274,4	85647,59	-241,715	-0,00536	319,173
-9,13E-08	310448,7	155108,8	85643,43	-241,699	-0,00537	319,174
-9,31E-08	315800	158113	85693,47	-241,997	-0,00536	319,160
-5,77E-08	310794	155695,7	85641,04	-241,756	-0,00537	319,171
-5,77E-08	311156,5	155274,4	85647,59	-241,715	-0,00536	319,173
-3,86E-07	261775,1	132943,1	78513,15	-238,946	-0,01289	319,282
-3,97E-07	267126,4	135947,4	78567,73	-239,282	-0,01287	319,268
-2,14E-07	262120,4	133530	78510,55	-239,011	-0,0129	319,279
-2,22E-07	262482,9	133108,7	78517,69	-238,964	-0,01289	319,281

-9,31E-08	261775,1	132943,1	78513,15	-238,946	-0,01289	319,282
-9,31E-08	267126,4	135947,4	78567,73	-239,282	-0,01287	319,268
-5,59E-08	262120,4	133530	78510,55	-239,011	-0,0129	319,279
-5,77E-08	262482,9	133108,7	78517,69	-238,964	-0,01289	319,281
-3,80E-07	181420,8	87243,33	47326,86	-230,109	0,081177	319,503
-3,89E-07	186772,2	90247,57	47417,36	-230,644	0,080692	319,489
-2,12E-07	181766,1	87830,24	47322,55	-230,212	0,081172	319,500
-2,16E-07	182128,6	87408,9	47334,4	-230,139	0,081167	319,502
-9,31E-08	181420,8	87243,33	47326,86	-230,109	0,081177	319,503
-9,50E-08	186772,2	90247,57	47417,36	-230,644	0,080692	319,489
-5,77E-08	181766,1	87830,24	47322,55	-230,212	0,081172	319,500
-5,77E-08	182128,6	87408,9	47334,4	-230,139	0,081167	319,502
-3,78E-07	241744,7	120552,1	64966,73	-236,546	-0,00358	319,347
-3,87E-07	247096	123556,4	65032,69	-236,934	-0,00358	319,333
-2,10E-07	242090	121139,1	64963,59	-236,622	-0,00359	319,344
-2,14E-07	242452,4	120717,7	64972,22	-236,568	-0,00357	319,346
-9,31E-08	241744,7	120552,1	64966,73	-236,546	-0,00358	319,347
-9,50E-08	247096	123556,4	65032,69	-236,934	-0,00358	319,333
-5,77E-08	242090	121139,1	64963,59	-236,622	-0,00359	319,344
-5,96E-08	242452,4	120717,7	64972,22	-236,568	-0,00357	319,346
-4,14E-07	215769,8	106327,1	56175,87	-233,947	-0,00903	319,408
-4,23E-07	221121,2	109331,3	56252,14	-234,391	-0,00901	319,394
-2,31E-07	216115,1	106914	56172,24	-234,033	-0,00905	319,405
-2,38E-07	216477,6	106492,7	56182,22	-233,972	-0,00901	319,407
-9,87E-08	215769,8	106327,1	56175,87	-233,947	-0,00903	319,408

-1,01E-07	221121,2	109331,3	56252,14	-234,391	-0,00901	319,394
-5,96E-08	216115,1	106914	56172,24	-234,033	-0,00905	319,405
-6,33E-08	216477,6	106492,7	56182,22	-233,972	-0,00901	319,407
-4,12E-07	165974,5	84161,44	44534,33	-229,278	-0,05572	319,514
-4,25E-07	171325,8	87165,68	44630,49	-229,84	-0,05538	319,500
-2,33E-07	166319,8	84748,35	44529,74	-229,387	-0,05577	319,511
-2,37E-07	166682,3	84327,02	44542,34	-229,31	-0,05565	319,513
-9,87E-08	165974,5	84161,44	44534,33	-229,278	-0,05572	319,514
-1,02E-07	171325,8	87165,68	44630,49	-229,84	-0,05538	319,500
-6,15E-08	166319,8	84748,35	44529,74	-229,387	-0,05577	319,511
-6,33E-08	166682,3	84327,02	44542,34	-229,31	-0,05565	319,513
-3,78E-07	162719,3	83262,31	41066,8	-228,772	0,009356	319,522
-3,89E-07	168070,6	86266,55	41171,06	-229,356	0,009253	319,508
-2,10E-07	163064,6	83849,22	41061,83	-228,885	0,009317	319,519
-2,14E-07	163427,1	83427,88	41075,48	-228,805	0,009393	319,521
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-9,31E-08	168070,6	86266,55	41171,06	-229,356	0,009253	319,508
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-3,78E-07	223452,7	116571,1	60562,08	-235,715	-0,03984	319,366
-3,87E-07	228804	119575,4	60632,83	-236,122	-0,03972	319,352
-2,09E-07	223798	117158	60558,71	-235,794	-0,03986	319,363
-2,14E-07	224160,4	116736,7	60567,97	-235,737	-0,03982	319,365
-9,31E-08	223452,7	116571,1	60562,08	-235,715	-0,03984	319,366
-9,50E-08	228804	119575,4	60632,83	-236,122	-0,03972	319,352

-5,59E-08	223798	117158	60558,71	-235,794	-0,03986	319,363
-5,96E-08	224160,4	116736,7	60567,97	-235,737	-0,03982	319,365
-4,10E-07	197068,3	102346,1	51007,05	-232,941	-0,07306	319,427
-4,27E-07	202419,6	105350,3	51091,03	-233,413	-0,07272	319,413
-2,31E-07	197413,6	102933	51003,05	-233,032	-0,0731	319,424
-2,38E-07	197776,1	102511,6	51014,04	-232,967	-0,07301	319,426
-9,69E-08	197068,3	102346,1	51007,05	-232,941	-0,07306	319,427
-1,02E-07	202419,6	105350,3	51091,03	-233,413	-0,07272	319,413
-5,96E-08	197413,6	102933	51003,05	-233,032	-0,0731	319,424
-6,33E-08	197776,1	102511,6	51014,04	-232,967	-0,07301	319,426
-4,10E-07	147273	80180,42	37811,67	-227,849	-0,23919	319,533
-4,23E-07	152624,3	83184,66	37924,88	-228,465	-0,2371	319,519
-2,31E-07	147618,2	80767,33	37806,27	-227,968	-0,23935	319,531
-2,37E-07	147980,7	80346	37821,1	-227,883	-0,23896	319,533
-9,69E-08	147273	80180,42	37811,67	-227,849	-0,23919	319,533
-1,01E-07	152624,3	83184,66	37924,88	-228,465	-0,2371	319,519
-5,96E-08	147618,2	80767,33	37806,27	-227,968	-0,23935	319,531
-6,33E-08	147980,7	80346	37821,1	-227,883	-0,23896	319,533
35555,68	173532,2	95303,57	37272,58	-230,72	0,210362	319,465

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EDUCATION

Degree	Institution	Year of Graduation
MS	METU Operational Research	1984
BS	METU Statistics & Operational Research	1982
High School	Ankara Kız Lisesi	1975

WORK EXPERIENCE

Year	Place	Enrollment
2004-2007	Eskidji Int'l Auctioneer	Ownership of GOP Regional Office
1991-2000	Turser A.Ş-Nurol Holding	General Manager
1989-1991	Bodrumtour A.Ş-Kavala	Deputy General Manager
1988-1989	General Dynamics Int'l.	Indirect Offset Manager
1986-1988	METU-Industrial Eng.	Research Assistant
1982-1986	METU-SİBAREN	Researcher