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Information System Product Development by Integration of Kano's Customer Satisfaction Model with Quality Function Deployment

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INFORMATION SYSTEM PRODUCT DEVELOPMENT BY INTEGRATION OF KANO'S CUSTOMER SATISFACTION MODEL WITH QUALITY FUNCTION DEPLOYMENT

by

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ABSTRACT

INFORMATION SYSTEM PRODUCT DEVELOPMENT BY INTEGRATION OF KANO'S CUSTOMER SATISFACTION MODEL WITH QUALITY FUNCTION DEPLOYMENT

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Product development of complex, innovative, information technology related systems presents difficult challenges for technology managers, and new product failures are a significant problem. A primary reason for this is the lack of a customer-oriented product development process in the information system (IS) companies, which is often related to deficiencies in cooperation between R&D and marketing departments. Integrating consumer requirements into the product design phase is an important factor for improving market success and product development decision models are needed to support more accurate managerial decisions about the characteristics of the new products that meet customer needs.

This research examines various decision models for IS product design and concludes that an integrated approach including Quality Function Deployment (QFD) and Kano's customer satisfaction model has significant potential to improve the new product development problems of the IS industry. It develops a unique methodology employing a combined model specifically focused on IS design and provides critical differences and improvements in current modeling research: Integration of Kano's model into QFD. The potential of this new approach is demonstrated by successfully testing this methodology on an information system product development case: a NASA problem on new general aviation (GA) cockpit weather information system development. In summary, this research develops a unique, useful and valid decision model to improve the IS product development success and successfully tests the model on a relevant problem.

This dissertation is dedicated to:

My mother, Ayse, who showed me how to be a better person,

My father, Attila, who encouraged me to explore new things,

My grandfather, Muharrem, who taught me how to read in the first place, and

My brother, Erdem, who kept me smiling along the way.

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CHAPTER I
PROBLEM STATEMENT

Pro*duct development of complex information technology related systems presents difficult challenges for technology managers and new product failures are a significant problem. Projects are often behind schedule, exceed budgets, and are unable to satisfy customer needs. One solution to these problems is to collect accurate data about customer requirements and convert it to useful information, which can be used in the design phase of the product. Since integrating consumer requirements into the product design phase is an important factor for improving market success, a product development decision model is an essential tool for the managers of information system organizations to make more accurate decisions about the characteristics of the new products that meet customer needs.

This research addresses the problem by developing a unique decision model, which helps engineering managers evaluate the technological characteristics of an information system product based on customer requirements. The validity of the model concept is also demonstrated by applying it to general aviation (GA) cockpit weather information systems as a case study. This is a challenging test since the engineering management decisions in this market encompass a wide spectrum of advanced technology and information system product development. GA cockpit weather information systems are emerging new information systems, which inform the pilot about the weather conditions ahead of the aircraft based on communication with the ground via a data link. The decision model developed in this research is tested to identify the most promising technological systems to provide the needed consumer requirements and technical characteristics to achieve market success. The model demonstrates its usefulness by developing credible results.

1.1 Current Status of the Information Systems Market for New Product Development

Achieving success with new product development is becoming more and more difficult in many markets. Customers are demanding not only the fulfillment of their

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* Journal reference: Engineering Management Journal.

needs more quickly, but also highly customized products and services (Feitzinger and Lee, 1997). The market trend of shortening the product life-cycle and the customer requirement for more unique products that satisfy exact needs calls for an agile organization that is not only responsive to changes in the business environment, but is also able to act proactively to a market trend (Tam et al, 2000).

Over the last three decades, there has been significant worldwide increase in information technology investment (Tam and Hui, 1999). However, numerous studies show that new product failures are one of the biggest problems in the information systems industry (Berggren and Nacher, 2001; Jiang and Klein, 2001). After allocating substantial resources, many organizations are either abandoning their efforts or failing to achieve the anticipated outcomes from their investments. Despite remarkable advances in information technology, many technology-based information systems continue to fall short of organizational objectives. A recent survey found that only 24% of the implementations were considered successful, 64% of management had mixed feelings about the success of the projects, and the remainder felt their projects were failures (Jiang and Klein, 2001). Other recent studies have shown similar results: projects are years behind schedule, exceed budgets by millions, and fail to meet user needs once implementation is complete (Gallagher, 1998). One critical factor in this problem involves decision-making systems for new product development. This issue is discussed in the following sections of this chapter.

1.2 Challenges of the Information Systems Industry

The high failure rates associated with information system (IS) projects suggest that organizations need to improve their ability to identify and to manage associated risks. Consequently, IS product selection is a critical task for IS executives (Jiang and Klein, 2001). For innovative product design in general, management risks are especially high when a project involves the development of new technologies (Paté-Cornell and Dillon, 2001). Therefore, many researchers have attempted to identify the various risks associated with the IS development related to new products (Jiang and Klein, 2001). Alter (1979) identified the following risk factors as influencing project success:

- Nonexistent or unwilling users

- Multiple users or implementers
- Inability to specify purpose or usage
- Inability to cushion the impact on users

These factors suggest that identifying user needs and obtaining user involvement at the beginning of design are important issues and, since Alter identified these factors, a number of authors have corroborated these results (Anderson and Narasimhan, 1979; Ives and Olson, 1984; Cafasso, 1994; Sethi et al, 2001).

Customer-oriented product development is even more important today due to globalization, increased competitiveness, rapid technological change, and discriminating customers (Cristiano et al, 2001). Market uncertainty in new product development is strongly related to the degree of customer involvement in the design phase. Moriarty and Kosnik (1989) describe market uncertainty as the ambiguity about the type and extent of customer needs that can be satisfied by a particular technology. According to Mohr (2000), market uncertainty can greatly disrupt the progression from product introduction to growth and maturity. Market uncertainty arises from consumer fear, uncertainty, and doubt about what needs and/or problems the new technology will address and how well it will meet those needs. Anxiety about these factors means that customers may delay adopting a new innovation, require a high degree of education and information about the new innovation, and need reassurance and reinforcement to assuage any lingering post-purchase doubt.

All major studies on new product development in the IS industry confirm that the most important factor to achieve market success is the product's fit with the customers' needs (Sethi et al, 2001). As summarized in Table 1, a decision model that integrates the customer's voice with the product design phase can help the IS product developers to make more accurate decisions to improve market success.

Table 1. IS product development problem.

Problem	Problem Content	Solution
Market failures in complex and innovative product development due to inadequacy of satisfying customer expectations.	A management problem based on decision-making.	• Identifying customers' needs accurately in the design phase, and linking them to technical characteristics of the product • A decision-making model for engineering managers that supports this need.

Table 2 summarizes literature related to the IS product development problem. This table covers researchers and their studies in chronological order reviewed from the earliest to the latest. The marked portions indicate the areas that each researcher has examined and the following conclusions can be observed from the table:

- High rates of product failures are an area of increased study in recent years.
- Applying a customer-driven product development strategy has been studied consistently, and has recently become an area of increasing focus due to increasing market failures in this industry.
- Gathering accurate customer data and encouraging communication between R&D and marketing in the design phase are important research areas. In addition, finding improved decision-making tools presents a consistent need to help product developers.

Table 2. Literature search summary for the IS Industry.

Researchers on the IS Industry:	General IS market.	High rates of product failures and challenges in IS market.	Importance of applying a customer-driven product development strategy.	Inadequacy of gathering customers' requirements in the design phase, and communication between marketing and R&D.
Alter, 1979		X		
Anderson and Narasimhan, 1979				X
Ives and Olson, 1984				X
Moriarty and Kosnik, 1989		X	X	
Moore, 1991			X	
Wallace, 1992			X	
Cafasso, 1994				X
Song and Zie, 1996			X	X
Feitzinger and Lee, 1997			X	
Ottum and Moore, 1997			X	
Gallagher, 1998		X	X	X
Tam and Hui, 1999	X			
Omar et al, 1999				X
Moeller, 1999		X	X	X
Tam et al, 2000		X	X	
Wei et al, 2000				X
Mohr, 2000		X	X	X
Paté-Cornell and Dillon, 2001		X		
Berggren and Nacher, 2001	X	X	X	X
Jiang and Klein, 2001	X	X	X	X
Sethi et al, 2001			X	X
Christiano et al, 2001			X	X

The literature summary in Table 2 supports the focus of this research problem by emphasizing the need for the development of a useful and valid decision model to mitigate the IS product development failures. This literature also highlights a pathway to improvement. In order to develop IS products that meet customer expectations, there are two related problems to solve: customer data collection and communication between R&D and marketing. These issues are discussed in the next sections.

1.2.1 Customer Data Collection

For businesses to win in the marketplace, it is important to adopt a customer-driven strategy that delivers products and services to meet or exceed customer expectations (Wallace, 1992). The role of market information is critical to the success or failure of new product introduction (Ottum and Moore, 1997), but customer requirements are seldom gathered (Omar et al, 1999).

Customer data collection can be carried out by a variety of methods such as surveys, interviews, or focus groups (Cohen, 1995). However, the most important challenge in data collection for most new products is to obtain information that accurately reflects customer needs (Berggren and Nacher, 2001). In order to achieve product success, managers should think solutions, not products (Berggren and Nacher, 2001). New-product development in the IS industry will continue to have unacceptably high failure rates until it is realized that the objective is not to introduce a product and/or leverage strengths, but rather to deliver new complete solutions to customers. Firms should consider new-product development as new-solutions delivery. In order to provide solutions to customers, the main interest of the first phase of product development should be capturing accurate data about customer's needs.

1.2.2 Communication Between Research & Development and Marketing

The most important function of Research & Development (R&D) should be designing quality products to meet customer needs (Jiang and Klein, 2001; Ives and Olson, 1984; Alter, 1979). Achieving this requires integration of R&D and marketing to develop a clear, accurate understanding of user needs. However, information collected from the customer is rarely shared between marketing and R&D divisions or made available to design engineers (Omar et al, 1999). Because of the inadequacy of communication between R&D and marketing departments in many organizations, product ideas generated by R&D may not meet the market trends and customers needs (Wei et al, 2000).

High-technology companies must effectively link R&D and marketing efforts to be successful (Mohr, 2000). The nature of the interaction between marketing and R&D should also be matched to the type of innovation and the phase of product development. For example, cross-functional interaction is especially helpful to determine desired product features and to assess engineering feasibility. Research findings validate the importance of close R&D and marketing interaction in new product development planning, to establish the direction for commercialization, to design marketing plans, and to implement the product launch (Song and Zie 1996). Similarly, marketing should participate during the pre-commercialization period, bringing the voice of the customer and marketplace into the development process (Mohr, 2000). It is a difficult cultural change for people in technology-oriented firms to shift to a marketing or customer orientation. Even Microsoft still sees itself as "doing technology for technology's sake rather than based on customer needs" (Moeller, 1999).

1.3 Research Objective

The comprehensive literature describing the problems of the information systems industry shows that a significant portion of IS new product failures are due to insufficient decision-making in product development related to the inadequacy of identifying and satisfying customer expectations. A primary reason for this is the lack of a customer-oriented product development process that is related to deficiencies in cooperation between R&D and marketing departments.

Involvement of the customer's voice in every step of information system product design, including the identification of product features and evaluation of enabling technologies, is essential for improved market success. For this reason, the primary objective of this research is defined as developing and demonstrating a product development decision model for the information systems industry that can:

- Successfully capture customer's requirements and reflect market conditions.
- Integrate the customer's voice into the IS design requirements.

- Promote communication between R&D and marketing.
- Evaluate and compare product characteristics and enabling technologies according to customer expectations.
- Support complex, innovative IS development involving a large number of attributes and multiple decision layers.
- Provide results to IS product developers, suggesting technical directions for a potentially successful product.

1.4 Contributions

To achieve the stated objectives, this research found that Quality Function Deployment (QFD) is a decision model that has the potential to provide detailed product development directions for IS based on customer needs from selecting product features to identifying the enabling technologies. However, QFD has shortcomings in reflecting accurate customer preferences that reflect real market conditions. Numerous researchers have found Kano's customer satisfaction model useful to compensate for this deficiency. However, the analysis of Kano's model and the integration of these two techniques have a number of challenges as well:

- The analysis of Kano's model results is qualitative and subjective,
- Although there are few approaches to integrate the two models, there is no uniform methodology for this integration,
- There are no applications of this integration in the literature including innovative and complex product development such as IS products.

This research improves the areas stated above by extending a recent integration approach (Matzler and Hintenhuber, 1998) and it contributes to the following engineering management areas:

- *Methodology:* This research creates a unique methodology to form an integrated (combined) decision model that identifies enabling technologies based on customer needs by quantitatively integrating the Kano model into QFD to mitigate the IS product development failures.

- *Application:* It demonstrates this model's usefulness and validity on a complex and innovative IS development problem: General Aviation (GA) cockpit weather information system development.

1.5 Organization of the Dissertation

The remaining chapters are organized in the following topical areas:

- Chapter 2 examines decision model alternatives for product design, selects the most appropriate tool for the IS industry, and creates a methodology to develop a unique decision model for IS development.
- Chapter 3 examines the NASA problem for testing the model: development of new general aviation (GA) cockpit weather information systems.
- Chapter 4 covers the model analysis.
- Chapter 5 examines model validation.
- Chapter 6 summarizes research results.

1.6 Summary

A comprehensive literature review indicates that new product failures in the IS industry are one of the industry's biggest challenges. Projects are often behind schedule, exceed budgets, and are unable to satisfy customer needs. The reasons for this situation are the inadequacy of:

- Methods for identifying and managing customer requirements,
- Tools for making the right decisions about the detailed technical characteristics of the new products that meet customer demand,
- Lack of collaboration between engineering and marketing divisions in the IS companies.

The primary objective of this research is to develop and demonstrate a product development decision model for the information systems industry that can:

- Successfully capture customer's requirements that reflect real world conditions,
- Bring the customer's voice to the IS design,
- Promote communication between R&D and marketing,

- Evaluate product characteristics and enabling technologies according to customer expectations,
- Be applicable to complex innovative IS development involving large number of attributes,
- Provide an outcome to IS product developers, suggesting the technical details of a potentially successful product.

To achieve the research objectives, this research selects a combined model approach that integrates Kano's model of customer satisfaction into QFD. However, Kano's model and its integration into QFD has challenges since the Kano model analysis is generally qualitative and subjective, there is no uniform methodology for this integration and no complex product development applications by using this integration. To achieve the selection of enabling technologies for the IS products based on customer requirements, these areas should be improved. For this reason, this research extends a recent integration approach (Matzler and Hintenhuber, 1998) and it contributes to the following engineering management areas:

- *Methodology:* This research creates a unique methodology to form an integrated (combined) decision model that identifies enabling technologies based on customer needs by quantitatively integrating the Kano model into QFD to mitigate the IS product development failures.
- *Application:* It demonstrates this model's usefulness and validity on a complex and innovative IS development problem: General Aviation (GA) cockpit weather information system development.

This research selects the integration of these two models as the most appropriate for IS development as a result of an investigation of other alternative decision models that could be employed to achieve the research objectives. The next chapter provides this overview.

CHAPTER II

DECISION MODELS FOR INFORMATION SYSTEM DESIGN

New product development decisions related to feature selection are generally the most important marketing decision a manager can make since they involve significant cost implications. These include substantial investments in R&D, design, manufacturing, promotion, and distribution and are also very difficult to change once initiated (Lilien et al, 1992). This chapter examines major categories of decision models for product design that have the potential to improve this decision process for the IS industry.

The previous chapter found that the IS industry suffers from new product failures due to inadequately satisfying customer expectations and ineffective decision-making in complex, innovative product development. A primary reason for this is the lack of a customer-oriented product development process in the IS organizations often due to deficiencies in cooperation between R&D and marketing departments.

The customer's voice needs to influence every step of an IS product design from the identification of product features to the evaluation of enabling technologies. Based on the primary objective of this research, the following criteria will be used for selecting the appropriate model(s):

1. Capturing the nuances of customer's requirements that reflect real world conditions for new IS development.
2. Carrying the customer's voice to every step of the IS design including the evaluation of detailed product characteristics and selection of enabling technologies that support meeting customer expectations (multi-level decision analysis).
3. Promoting communication between R&D and marketing.
4. Applicability to complex, innovative IS development involving large numbers of attributes.

As a first step, this chapter reviews major product development categories: perceptual mapping models, preference models, quality function deployment (QFD), and Kano's customer satisfaction model. Based on the above criteria, it develops a comparative selection matrix to choose the most appropriate model(s). Based on this evaluation, it develops a unique combination of QFD and Kano's model as the most suitable tool for customer-oriented product development in the IS industry.

2.1 Perceptual Mapping Models

Perceptual mapping promotes understanding how customers think about products in existing markets (Lilien et al, 1992). In perceptual maps, products are represented (mapped) by locations in a space of several dimensions (such as "value for the money," "user-friendliness," "effectiveness," etc.) that distinguish among the products.

Perceptual theory suggests that although customers can be questioned about hundreds of different product attributes, they generally use a small number (two to four) when they think about a particular product or product class. Thus, an objective of these models is to identify the relevant dimensions and to locate the positions of existing and potential new products along these dimensions. For example, Figure 1 shows the perceptual map of positioning for four detergent brands based on the consumers' preferences for two attributes: mildness/$, and efficiency/$ (Lilien et al, 1992).

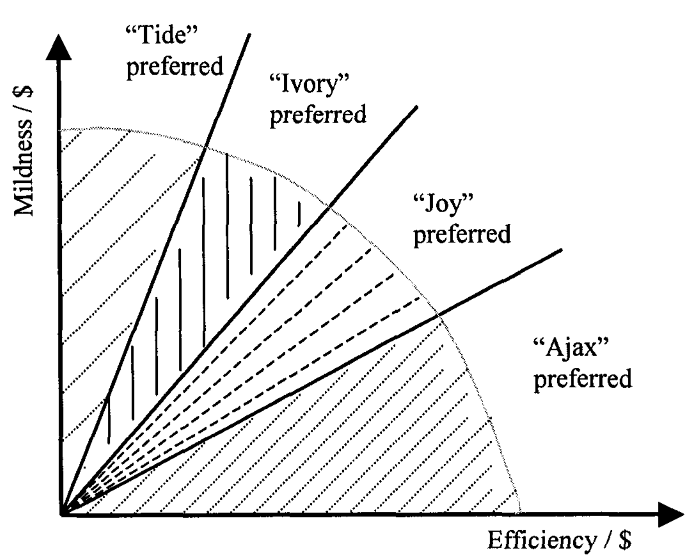

Figure 1. Perceptual map of positioning for four detergent brands.

Since the base of specific knowledge is often minimal at the time of feasibility assessment, mapping (or product space) models are useful for a conceptual and competitive view of the proposed product. For example, Figure 2 indicates the feasible product space for a new environmental binder for the casting industry among four other alternatives for emission control (Kauffmann, 1997).

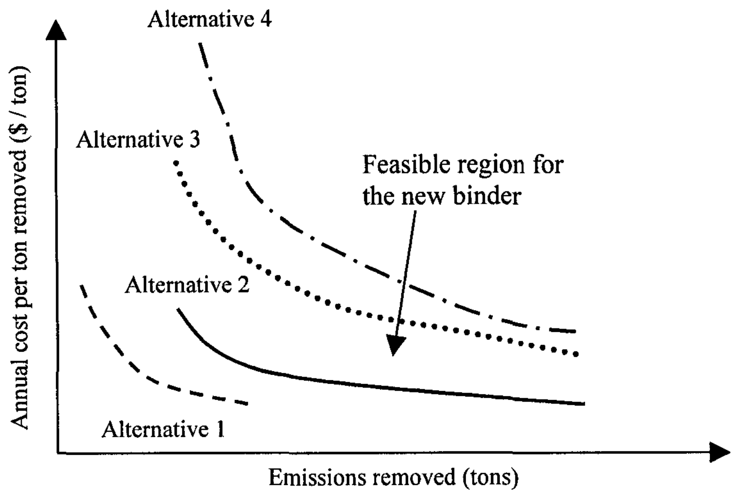

Figure 2. Feasible product space for a new binder among four other alternatives.

Although perceptual mapping identifies the product spaces, it is not a useful tool for determining product characteristics based on customer needs. Perceptual maps are more appropriate for comparing products or finding spaces that are not currently occupied by existing products.

2.2 Preference/Choice Models

Preference models evaluate product selection based on a broad range of attributes, while choice models evaluate selection based on a specific characteristic set versus a given alternative. Preference models are typically used with multi-attribute feasibility analysis (Kauffmann, 1997).

While early work in most product categories may concentrate on the mapping of existing product spaces to identify potential opportunities, later work should concentrate on estimating how products with given physical features are likely to perform in the marketplace (Urban and Hauser, 1980). This estimation can be accomplished with preference models. Preference/choice models are generally used to determine the demand for new products with new attributes or features, by analyzing consumer behavior data (Louviere et al, 2000).

Three widely used preference models are expectancy-value, preference regression, and conjoint analysis (Lilien et al, 1992). Each of these plays a relatively different role in new product design.

2.2.1 Expectancy Value Models

For predicting use of a new product or concept, the expectancy-value approach is low in cost and easy both to administer and to evaluate. It also provides a quick, early guide to the likely success of the product (Lilien et al, 1992). However, it has several disadvantages:

- It is not as accurate as other methods in predicting consumer preference.
- It deals with the attributes themselves, rather than the underlying perceptual dimensions.
- It is subject to halo effects (Beckwith and Lehmann, 1975), in which an individual rates his or her most preferred product high on all scales, biasing the results.
- In addition, the model employs a linear additive form and, therefore, it is appropriate only for use as a guide in early design work, especially in those categories, such as frequently purchased products, where the consumer choice process is relatively simple (Lilien et al, 1992).

According to Fishbein's expectancy value model, attitudes relate to beliefs about the attitude object. Belief is a statement that connects the attitude object with another object, goal or value (Lilien et al, 1992). For instance if someone believes that smoking causes cancer, the attitude object is smoking, and the goal is cancer. Equation (1) states the mathematical relationship between attitudes and beliefs.

$$p_i = \sum_{j=1}^{J} w_{ij} y_{ij} \quad , \qquad i=1,\ldots,I \qquad \text{Equation 1}$$

- p_i is the value or utility of the product for individual i.
- w_{ij} is the strength of belief or importance placed by individual i on attribute j.

- y_{ij} is the evaluation of attribute (e.g. good to bad) or individual i's perception of the product on attribute j.
- j is the number of attributes.

For example, if a consumer (individual i) is asked whether the new model of Toyota will have market success, w and y values can be scaled as:

w:	likely	+3	+2	+1	0	-1	-2	-3	unlikely
y:	good	+3	+2	+1	0	-1	-2	-3	bad

According to Urban and Hauser (1980) and Lilien et al (1992), the best application of this method is when the constraint is the cost and there is a need to find an inexpensive way of getting a rough idea of the linear effects of product attributes in forming preferences. Since this method is appropriate for basic information on simple consumer products, it is not detailed and accurate enough to identify customer expectations and match them to the technical characteristics of a new IS product.

2.2.2 Preference Regression

Preference regression is similar to the expectancy-value approach. However, changes in its mathematical model make it more realistic than the expectancy-value approach. Equation (2) states the linear model for preference regression.

$$p_i = \sum_{j=1}^{J} w_j x_{ij} + \text{error} \quad , \qquad i = 1,\dots,I \qquad \text{Equation 2}$$

- p_i is the preference judgements for the product by individual i.
- w_j is the importance weight.
- x_{ij} is the individual i's rating for the product on attribute j.
- j is the number of attributes.
- error represents the unexpected variation.

According to Urban and Hauser (1980) and Lilien et al (1992), the best application of this method is for positioning products relative to competition. Although this method gives more realistic results than the expectancy value method, it still does not provide the consumer needs - technical characteristics link needed for new product development in the IS industry.

2.2.3 Conjoint Analysis

Conjoint analysis is a set of methods designed to measure consumer preferences for a multi-attribute product. The respondent is traditionally asked to react to a total product profile and then the resulting total preference score is decomposed into a set of utilities for each of the attributes (Lilien et al, 1992). In a typical conjoint analysis, the researcher first constructs a set of real or hypothetical products/services by combining several levels of each attribute. The combinations (conjoint profiles) are then presented to selected respondents who provide their overall evaluations in the form of a ranking or numerical rating (Verma et al, 2001). Equation (3) states the mathematical model for conjoint analysis.

$$R_i = \sum_{k=1}^{K} \sum_{l=1}^{L} \lambda_{ikl} d_{kl} + \text{error} \quad , \ i = 1, \ldots, I \qquad \text{Equation 3}$$

- R_i is the rank order preference given by individual i for the product.
- λ_{ikl} is the part-worth given by individual i for attribute k at level *l*.
- d_{kl} is the individual i's rating for the product on attribute k at level *l*.
- k is the number of attributes.
- *l* is the number of attribute levels.
- error is an unexpected variation.

Conjoint analysis is considered a good tool for selection of product features based on customer preferences. On the other hand, the main difficulty with this tool is that it becomes unwieldy when the number of attributes and/or levels is high because the consumer must then rank a large number of combinations. For example, 4 attributes ($k = 4$) at 4 levels ($l = 4$) would lead to $4^4 = 256$ combinations that the consumer must rank (Lilien et al, 1992).

According to Urban and Hauser (1980) and Lilien et al (1992), the best application of this method is achieved when physical features of products are the focus of the design problem. Since it is a good method to capture customer preferences, conjoint analysis has recently been introduced as a tool supporting the use of quality function deployment (QFD) in the design process (Gustafsson et al, 1999).

Conjoint analysis is the best alternative method of the approaches discussed thus far, since it helps select product features based on consumer preferences. However, it becomes difficult to implement when the number of product attributes is large as in the case of the complex information systems that are the focus of this research. As another alternative, QFD is examined in the next section.

2.3 Quality Function Deployment (QFD)

Quality function deployment is a systematic methodology for quality management and product development (Shen et al, 2000). It is a system for translating consumer requirements into appropriate company requirements at each stage from research and product development to engineering and manufacturing to marketing/sales and distribution (Slabey, 1990). This technique requires the consideration of consumer requirements for a new product in the design phase, providing a structured framework ensuring that the "voice of the customer" is incorporated into product development (Govers, 1996). Therefore, it helps project teams and managers to develop a product according to user needs (Shen et al, 2000; Park and Kim, 1998).

QFD is a powerful tool to help with complex decisions (Lyman et al, 1994) with a visual, compact form, and good product definition (Partovi, 1999). It provides a structured decision-making process across functional areas, team building, and the dissemination of key information to users (Cristiano et al, 2001). This method helps stimulate the marketing and R&D interaction into the detailed design of the product (Cristiano et al, 2001; Khurana and Rosenthal, 1997) by promoting close collaboration between marketing, engineers, and customers (Mohr, 2000).

The concept of QFD was first introduced by Akao in 1966 and was used at the Kobe Shipyards of Mitsubishi Heavy Industries, Ltd. in 1972 (Ho et al, 1999). Subsequently, Toyota and its suppliers developed it further in a rust prevention study (Park and Kim, 1998). This technique has been widely used by many IS companies such as General Motor, Hewlett-Packard, Digital Equipment, Motorola, IBM, and AT&T for different purposes from new product idea generation to innovative product development (McElroy, 1989; Fung et al, 1999; Cristiano et al, 2001).

Based on the selection criteria for this research, QFD is the most promising model for future IS development and is investigated further in the following sections.

2.3.1 Quality Function Deployment Framework

The QFD methodology provides a structured framework for concurrent engineering that ensures that the "voice of the customer" is incorporated into product development (Govers, 1996). It converts customer requirements into directions and actions that can be deployed through planning, engineering, and productivity disciplines (Presley et al, 2000), coordinating the design, manufacturing, and marketing of goods (Ho et al, 1999). The process prioritizes and ensures that all design decisions take into account the importance of design requirements from the customer's perspective. The ultimate outcome is a new product that provides superior value to the marketplace via a customer-informed design team. Numerous studies (Shen et al, 2000; Wei et al, 2000; Omar et al, 1999; Hellsten and Klefsjo, 1998; Park and Kim, 1998; Gevirtz, 1994; Clausing, 1994; Slabey, 1990) document that QFD is a useful technique that can systematically transform market-based customer needs into detailed product specifications, helping the companies to keep and expand their market share.

The central element of the QFD model is the relationship matrix (often called the "house of quality") illustrated in Figure 3. The matrix lists the customer requirements (CRs or "whats") in the first column of the left wing of the house of quality. Each of these requirements has an importance value elicited from the customer via surveys, interviews, or focus groups (Cohen, 1995). Design requirements (DRs or "hows") for meeting the customer requirements are listed horizontally along the top of the matrix and typically relate to a column. The "roof" represents the relationships among the various design requirements. The right wing of the house shows the comparative evaluation of competing alternatives (Ho et al, 1999). The bottom of the matrix contains importance weights (importance of a DR in meeting the CRs) that are developed using matrix row and column operations based on the strength of relationship of each design requirement to the customer requirements (Presley et al, 2000).

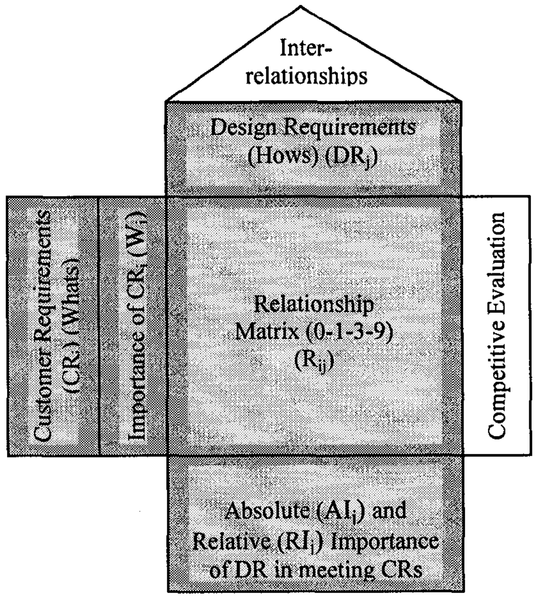

Figure 3. General framework of QFD's house of quality.

The cells of the relationship matrix describe the strength of the relationship of the design requirements to customer requirements (Ho et al, 1999). The impact of DRs on providing CRs are typically specified as "strong," "moderate," "weak," or "none" and the matrix cells often employ a scoring system based on 9, 3, 1, and 0 respectively for each impact (Presley et al, 2000). Some early QFD applications used a 5, 3, 1, 0 scale, but over time, QFD researchers identified the importance of creating a stronger contrast between "strong" and the other relationship ratings, so that strong impacts would have more influence on the importance values of DRs. The value 9 was rapidly adopted to serves the purpose of making the strong impacts dominate the matrix. Some researchers favor 7, because it is a compromise between 5 and 9. However, if the ratio between "strong" and "moderate" is high, it is less likely that a DR with only moderate ratings will have a technical importance greater than a DR with at least one strong rating (Cohen, 1995). Consequently, the 9, 3, 1, 0 scale is often preferred and is employed in this study for these reasons.

In some applications, the house of quality may include negative impacts in a scale containing -9, -3, and -1 for a "strong negative impact," "moderate negative impact," and "weak negative impact" respectively. Such negative relationships occur when a DR has a positive impact on one CR, but a negative impact on another. For example, in computers, faster internal clock speed may have a positive impact on the customer's need to get work done faster, but it may also have a negative impact on the customer's need for system reliability. Faster clock speed implies higher internal operating temperatures that generally cause parts to deteriorate faster. However, negative impacts complicate QFD discussion and analysis. As a result, identifying DRs that result in consistent positive ratings on all CRs is preferred (Cohen, 1995). Since the goal of the model is to enhance marketing and R&D interaction, this study uses positive impacts in the QFD matrix.

The QFD matrix includes relationship ratings between CRs and DRs that are identified by various means. The customer requirements are determined as a result of customer surveys, interviews, or focus groups. The design requirements and their impact on the CRs are identified based on the experience of subject matter experts employed by the organizations using QFD for their product development applications (Cristiano et al, 2000).

The QFD application for IS product development may not utilize every feature of the house of quality. For example, in innovative product development in the information systems industry, the model may not include competitive analysis since a competing product alternative may not exist. In addition, the design requirements may be seen as essentially independent at an early stage in product development, and the inter-relationship section in the roof may not be employed.

Beyond the initial house of quality, QFD also provides the option of constructing additional matrices that further guide the detailed decisions that must be made throughout the product development process: multi-level analysis (Cohen, 1995). In this approach, quality functions may be deployed multiple times carrying "how to do" into successive houses of quality as "what to do (Ho et al, 1999). Figure 4 demonstrates a two-level analysis that can be applied to information system development.

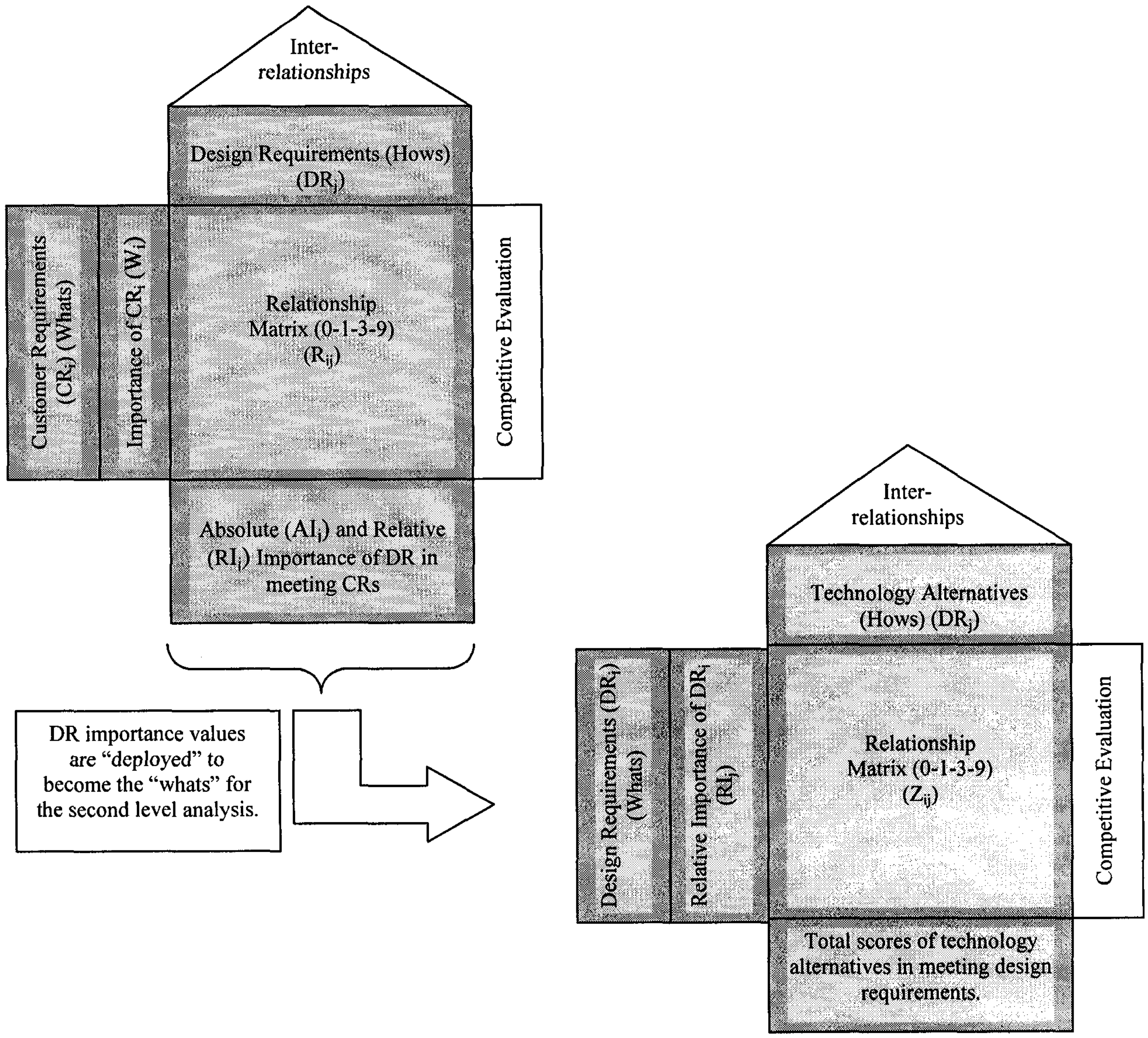

Figure 4. Multi-level QFD analysis.

Using the results of mapping customer requirements into general design requirements shown in the house of quality, a successive mapping (deployment) evaluates the capabilities of the specific technology alternatives to meet the design requirements as shown by the importance ratings. For example, in a new personal digital assistant (PDA) development case, design requirements in the first matrix may include various microprocessor types that potentially meet customer requirements. Once these are evaluated, they become new "whats" in the second matrix and new "hows" can be identified as different operating systems that should be evaluated in terms of their capabilities to support the microprocessor alternatives. In multi-level analysis, technical characteristics of a new product can be examined in detail as necessary by keeping the customer requirements in mind throughout the whole process.

This section provided the general framework of QFD including multi-level analysis. The next subsections examine the mathematics of this technique followed by a discussion of potential IS related deficiencies.

2.3.2 QFD Calculations for the Decision Model

The QFD model calculates the importance values of the DRs using matrix row and column operations (Park and Kim, 1998). For each DR, the absolute importance rating is computed using Equation (4):

$$AI_j = \sum_{i=1}^{m} W_i R_{ij} \qquad \text{Equation 4}$$

- AI_j = absolute (technical) importance rating of DR_j.
- W_i = relative degree of importance of the CR to the customer (i.e., relative importance weight) of CR_i, i=1, 2, ..,m, where m is the total number of CRs.
- R_{ij} = relationship rating representing the strength of the relationship between CR_i and DR_j, j=1,.2, ..,n, where n is the total number of DRs. The absolute impact rating can then be transformed into the relative impact rating, RI_j, using equation (5):

$$RI_j = \frac{AI_j}{\sum_{j=1}^{n} AI_j} \qquad \text{Equation 5}$$

Information system development may require multiple levels of QFD analysis. For example, for general aviation weather information systems (briefly explained in Chapter 1), it is necessary to identify the best data link alternatives (technology alternatives) to support the most important design requirements to meet customer needs. In order to evaluate these alternatives in the second level application of QFD, a similar scoring method can be used. This time the design requirements and their relative importance values, calculated by Equation (5), are included in the first column of the left hand-side of the model (Figure 3 and 4), and a number of alternative technologies are evaluated according to these DRs in a similar approach. The relationship ratings between the DRs and the technology alternatives can be scored by using the same 9, 3, 1, and 0 scale by redefining their meanings:

9: Best; available

3: Moderate performance; restricted availability

1: Poor performance; insufficient

0: No provision

Using these relationship ratings and Equation (6), a total score can be identified for each technology alternative. This score allows comparison of different technology alternatives based on customer-required design characteristics.

$$\text{Total score}_i = \sum_{j=1}^{n} Z_{ij}\, RI_j \qquad \text{Equation 6}$$

- RI_j= relative importance rating of DRj, j=1, ..,n, where n is the total number of DRs.
- Z_{ij} = ratings of the technology alternatives, i = 1,…,k, where k is the total number of data links.

QFD provides a structure to organize hows (DRs), whats (CRs) and their relationships in a matrix that enables evaluation of the impact values of DRs in both absolute (AI_j) and relative terms (RI_j). The larger the RI_j value, the more important the DR_j is in meeting customer requirements and this allows DRs to be prioritized based on these importance values. However, this method also presents a number of challenges that are discussed in the next section.

2.3.3 Challenges of QFD

One of the most important challenges in using QFD is the difficulty of implementing the analysis due to problems with capturing, understanding, and organizing customer needs (Cristiano et al, 2001). Customer data is the key starting point for execution of this technique. If the customer data does not reflect the real world conditions and express the nuances of the customer's decision on purchasing the product, the outcome of the QFD model can lead to inaccurate forecasts (Berggren and Nacher, 2001; Cristiano et al, 2000). For example, QFD created the technologically superior Betamax format, but missed the importance of video-rental availability in the battle with VHS. The winning solution was based on ease and convenience in watching videos, and product technical superiority contributed less to market success.

QFD relies on traditional methods such as surveys, interviews, and focus groups to rank-order customer requirements and identify the degrees of importance for each CR (voice of customer). However, this method does not capture all aspects of the customer's experience with an existing product or the expectations for a new product (Zultner, 1990). For example, Equation (4) and (5) demonstrate that the relative degree of importance of each CR (W_i) is a critical value that has significant impact on model results. QFD employs a linear relationship for the W_i (i.e 20% importance is twice as good as 10%) that may not adequately represent the complexity of customer preferences and may not accurately portray the importance of customer requirements. Some product characteristics may make the customer disproportionately satisfied while others may not affect customer satisfaction to a large extent even though their performance level is high since the customer already expects them. For instance, a cell phone that has basic features may not impress the customer very much even though its performance is very good. On the other hand, a cell phone that is capable of taking pictures and sending them to others can be extremely satisfactory for certain customers.

Total customer satisfaction is the ultimate goal of IS product development and, to reach this goal, QFD must better integrate customer requirements in finer detail. Kano's model of customer satisfaction has been identified as a possible method to overcome this issue (Tan and Shen, 2000; Matzler and Hintenhuber, 1996, 1998; Govers, 1996, 1994; Cohen, 1995; Robertshaw, 1995) because it provides an effective approach to categorize customer attributes and help understand their nature (Matzler and Hintenhuber, 1998). Since this is a promising model to investigate for enhancing QFD as a tool for IS development, the next section examines Kano's model in detail.

2.4 Kano's Customer Satisfaction Model

N. Kano and other researchers (Kano et al, 1984) developed a unique and flexible model for characterizing customer needs. In traditional customer satisfaction models often employed to analyze surveys, interviews, and questionnaires, linearity is assumed between product performance and customer satisfaction. For example, customer satisfaction is assumed to increase or decrease linearly when the product performance is improved or weakened respectively (Huiskonen and Pirttila, 1998). However, increasing fulfillment of customer expectations does not always mean a proportional increase or decrease in customer satisfaction since this change also depends on the "type" of the expectation (Matzler et al, 1996). Different types of customer expectations have different effects on customer satisfaction.

For some customer attributes, customer satisfaction is dramatically improved with only a small improvement in performance; for other customer attributes, customer satisfaction is improved only a small amount even when the product performance is greatly increased (Tan and Shen, 2000). For example, a customer may rate air conditioning as a 25% weight in apartment selection and may not be totally satisfied with the apartment even if the air conditioner works perfectly. On the other hand, dissatisfaction with a poorly working unit will be significant and absence of air conditioning may be a "deal breaker" even if other attractive apartment features are available (e.g. deck, pool). In each of these cases, the impact of changes in the air conditioning characteristic is different than a simple 25% value. This example demonstrates two issues: linearity of characteristic performance and the impact on customer dissatisfaction as well as satisfaction.

If the level of customer satisfaction is plotted on a vertical axis, and the degree of a given performance attribute that the product or service has achieved on the horizontal axis, different types of customer needs can be shown to cause widely different responses. Figure 5 shows how the Kano model distinguishes three types of product requirements that influence customer satisfaction in different ways.

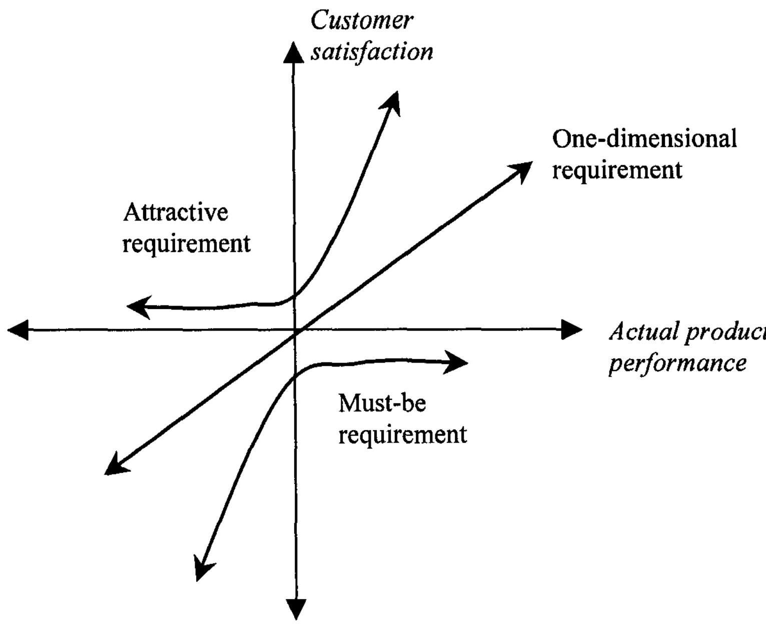

Figure 5. Kano's model of customer satisfaction.

- Must-be requirements (M): These are basic criteria of a product since, if they are not fulfilled, the customer will be extremely dissatisfied. However, their fulfillment will not increase satisfaction since the customers take them for granted. For example, having poor brakes in a car causes high customer dissatisfaction. However, having good brakes does not increase customer satisfaction (Berger et al, 1993). Must-be requirements are a decisive competitive factor and, if they are not fulfilled, the customers will not be attracted to the product (Tan and Shen, 2000; Matzler and Hinterhuber, 1998).
- One-dimensional requirements (O): These result in customer satisfaction when fulfilled, and dissatisfaction when not fulfilled (Tan and Shen, 2000). The higher the level of fulfillment, the higher the customer's satisfaction, and vice versa (Matzler and Hinterhuber, 1998). For example, better gas mileage in a car provides proportional customer satisfaction, and worse gas mileage causes proportional customer dissatisfaction (Berger et al, 1993). Therefore, in the Kano model, customer reaction depends linearly on the level of fulfillment only for one-dimensional requirements.
- Attractive requirements (A): These are the product criteria that have the highest influence on customer satisfaction with a given product. The customer may not explicitly express or expect them, however, fulfilling them leads to more than proportional satisfaction. On the other hand, if they are not met, there is no feeling of dissatisfaction

(Matzler and Hinterhuber, 1998). For example, lack of automatic seatbelts in a car may not cause customer dissatisfaction, but having them can provide more then proportional satisfaction. Consequently, attractive requirements can differentiate the product from competitors.

Table 3 provides more examples of must-be, one-dimensional and attractive requirements (Strubler, 2000). Next, section 2.4.1 discusses a special survey approach for collecting customer data for this model.

Table 3. Examples of Kano classifications.

	Must-be Requirements	**One-dimensional Requirements**	**Attractive Requirements**
Examples	*Provides expected features*	*Promotes loyal customers*	*Builds competitive advantage*
A restaurant	Cleanliness	Reservations accepted	Live music
An airline	Seat space confirmation	Accurate information about cancellations and delays	Delay information provided before the time customer leaves home
A car	Cup-holders included	A GPS included	A night vision device included

2.4.1 Kano Questionnaire

Kano's model of customer satisfaction employs a specific questionnaire format since the type of customer requirement cannot be detected via traditional customer surveys. For example, in traditional surveys, must-be requirements often remain forgotten or get low grades on the importance scales. One-dimensional questions (e.g. "How important is having a television screen with high resolution?") do not necessarily reveal the must-be type requirement since the customer's response is usually based on earlier experiences. If the earlier experiences have been satisfactory, the answer would probably be "not very important", but if they have been unsatisfactory, the answer would be "very important" (Huiskonen and Pirttila, 1998).

In order to detect the types of the customer requirements (CRs), attractive, must-be and one-dimensional requirements are identified via a specially designed questionnaire that contains a pair of questions for each product characteristic. The question pair includes one functional and one dysfunctional form of the same question and this provides deeper understanding of the customer's opinion about the product attributes. The functional form of the question provides the customer's reaction if the product has a certain characteristic. On the other hand, the dysfunctional form identifies the customer's reaction if the product does not have that characteristic (Matzler and Hinterhuber, 1998). Both forms of the question include five different response options for the customer to select as shown in Table 4. For example, the Kano questionnaire used in the application phase of this study (discussed in Chapter 3) included a question about dangerous weather conditions (such as thunderstorms, icing, turbulence, and high winds) and whether or not the general aviation pilots wanted to be alerted to these hazards by the new cockpit weather information system. The functional form of the question asked how the pilots would feel if these alert conditions were included in a new weather information system. On the following question (the dysfunctional form), they were asked how they would feel if the same alert conditions were not included in the system. Used together, the answers to both questions provide understanding on the Kano category for each weather alert condition.

Table 4. Kano evaluation table.

		Dysfunctional form of the question				
		I like this alert condition omitted	**I need this alert condition omitted**	**I am neutral about this alert condition**	**I can live with omitting this alert condition**	**I dislike omitting this alert condition**
Functional form of the question	**I like this alert condition included**	*Q	*A	A	A	*O
	I need this alert condition included	*R	*I	I	I	*M
	I am neutral about this alert condition	R	I	I	I	M
	I can live with including this alert condition	R	I	I	I	M
	I dislike including this alert condition	R	R	R	R	Q

*A: Attractive requirement, *O: One-dimensional requirement, *M: Must-be requirement, *I: Indifferent, *R: Reverse, *Q: Questionable.

Analysis of the Kano questionnaire results in classification of the product characteristics into the three types of requirements defined above (A, O, and M). Since respondents may not rate all attributes included in the questionnaire in these categories, other classifications are also possible: indifferent (I), questionable (Q), and reverse (R).

- Indifferent means that the customer is indifferent to this product attribute and is not very interested whether it is present or not. For example, customers may be indifferent to having a cigarette lighter in a car (Berger et al, 1993). Indifference can be plotted along the horizontal axis in Figure 5 since the customer is neither satisfied nor dissatisfied by including that product attribute.

- A questionable rating indicates the question was phrased incorrectly, the customer misunderstood the question, or an incorrect response was provided.
- Reverse means that, not only do the customers not desire that product attribute, but they also expect the reverse of it (Matzler and Hinterhuber, 1998). For example, some customers may find it undesirable to have unusually large windows in a house due to insulation concerns and, therefore, they may want small windows instead.

The next subsection includes the details of evaluating the responses to define a category for each customer requirement. It also discusses issues with the Kano model analysis.

2.4.2 Analysis of Kano's Model

Kano classification begins with tabulation of survey responses and identification of the category for the CR (A, O, M, I, R, or Q) based on the largest number of inputs. For example, if the highest number of responses for a specific weather alert condition is in the must-be category, this customer requirement is labeled as a must-be (M) requirement. Classifying customer requirements by means of the Kano model provides product developers the following advantages:

It sets priorities for product development. For example, a general guideline for product development based on the survey results may be to fulfill must-be requirements, be competitive in the market with one-dimensional requirements, and include differentiating attractive requirements. In competitive product analysis, improving performance on a must-be requirement that is already at a satisfactory level is not as productive as improving performance on a one-dimensional or attractive requirement. Kano's classification of customer expectations allows product developers to focus their efforts where the customer will notice their effect the most (Berger et al, 1993).

It provides valuable help in product development trade-off studies. If two requirements cannot be met simultaneously due to technical or financial reasons, the requirement having the greatest influence on customer satisfaction is selected (Sauerwein et al, 1996).

Based on the classifications of CRs, customer-tailored solutions for specific problems can be elaborated, which can provide an optimal level of satisfaction in different customer segments (Sauerwein et al, 1996).

Although it is common to identify the Kano category of a CR based on the largest number of inputs, there are a variety of approaches for further analysis that have been developed in individual organizations seeking customer input for the improvement or competitive positioning of their products or services (Berger et al, 1993). Other organizations employed qualitative approaches such as applying common sense to choose the Kano category for a CR when the category selected based on the largest number of responses seems misleading. As a result of this variety, there is no uniform computational guidance or methodology for Kano analysis. In addition, the output of the analysis depends strongly on the particular situation to which Kano's model is applied and the interpretation of the results is usually based on the opinions of the people who apply the method. Quantification of these issues is necessary and presents an ongoing research area (Berger et al, 1993), thus, this research contributes to improving this area as discussed in upcoming sections.

Kano's model was the last model investigated for application to IS product development as explained. The next section compares the models based on the selection criteria and selects the technique(s) that has the most potential for addressing the IS industry's new product failure problems.

2.5 Model Selection Summary

Previous discussion identified the four model selection criteria as the capability of:

1. Capturing the nuances of customer's requirements that reflect real world conditions for new IS development,
2. Carrying the customer's voice to every step of the IS design including the evaluation of detailed product characteristics and enabling technologies according to customer expectations (multi-level decision analysis),
3. Promoting communication between R&D and marketing, and
4. Application to complex innovative IS development involving large number of attributes.

Table 5 evaluates the six candidate models examined above by summarizing their characteristics based on the four selection criteria.

Table 5. Evaluation of models for IS product development.

Models	Model Focus	Criterion 1- customer nuances	Criterion 2- multi level voice of customer	Criterion 3- communication between marketing and R&D	Criterion 4- applicability to complex innovative IS development	Selection decision
Perceptual mapping	Perceptions of existing products	Does not capture the nuances of customer needs	Not detailed enough	Usually applied by marketing	Not for innovative products	Not selected
Expectancy value	Rough idea on simple products	Does not capture the nuances of customer needs	Not detailed enough	Usually applied by marketing	Not detailed enough for IS development	Not selected
Preference regression	Positioning product relative to competition	Does not capture the nuances of customer needs	Not detailed enough	Usually applied by marketing	Not detailed enough for IS development	Not selected
Conjoint analysis	Measuring basic consumer preferences	Although more detailed than the first 3 models, not good enough to capture the nuances of customer needs	Although more detailed than the first 3 models, it is used for selecting product features, not for identifying enabling technologies	Usually applied by marketing (but may include R&D input in some cases)	Excessively complex in development of products with a large number of attributes such as innovative IS systems.	Not selected
QFD	Identification of technical details based on customer needs	Although more detailed than the first 3 models, not good enough to capture the nuances of customer needs	Has the ability to identify enabling technologies based on customer needs (multi-level decision analysis)	Promotes interaction between R&D and marketing	Applicable to complex and innovative product development such as IS development	Selected
Kano	Capturing accurate nuances of customer preferences	Has the ability to capture the nuances of customer requirements and to help overcome QFD's customer data collection issues	Sets a dependable basis for multi-level decision analysis by capturing accurate market data	Needs R&D input to ask meaningful questions to customers	Has flexibility for application to complex and innovative products	Selected as a supporting tool to QFD

QFD presents the most potential as the product development technique appropriate for this research since it identifies enabling technologies based on customer requirements and it promotes information sharing between different functional areas in an organization such as marketing and R&D departments. In addition, this method provides multi-level decision analysis to carry customer needs to detailed technical characteristics of the product. However, QFD includes a challenge in capturing and organizing nuances of customer needs. Customer data is the key for proper execution of this technique because if customer data does not reflect the market conditions, and does not express the nuances of the customer's decision on purchasing the product, the outcome of the QFD model can lead to inaccurate forecasts.

Kano's model of customer satisfaction has potential to resolve QFD's deficiency in capturing nonlinear customer preferences that reflect market requirements. Kano's model is useful to gain deeper insight about customer needs and, based on the classifications of CRs, customer-tailored solutions for specific problems can be elaborated (Sauerwein et al, 1996). This is an important characteristic that is essential for the IS development. In addition, Kano's model is also a tool that can potentially be integrated into QFD to overcome its data collection challenges (Tan and Shen, 2000; Matzler and Hintenhuber, 1996, 1998; Govers, 1996, 1994; Cohen, 1995; Robertshaw, 1995). Integration of QFD and Kano's model has potential for better application of QFD to IS product development to achieve total customer satisfaction (Tan and Shen, 2000). This study develops a methodology to integrate Kano's model with QFD that is discussed in detail in the next section.

2.6 Integration of Kano's Model of Customer Satisfaction into QFD

The literature on the integration of Kano's model with QFD shows that researchers started to associate these two models in the 1990s. For example, Govers (1994) stated that the combination of Kano's method and QFD could provide the following benefits:

- Deeper understanding of customer requirements and problems.
- More effective management of trade-offs within product development.
- Fewer start-up problems.
- Same customer-oriented design intent through to manufacturing.

Sauerwein et al (1996) suggested combining Kano's model and QFD for customer-oriented product development.

Although Kano's model has been related to QFD by a number of researchers, there is no uniform methodology to integrate these two models. As Robertshaw (1995) states, "Kano classifications are not usually weighted in the QFD matrix," which means that most integration attempts include Kano categories for each CR in a separate column of the QFD model without assigning any weights to them. Although defining a Kano category for each CR helps product developers to understand the requirement, the impact of Kano categories on customer satisfaction is not represented in the equations of the QFD model. In some QFD applications weights are assigned to each CR based on Kano classifications, but the selection of weights is very subjective (Tan and Shen, 2000; Islam and Liu, 1995; Robertshaw, 1995).

Matzler and Hinterhuber (1998) and Tan and Shen (2000) presented two analytical approaches for the integration of Kano's model and QFD. Matzler and Hinterhuber (1998) proposed a general integration method for innovative product development as well as product/service improvement and concluded that the integration of the two models could improve customer satisfaction with regard to important product features and establish sustainable competitive advantages for a product developer. They also concluded that the integration could provide more systematic management of product development projects. Tan and Shen (2000) also presented an integration method for product development applicable only in competitive analysis. The supporting literature on QFD, Kano's model and their integration is summarized in Table 6 in chronological order.

The combined decision model developed in this research is based on Matzler and Hinterhuber's approach (1998) since it provides a general integration method applicable to innovative product development such as an information technology product. Tan and Shen's approach (2000) was not considered to develop the decision model in this research since it suggests a method only for competitive product development analysis, which is not examined here. Matzler and Hintenhuber's (1998) approach is summarized in the next section.

Table 6. Literature search summary for QFD and Kano.

Researcher List:	General info on QFD	Inadequacy of QFD usage in industry	QFD challenges on identification of customer needs and linearity assumption	QFD's usage as a product development decision model	General info on Kano's model	Need for integration of Kano's model and QFD	Integration approaches
Kano et al, 1984					X		
Sullivan, 1986		X					
McElroy, 1989		X					
Zultner, 1990						X	
Slabey, 1990	X						
Zairi, 1993			X				
Berger et al, 1993					X		
Clausing, 1994	X						
Gevirtz, 1994	X						
Lyman et al, 1994				X			
Zairi and Youssef, 1995	X						
Robertshaw, 1995					X	X	
Cohen, 1995					X	X	
Islam and Liu, 1995						X	
Govers, 1996	X						
Sauerwein et al, 1996					X	X	
Matzler et al, 1996					X		
Fong, 1996					X		
Park and Kim, 1998	X		X				
Khurana and Rosenthal, 1997	X						
Hellsten and Klefsjo, 1998	X						
Zairi and Youssef, 1998	X						
Matzler and Hinterhuber, 1998					X	X	X
Huiskonen and Pirttila, 1998					X		
Fung et al, 1999		X					
Ho et al, 1999	X	X					
Omar et al, 1999	X	X		X			
Boucherau, 2000			X				
Mohr, 2000	X						
Presley et al, 2000	X						
Shen et al, 2000	X	X					
Wei et al, 2000	X		X				
Tan and Shen, 2000					X	X	X
Berggren and Nacher, 2001			X				
Cristiano et al, 2001	X	X	X				

2.6.1 Matzler and Hintenhuber's Integration Approach

Matzler and Hinterhuber (1998) suggest integrating Kano classifications into the QFD model by using a quantitative method developed by Berger et al (1993) that involves two values related to a CR: *Impact on Customer Satisfaction* in case a CR is included in the product (S_i) and *Impact on Customer Dissatisfaction* in case the same CR is not included in the product (D_i). Impact on Customer Satisfaction (S_i) indicates how much the influence on customer satisfaction is increased by providing that CR, and Impact on Customer

Dissatisfaction (D_i) indicates how much the influence on customer satisfaction is decreased by NOT providing that CR. These are calculated using Equations (7) and (8):

Impact on satisfaction: $S_i = \frac{A_i + O_i}{A_i + O_i + M_i + I_i}$ Equation 7

Impact on dissatisfaction: $D_i = \frac{O_i + M_i}{A_i + O_i + M_i + I_i}$ Equation 8

- A, O, M, and I represent the percentages of responses in the Table 5 cells for the CRs for i=1,...,m.
- m is the total number of CRs.

Matzler and Hinterhuber's paper (1998) illustrates these two values together in the QFD model as an indication of how important the CRs are. In their model, both values are included in the model in two columns as one S_i and one D_i value for each CR. They also suggest expressing the relationships between the DRs and CRs by the following scoring method:

- +2: Strong positive impact,
- +1: Strong negative impact,
- 0: No impact,
- -1: Weak negative impact, and
- -2: Strong negative impact.

This research builds on the new product development methodology of of their study and can be summarized as follows:

1. Prepare the Kano questionnaire and survey customers.
2. Conduct survey analysis and identify Kano categories for CRs based on the most frequent observation approach.
3. Calculate the impact on satisfaction and the impact on dissatisfaction values for each CR by using Equations (7) and (8).
4. Identify the DRs and the CR-DR relationship ratings based on the ±2-±1-0 scale.

5. Estimate the feasibility and technical difficulty of DRs (no related equation is included in the paper). Identify the importance of DRs from the results of a one-level decision analysis.

This 5-step integration methodology is illustrated in Table 7. The next section discusses the combined model approach developed in this study including improvements to Matzler and Hinterhuber's approach to address the information systems industry needs.

Table 7. Matzler and Hintenhuber's integration methodology.

Matzler and Hintenhuber's Model Development Steps		Related Explanation / Equation / Section
1	Prepare Kano questionnaire and survey customers.	A functional and a dysfunctional question for each CR (Section 2.4.1).
2	Conduct survey analysis and identify Kano categories for CRs.	The most frequent observation approach (Section 2.4.2).
3	Calculate the impact on satisfaction and the impact on dissatisfaction for each CR, and enter them to the QFD matrix.	$S_i = \frac{A_i + O_i}{A_i + O_i + M_i + I_i}$ and $D_i = \frac{O_i + M_i}{A_i + O_i + M_i + I_i}$ (Equation (7)-(8) / Section 2.6.1).
4	Identify the DRs (hows) and enter them and CR-DR relationship ratings into the house of quality	Based on a ±2-±1-0 scale.
5	Estimate the feasibility and technical difficulty of DRs	No equation is included in the paper.
	Most important second DRs are identified based on customer expectations as a result of a one-level analysis.	

2.6.2 Combined Model Development

This research builds on Matzler and Hinterhuber's approach for integration of Kano's model and QFD and extends it by including the following critical differences that facilitate application to IS product development:

- Improved scoring method,
- Elimination of negative ratings,
- Capability to integrate S_i or D_i,
- Capability to define products based on Kano classifications,
- Use of statistical significance to classify Kano categories,
- Capability of multi-level decision analysis.

These additions are discussed below.

Improved Scoring Method: QFD scoring research indicates that the method suggested by Matzler and Hinterhuber (1998) may be inadequate to differentiate strong, moderate, and weak DR impacts on CRs since the contrast between 2, 1, and 0 is not as high as the preferred 9, 3, 1, 0 scale, especially when CR importance values are close to each other. This may prevent the correct identification of the most important design requirements according to customer needs (see Section 2.3.1), which is one of the main problems in the information systems industry. For this reason, this research uses the 9, 3, 1, 0 scale in the QFD relationship matrix.

Elimination of Negative Ratings: Negative impacts in the house of quality are not desired since they complicate the practical use of the model for promoting marketing and R&D interaction (see Section 2.3.1). This is particularly true for information systems that are usually complex systems with a large number of CRs and DRs. For this reason, an improvement for IS product development would include use of positive relationship ratings in the QFD matrix.

Capability to integrate S_i or D_i: Integration of impact on customer satisfaction (S_i) and impact on customer dissatisfaction (D_i) values into the matrix provides deeper understanding of customer needs as Metzler and Hintenhuber suggested (1998). As the impact on satisfaction reflects how the customer feels about the product with a particular CR, the impact on dissatisfaction provides insight on how the customer feels about the product without that CR.

However, including both values into the QFD matrix will complicate the application, inhibit use by IS management, and diminish interaction and discussion between critical departments such as marketing and R&D. On the other hand, achieving customer satisfaction and avoiding dissatisfaction are important to develop products that meet customer needs in the IS industry. Therefore, this research proposes a critical simplifying assumption: *To develop IS products that satisfy customer requirements, achieving customer satisfaction is as important as avoiding customer dissatisfaction for the information systems industry.*

Consequently, this study includes both S_i and D_i values in the QFD model and absolute importance of each CR is selected as the highest of either the impact on customer satisfaction or the impact on customer dissatisfaction value calculated using Equations (7) and (8). Therefore, both S_i and D_i values for each CR are used to identify the relative importance values (W_i) to be entered into the QFD model (Figure 3), and the relative importance of each CR is found using Equation (9) depending on the highest value of S_i or D_i.

$$W_i = \frac{S_i}{\sum_{i=1}^{m} S_i} \quad \text{or} \quad W_i = \frac{D_i}{\sum_{i=1}^{m} D_i} \qquad \text{Equation 9}$$

W_i is entered into the QFD house of quality as explained in Section 2.3.1. This provides the integration of the Kano categories and the related impact on satisfaction and dissatisfaction values into the equations of the QFD model.

Capability to Define Products Based on Kano Classifications: Based on the classifications of CRs, customer-tailored products for specific market goals can be identified that provide an optimal level of customer satisfaction (Sauerwein et al, 1996). Matzler and Hintenhuber's study (1998) does not employ this characteristic of the Kano model. Since product solutions that satisfy customer needs are required for new product development in the IS industry, this research proposes using Kano classifications for defining products with different features. These features may reflect the evolutionary life cycle of an advanced information system product such as basic, entry-level, advanced, and high-end products. Providing these products at different costs to the market can satisfy customers in various segments (Kotler, 2000) and provide a long-term product evolution path. For example product categories may be based on the following feature types:

- Basic product: "Indifferent" customer requirements.
- Entry-level product: "Must-be" requirements.
- Advanced product: "One-dimensional" requirements in addition to previous "must-be" requirements.
- High-end product: "Attractive" requirements in addition to previous "must-be" and "one-dimensional" requirements.

This differentiation method may have the potential to achieve market success by providing satisfactory products to the customer at different levels, and may streamline and improve product development cycles in advanced technologies. This is particularly important since these systems have short life cycles and the product evolution must be pre-planned.

Use of Statistical Significance to Classify: An important issue in Kano analysis is the evaluation of Kano categories with nearly equal number of occurrences (Fong, 1996; Lee and Newcomb, 1996; Berger et al, 1993). The most frequent observation approach works well when one response dominates the sample, that is, when the frequency of the mode is much greater than any other characterization. However, as the difference between the frequencies of two classifications becomes narrower, the proper classification of the requirement becomes less clear (Fong, 1996). As a result, it becomes difficult to label that CR with a definite requirement type. Since this affects the accuracy of the category selection of that CR, it may have a negative effect on the identifying characteristics for product definitions. For this reason, this research integrated a test, developed by Fong (1996), at the beginning of the Kano analysis, to measure significance differences between two closely ranked categories. Equation (10) determines if there is a statistically significant difference between the two most frequent observations (Fong, 1996): If

$$|a - b| < 1.65\sqrt{\frac{(a+b)(2N-a-b)}{2N}} \, , \qquad \text{Equation 10}$$

then the difference is not statistically significant, where a and b are the frequencies of the two most frequent observations and N is the total number of responses. This equation is derived from a hypotheses test (Hogg and Tanis, 2001):

H_0: $p_a - p_b = 0$

H_1: $p_a - p_b > 0$

$$\text{Critical region: } \frac{a/n_1 - b/n_2}{\sqrt{\left(\frac{a+b}{n_1+n_2}\right)\left(1-\frac{a+b}{n_1+n_2}\right)\left(\frac{1}{n_1}+\frac{1}{n_2}\right)}} \geq z_\alpha \qquad \text{Equation 11}$$

- H_0 and H_1 are the null and alternative hypotheses respectively.
- p_a and p_b are the probabilities of having a and b numbers of observations in a population respectively.
- n_1 and n_2 are the total sizes if a hypothesis test if two different populations is considered.
- z_α is the critical point for a standard normal distribution, and α is the significance level.

Fong (2003) uses this test to prove that the probability of having "a" number of frequencies is greater than the probability of observing "b" number of frequencies in a population or vice versa by disproving the null hypothesis. Therefore, Equation (10) can be derived for:

- $n_1 = n_2 = N$, and
- 90% confidence level ($\alpha = 0.10$), $z_\alpha = 1.65$.

This research employs the significance test to determine whether it is possible to conclude with 90% confidence that the Kano category selected for a CR is accurate. This improves credibility of the category selection and the ultimate product concept.

Capability of Multi-level Decision Analysis: Matzler and Hintenhuber (1998) do not provide a multi-level decision analysis in their integration study. However, the capability of using additional matrices in QFD is very important for the IS industry to make decisions about technical characteristics and enabling technologies of an innovative system, by including the impact of customer satisfaction during the whole product development process. For this reason, this research creates an integration methodology that is capable of multi-level decision analysis for IS development.

The next section develops a 12-step methodology to apply the combined model for the IS industry that extends Matzler and Hintenhuber's 5 step approach in Table 7.

2.6.3 Integrated Methodology

Based on the discussions on the Kano model, QFD, and the integration of the Kano model and QFD, the following methodology is created to develop the combined model for a multi-level decision analysis for the IS industry.

1. Prepare the Kano questionnaire and survey customers.
2. Conduct survey analysis and identify Kano categories for CRs based on the most frequent observation approach.
3. Test statistical significance of the Kano categories by using Equation (10). If they are not statistically significant with 90% confidence, that category is labeled inconclusive.
4. Define different levels of products based on CRs with statistically significant Kano categories from the previous step. Then, repeat the following steps for each product definition.
5. Calculate the impact on satisfaction and the impact on dissatisfaction values for each CR by using Equations (7) and (8), and select the highest one as the absolute importance value.
6. Calculate the relative importance value for CRs (whats) based on the output of the previous step by using Equation (9).
7. Identify the DRs (hows); then enter them and CR-DR relationship ratings into the house of quality as illustrated in Figure 3 and 4 by employing the 9-3-1-0 scale.
8. Calculate the absolute importance of each DR by using Equation (4).
9. Calculate the relative importance of each DR by using Equation (5). This provides the identification of the most important DRs based on customer expectations. If there is no need for multiple-level analysis, this step presents the outcome of the decision model. If multiple matrices are needed for more detailed analysis, employ the next steps.
10. DRs (hows) become the new "whats" for the second level analysis as illustrated in Figure 4 and discussed in Section 2.3.1.
11. Identify the new "hows" (second level DRs); then enter them and the new relationship ratings into the second QFD matrix by employing the 9-3-1-0 scale.
12. Calculate the total score for the new "hows" (second level DRs) by using Equation (6). If this two-level analysis is enough for the particular product development problem at hand, this step presents the outcome of the decision model. If more matrices are needed for more detailed analysis, repeat steps 10 - 12.

Table 8 illustrates this proposed methodology and Table 9 demonstrates the contrast with Matzler and Hintenhuber's (1998) approach, indicating how the 12-step methodology developed in this research extends it. The next section summarizes the development process of the combined model that was presented in this chapter.

Table 8. Proposed methodology for developing the combined decision model for a multiple-level analysis.

	Model Development Steps	Related Explanation / Equation / Section
1	Prepare Kano questionnaire and survey customers.	A functional and a dysfunctional question for each CR (Section 2.4.1).
2	Conduct survey analysis and identify Kano categories for CRs.	The most frequent observation approach (Section 2.4.2).
3	Test statistical significance of Kano categories.	$\lvert a - b \rvert \langle 1.65\sqrt{\frac{(a+b)(2N-a-b)}{2N}}$ (Equation (10) / Section 2.6.1).
4	Define different levels of products.	Based on CRs with statistically significant Kano categories from the previous step. (Section 2.6.1)
5	Calculate the impact on satisfaction and the impact on dissatisfaction for each CR, and select the highest one as the absolute importance value.	$S_i = \frac{A_i + O_i}{A_i + O_i + M_i + I_i}$ and $D_i = \frac{O_i + M_i}{A_i + O_i + M_i + I_i}$ (Equation (7)-(8) / Section 2.6.1).
Repeat the following steps for each product definition.		
6	Calculate the relative importance value for CRs (whats) based on the output of the previous step.	$W_i = \frac{S_i}{\sum_{i=1}^{m} S_i}$ or $W_i = \frac{D_i}{\sum_{i=1}^{m} D_i}$ (Equation (9) / Section 2.6.1).
7	Identify the DRs (hows) and enter them and CR-DR relationship ratings into the house of quality	Based on the 9-3-1-0 scale. (Section 2.3.1)
8	Calculate the absolute importance of each DR.	$AI_j = \sum_{i=1}^{m} W_i R_{ij}$ (Equation (4) / Section 2.3.2)
9	Calculate the relative importance of each DR.	$RI_j = \frac{AI_j}{\sum_{j=1}^{n} AI_j}$ (Equation (5) / Section 2.3.2)
Most important DRs are identified based on customer expectations as a result of the previous step.		
10	Hows (DRs) become new whats for the second level analysis.	In case a multiple-level analysis is needed. (Section 2.3)
11	Enter new hows (second level DRs) to the second QFD matrix.	Based on the 9-3-1-0 scale. (Section 2.3.1)
12	Calculate total score for new hows (second level DRs).	$\text{Total score} = \sum_{j=1}^{n} Z_{ij} RI_j$ (Equation (6) / Section 2.3.2)
Most important second level DRs are identified based on customer expectations as a result of the previous step, which is the outcome of the two-level model. Add more levels of analysis if needed.		

Table 9. Comparative summary of this research's integration methodology and Matzler and Hintenhuber's (1998) approach.

Combined Model Development Steps developed in this research		Model Development Steps in Matzler and Hintenhuber's integration approach	
1	Prepare Kano questionnaire and survey customers.	1	Prepare Kano questionnaire and survey customers.
2	Conduct survey analysis and identify Kano categories for CRs.	2	Conduct survey analysis and identify Kano categories for CRs.
3	Test statistical significance of Kano categories.		NOT ADDRESSED
4	Define different levels of products.		NOT AVAILABLE
5	Calculate the impact on satisfaction and the impact on dissatisfaction for each CR, and select the highest one as the absolute importance value.	3	Calculate the impact on satisfaction and the impact on dissatisfaction for each CR, and enter them both to the QFD matrix.
Repeat the following steps for each product definition.			NOT AVAILABLE
6	Calculate the relative importance value for CRs (whats) based on the output of the previous step.	4	Identify the DRs (hows) and enter them and CR-DR relationship ratings into the house of quality (BASED ON A ±2-±1-0 SCALE)
7	Identify the DRs (hows) and enter them and CR-DR relationship ratings into the house of quality (based on a 9-3-1-0 scale)		
8	Calculate the absolute importance of each DR.		NO APPLICATION INCLUDED
9	Calculate the relative importance of each DR.		NO APPLICATION INCLUDED
Most important DRs are identified based on customer expectations as a result of the previous step.		5	Estimate the feasibility and technical difficulty of DRs (NO APPLICATION INCLUDED)
10	Hows (DRs) become new whats for the second level analysis.		NOT AVAILABLE
11	Enter new hows (second level DRs) to the second QFD matrix.		NOT AVAILABLE
12	Calculate total score for new hows (second level DRs).		NOT AVAILABLE
Most important second level DRs are identified based on customer expectations as a result of the previous step, which is the outcome of the two-level model. Add more levels of analysis if needed.			NOT AVAILABLE

2.7 Summary

This chapter developed selection criteria for decision models that were potentially useful for IS product design and evaluated six models based on this criteria: perceptual mapping model, expectancy value model, preference regression, conjoint analysis, QFD, and Kano's customer satisfaction model.

These models were evaluated based on the criteria and, as a result, the first four models were not selected as primary tools for the IS product development. On the other hand, QFD and Kano's model had the potential to address the IS development problems.

QFD was the most promising product development technique appropriate for this research since it helps develop products with technical characteristics, identify enabling technologies based on customer requirements, and promotes information sharing between different functional areas in an organization such as marketing and R&D departments. However, this technique fails to adequately capture complex customer preferences that reflect real world conditions due to its assumption of linearity between actual product performance and customer satisfaction / dissatisfaction. Kano's model presented a useful tool to overcome these challenges since it has the ability to capture the nuances of customer requirements.

This research developed a 12-step methodology to integrate Kano's model into QFD, which extends Matzler and Hintenhuber's integration approach (1998) and includes improvements specific to IS industry needs. These improvements can be summarized as:

- Better scoring method,
- Elimination of negative ratings,
- Capability to integrate S_i or D_i,
- Capability to define products based on Kano Classifications,
- Use of statistical significance to classify Kano categories,
- Capability of multi-level decision analysis.

As a result, a combined decision model for IS development was created.

Chapter 3 and Chapter 4 illustrate the validity of the combined decision model by applying it to a current IS industry product development problem. The methodology is applied to the problem of developing general aviation (GA) cockpit weather information systems that are likely to achieve market success. This is a complex, multi-level product development problem that is especially sensitive to customer expectations. Chapter 3 includes the first five steps of the methodology, and develops four different product definitions based on a customer survey, and Chapter 4 executes steps 6 to 12 accomplishing the complete application of the two-level combined decision model.

CHAPTER III
MODEL TEST ON A NASA PROBLEM

Weather information has significant implications for aviation system safety and there is general agreement that improved cockpit weather information can reduce accidents and injuries, especially in general aviation. A range of possible product alternatives and delivery systems are possible but it is not clear how researchers and product developers should identify the most promising technological systems to provide the needed consumer requirements to achieve market success. A product development decision model is one possible tool to support resolution of this issue.

General Aviation (GA) cockpit weather information systems are innovative systems that inform the pilot about the weather conditions ahead based on communication with the ground via a data link. The engineering management decisions in this market encompass a wide spectrum of advanced technology and information system product development. Therefore, this problem was selected to test the combined decision model approach developed in the previous chapter. It is applied to select the most promising technological alternatives based on customer requirements to achieve market success in the GA segment of the IS market.

This chapter provides an overview of the problem context, problem description, and application objective. It then demonstrates the application of the first five steps of the combined model methodology created in the previous chapter to cockpit weather information system development.

3.1 NASA Aviation Weather Program

As a result of high aviation accident rates, the NASA Aviation Safety Program (AvSP) was launched in 1997 with a goal to develop and demonstrate technologies that contribute to a reduction in the aviation fatal accident rate by a factor of five by 2007 and a factor of ten by 2022 (Lockheed Martin, 1999). The program was formed as a partnership of NASA, the Federal Aviation Administration (FAA), the aviation industry, and the Department of Defense. Since weather was found to be a causal factor in approximately 30% of aviation accidents, the Aviation Weather Information (AWIN) project was established as a sub-element of AvSP to focus on weather issues. The goal of AWIN is to provide enhanced weather information to users in the national airspace system (NAS) and to foster the improved usage of this information by applying information technology to build a safer aviation system to support pilots (Stough, 1998).

3.2 Application Problem Description and Objective

The AWIN project presented a complex mix of technologies and capabilities since it required integration of varied systems such as weather radars, data-links, information processing, multi-function displays, and specialized aviation weather forecast products (Keel et al, 2000). The development of a complex information technology related system, such as AWIN, presents difficult challenges for technology managers.

For example, one of the key requirements for future cockpit weather information systems is the delivery and display of weather updates in graphical format. However, tailoring weather products according to the requirements of the aviation community reveals a critical deficiency (Keel et al, 2000). Graphical data meeting user expectations requires significant data link bandwidth for delivery to the user. An enabling technology to resolve this issue is a high data rate, air-ground communication link. Therefore, this application focuses on determining the specific weather information needs of the aviation community and selecting the enabling technology (data link) that is capable of delivering and displaying graphical weather information to the GA aircraft cockpit.

Based on the problem description, the objective of this application is: *The identification of the most appropriate data links to develop new GA cockpit weather information systems based on customer needs by means of the combined model developed in this research.*

The remaining sections of this chapter contain the application of the first five steps of the methodology developed in the previous chapter (Table 5) to this particular IS development problem:

1. Customer Survey (Section 3.3): Prepare the Kano questionnaire and survey customers.
2. Survey Analysis (Section 3.4): Conduct survey analysis and identify Kano categories for CRs based on the most frequent observation approach.

3. Significance Test (incorporated in Section 3.4): Test statistical significance of the Kano categories by using Equation (10). If a category is not statistically significant with 90% confidence, it is labeled "inconclusive."
4. Product Differentiation (Section 3.5): Define different levels of products based on CRs with statistically significant Kano categories from the previous step.
5. Absolute Importance Calculation (incorporated in Section 3.5): Calculate the impact on satisfaction and the impact on dissatisfaction for each CR, and select the highest one as the absolute importance value.

Consequently, this chapter defines different product levels of cockpit weather information systems based on the first five steps of the combined model methodology. Chapter 4 develops the models for each product by executing the remaining steps.

3.3 Customer Survey

This section discusses the preparation of a customer survey to capture customer data on new GA cockpit weather information systems by using a Kano questionnaire format (see Section 2.4.1). Surveys, interviews, or focus groups are often used as customer data collection methods (Cohen, 1995). The first step to gather this data is to decide who the customer is. The researcher must define the target population that will be sampled since it is essential to achieve market information that reflects customer needs (Kotler, 2000; Berkowitz et al, 1997). In this application, the sample population is general aviation (GA) pilots who are potential users of the new cockpit weather information systems.

The second step is to select the contact method from options such as mail, telephone, personal, or on-line interviews. There is increased use of on-line interviews (web-based surveys) because this method provides broad flexibility. For example, approaches include different presentation alternatives such as offering the questionnaire on the company web site, placing a banner on a popular website inviting people to complete the survey, or entering a target chat room and seeking volunteers for it (Kotler, 2000). This method is also flexible from the customer's perspective, because targeted customers can access the questionnaire easily without having the burden of mailing it or being interviewed (Sireli et al, 2002). To enhance participation, a web-based survey was employed in this application study.

On the other hand, the challenge in collecting data via web-based surveys is to make sure that the data are representative of the target population because the respondents may be self-selected (Kotler, 2000). In this study, to minimize the possibility of missing the target population, cooperation of organizations such as the Aircraft Owners and Pilots Association (AOPA), the Aviation Magazine & News Service, and the National Business Aircraft Association was enlisted since GA pilots frequently visit their web sites. The next subsection discusses the preparation process of the Kano questionnaire for this application.

3.3.1 Kano Questionnaire for GA Cockpit Weather Information System Development

A customer survey questionnaire should include meaningful questions that capture the customer expectations for a successful product (Kotler, 2000). Expert opinions and user input are essential to make sure that the questionnaire offers reasonable questions to the customers and provides accurate data in the survey analysis phase. Consistent with this need, the CR options presented to the participants in this survey were based on a previous study that identified basic needs of aviation customers (Sireli et al, 2001) and the recommendations of a focus group that helped prepare the questionnaire for this study. The group included the following experts:

- Six pilots from varied professions.
- Two NASA aviation managers with expertise on GA cockpit weather information systems.
- Two electrical engineers who are knowledgeable on graphical weather products and weather data links.
- Two engineering managers who developed the model concept.

The survey contained 8 sections included in Table 10, and they are described individually in the following paragraphs.

Table 10. Customer survey sections.

Survey section		Options offered to the participant
1	Pilot professions	Private Commercial Airline transport Student Recreational Helicopter
2	Customer Requirements (CRs): Graphical weather products	PIREPs AIRMETs METARs TAFs Winds Aloft Icing Convective Turbulence Ceiling/Visibility
3	Customer Requirements (CRs): Grid size	2x2 – 4x4 miles 5x5 – 8x8 miles 9x9 – 12x12 miles
4	Customer Requirements (CRs): Weather update interval	0-5 minutes 5-10 minutes 10-20 minutes 20-30 minutes 30-60 minutes
5	Customer Requirements (CRs): Display of hazardous weather	Text on screen Voice on request Symbols on the graph Forecast maps Radar loop animation
6	Customer Requirements (CRs): Weather alert conditions	Thunderstorm Icing Turbulence Heavy precipitation High winds Low visibility
7	Customer Requirements (CRs): Traffic	Optional display by switching to air traffic
8	Customer Requirements (CRs): Additional services	Such as Internet, short message service (SMS), or email

1. Pilot Professions: To examine the sample population, the survey included a question about the participant's profession. The profession options presented to the participants were:

- Private
- Commercial
- Airline transport
- Student
- Recreational
- Helicopter

2. Graphical Weather Products: Weather products are defined as information (such as measured data, processed data, and forecasts) that has been packaged for interpretation by the recipient to aid in making decisions affecting aviation safety (Keel at al, 2000). The graphical weather product options presented to the participants in the survey included:

- PIREPs (The Pilot Flight Report): A report of meteorological phenomena encountered by aircraft in flight.
- AIRMETs (AIRman's METeorological Information): An advisory of hazardous weather, without convective activity information.
- METARs (METeorological Aviation Routine Weather Report): An hourly surface weather observation, which provides information about winds, visibility, weather type, obstructions to visibility, sky conditions, temperature, dew point, and altimeter setting.
- TAFs (Terminal Aerodrome Forecast): A report including expected meteorological conditions at an airport during a specified period (usually 24 hours).
- Winds Aloft: A report including information about winds aloft.
- Icing: A report including information about icing at specific flight altitudes.
- Convective: A report including information about convective activity.
- Turbulence: A report including information about turbulence conditions.
- Ceiling/Visibility: A report including information about ceiling and visibility conditions.

3. Grid Size: The grid size defines the square area of the smallest graphic and these grid size options were presented to the survey participants.

- 2x2 – 4x4 miles
- 5x5 – 8x8 miles
- 9x9 – 12x12 miles

4. Weather Update Interval: This describes the frequency of uploading new graphical weather information to the cockpit. The weather update interval options presented to the participants in the survey were:

- 0-5 minutes
- 5-10 minutes
- 10-20 minutes
- 20-30 minutes
- 30-60 minutes

5. Display of Hazardous Weather: A description of the direction and rate of movement of hazardous weather patterns is a possible feature of weather information systems. The following display options were offered in the survey:

- Text on screen
- Voice on request
- Symbols on the graph
- Forecast maps
- Radar loop animation

The first three choices are self-explanatory and require minimal communication and hardware capabilities. On the other hand, forecast maps show the future position of the weather and provide an indication of its movement. Radar loop animation presents past and previous maps linked together in an animation providing a visual representation of weather movement.

6. Weather Alert Conditions: It is important for the safety of flight operations to receive en-route weather alerts about the presence of hazardous weather that may affect the flight. Weather alerts attract the attention of the pilot even if he/she is not monitoring weather at the time. The following weather alert conditions were offered in the survey:

- Thunderstorm
- Icing
- Turbulence
- Heavy precipitation
- High winds
- Low visibility

7. *Traffic:* An option could be included in the new cockpit weather information system allowing the user to receive air traffic information on the same display as weather information by switching the content of the display to traffic instead of weather.

8. *Additional Services:* The term "additional services" encompasses certain non-aeronautical capabilities whose inclusion may add a higher level of utility and attractiveness to the weather information system, such as Internet, e-mail and short message service (SMS).

These questions were prepared in the Kano questionnaire form described in the previous chapter and included one functional and one dysfunctional question for each topic. The complete questionnaire is provided in Appendix A.

The next section analyzes the survey results and assigns Kano categories to customer requirements based on the most frequent response approach discussed in the previous chapter. Fong's (1996) significance test is applied to more accurately classify each category.

3.4 Survey Analysis and Significance Test

The survey received 605 responses that represent a GA community characterized by a combination of private, commercial, airline transport, and student pilots. Private pilots form 62% of the respondents, commercial pilots represent 26%, airline pilots make up 8%, and students represent 4% of the population as shown in Figure 6.

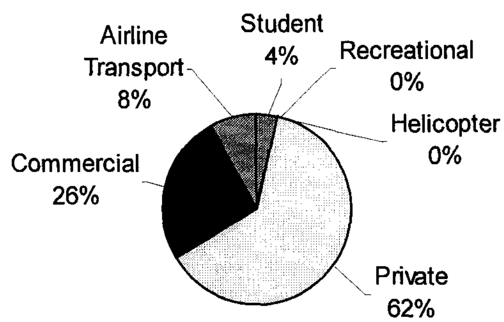

Figure 6. Sample population in terms of professions.

Using the Kano methodology and category definitions discussed in the previous chapter, Table 11 summarizes the survey results identified by the most frequent observation method and includes absolute importance values calculated by using Equation (7) and (8). The CRs that were labeled as “R - reverse” have an importance value of 0.0% since customers do not desire these characteristics in the product at all.

Table 11. Summary of customer requirements.

Customer Requirements (CRs)	Kano Category	Absolute Importance of CRs (highest of S_i or D_i)	$\lvert a - b \rvert$		$1.65\sqrt{\frac{(a+b)(2N-a-b)}{2N}}$	Kano category statistically significant?
Graphical weather products:						
PIREPs	O*	53.1%	14	<	24.8	***NO***
AIRMETs	I*	42.9%	64	>	25.1	Yes
METARs	M*	64.7%	43	>	25.9	Yes
TAFs	M	58.1%	52	>	25.3	Yes
Winds Aloft	I	43.7%	57	>	25.1	Yes
Icing	M	62.3%	79	>	26.0	Yes
Convective	M	68.0%	100	>	26.3	Yes
Turbulence	I	44.0%	55	>	24.8	Yes
Ceiling/Visibility	M	71.7%	76	>	26.7	Yes
Grid size:						
2x2 mi – 4x4 mi	I	39.1%	66	>	25.8	Yes
5x5 mi – 8x8 mi	I	42.0%	114	>	25.6	Yes
9x9 mi – 12x12 mi	I	43.0%	54	>	25.2	Yes
Weather update interval:						
0-5 minutes	A*	59.4%	36	>	25.0	Yes
5-10 minutes	M	54.5%	32	>	25.0	Yes
10-20 minutes	I	40.8%	35	>	25.8	Yes
20-30 minutes	R*	0.0%	192	>	27.4	Yes
30-60 minutes	R	0.0%	331	>	27.5	Yes
Display of hazardous weather:						
Text on screen	I	42.0%	78	>	24.7	Yes
Voice on request	I	26.6%	98	>	27.3	Yes
Symbols on the graph	I	48.8%	33	>	25.4	Yes
Forecast maps	O	55.6%	26	>	25.7	Yes
Radar loop animation	O	71.2%	32	>	26.5	Yes
Weather alert conditions:						
Thunderstorm	M	86.4%	91	>	27.6	Yes
Icing	M	66.1%	51	>	26.0	Yes
Turbulence	A	53.6%	32	>	24.8	Yes
Heavy precipitation	O	57.8%	27	>	25.0	Yes
High winds	M	49.2%	4	<	24.7	***NO***
Low visibility	M	60.4%	26	>	25.3	Yes
Traffic	A	63.0%	41	>	25.7	Yes
Additional services	I	35.8%	136	>	26.3	Yes

*A: Attractive requirement, *O: One-dimensional requirement, *M: Must-be requirement, *I: Indifferent, *R: Reverse

Table 11 also provides significance test results for each CR since the most frequent observation method may be inadequate to assign proper classifications to CRs with nearly equal number of occurrences. For example, the thunderstorm weather alert condition can be labeled with 90% confidence as a must-be (M) requirement, which means that the customer needs this feature and its absence will make the customer very dissatisfied. On the other hand, it is not possible to say with 90% confidence that PIREPs graphical weather product can be labeled as a one-dimensional (O) requirement, even though the most frequent observation approach assigns the Kano category "O" to this CR. High winds weather alert condition falls into the same category. For this reason, PIREPs and high winds are not included in the product differentiation step discussed in the next section.

3.5 Product Differentiation and Absolute Importance Values

Based on the responses of survey participants, this section develops four different product definitions that may reflect the evolution of an advanced information product life cycle:

- Basic product.
- Entry-level product.
- Advanced product.
- High-end product.

Defining the specifications of these products begins with the indifferent (I) and must-be (M) Kano categories. One-dimensional (O) and attractive (A) requirements are progressively added to the product characteristics as explained below. Customer requirements identified as statistically insignificant in Table 8 are not included in these product definitions since their Kano categories are not conclusive with 90% confidence.

Basic product: This product is conceived as a low-end, basic cockpit weather information system and it is comprised primarily of indifferent requirements with the highest importance values from every feature category possible. Indifferent requirements with low importance values are not included in any product definition. Table 12 illustrates customer requirements along with the related Kano categories and absolute importance values for the basic cockpit weather information system.

Table 12. Basic product customer requirements.

	Basic product CRs	Kano category	Absolute importance
Graphical weather products:	AIRMETs Winds aloft Turbulence	I I I	42.9% 43.7% 44.0%
Grid size:	2 x 2 miles - 4 x 4 miles	I	39.1%
Weather updates:	Every 10 – 20 minutes	I	40.8%
Display of hazardous weather:	Via text on screen	I	42.0%
Additional Services	e.g. Short Message Service (SMS), e-mail, or Internet	I	35.8%

Entry-level product: This product is conceived as an advanced entry-level product and includes must-be requirements in all feature categories possible. Indifferent requirements with high importance values are included when there is no must-be requirement in that feature group. Customer requirements with Kano categories and absolute importance values for the entry-level cockpit weather information system are illustrated in Table 13.

Table 13. Entry-level product customer requirements.

	Entry-level product CRs	Kano category	Absolute importance
Graphical weather products:	METARs TAFs Icing Convective Ceiling/Visibility	M M M M M	64.7% 58.1% 62.3% 68.0% 71.7%
Grid size:	5 x 5 miles - 8 x 8 miles	I	42.0%
Weather updates:	Every 5 – 10 minutes	M	54.5%
Display of hazardous weather:	Via symbols on graph	I	48.8%
Conditions for weather alert:	Thunderstorm Icing Low visibility	M M M	86.4% 66.1% 60.4%

Advanced product: This is conceived as an improved product that may be one generation beyond entry-level. One-dimensional requirements are included in every feature category possible in addition to highest rated must-be and indifferent requirements when there is no one-dimensional requirement in that feature group. Table 14 illustrates customer requirements with Kano categories and absolute importance values for the advanced cockpit weather information system.

Table 14. Advanced product customer requirements.

	Advanced product CRs	Kano category	Absolute importance
Graphical weather products:	METARs	M	64.7%
	TAFs	M	58.1%
	Icing	M	62.3%
	Convective	M	68.0%
	Ceiling/Visibility	M	71.7%
Grid size:	9 x 9 miles - 12 x 12 miles	I	43.0%
Weather updates:	Every 5 – 10 minutes	M	54.5%
Display of hazardous weather:	Via forecast maps	O	55.5%
Conditions for weather alert:	Thunderstorm	M	86.4%
	Icing	M	66.1%
	Heavy precipitation	O	57.8%
	Low visibility	M	60.4%

High-end product: This is conceived as a premium product with high margins. Highly rated attractive requirements are included in every feature category possible. The highest rated one-dimensional, must-be and indifferent requirements are included when there is no attractive requirement in that feature group. Table 15 illustrates customer requirements with Kano categories and absolute importance values for the high-end cockpit weather information system.

Table 15. High-end product customer requirements.

	High-end product CRs	Kano category	Absolute importance
Graphical weather products:	METARs	M	64.7%
	TAFs	M	58.1%
	Icing	M	62.3%
	Convective	M	68.0%
	Ceiling/Visibility	M	71.7%
Grid size:	9 x 9 miles - 12 x 12 miles	I	43.0%
Weather updates:	Every 0 – 5 minutes	A	59.4%
Display of hazardous weather:	Via radar loop animation	O	71.2%
Conditions for weather alert:	Thunderstorm	M	86.4%
	Icing	M	66.1%
	Heavy precipitation	O	57.8%
	Low visibility	M	60.4%
	Turbulence	A	53.6%
Traffic	Air traffic info by switching the display to traffic	A	63.0%

This section demonstrated how four product levels were derived based on the Kano categories assigned to CRs as an innovative improvement to the previous literature on the Kano model. The next section summarizes the application of the first five steps of the methodology developed in Chapter 2.

3.6 Summary

Weather is a causal factor in approximately 30% of aviation accidents and NASA's Aviation Weather Information (AWIN) project focuses on weather issues with a goal of providing improved weather information to GA pilots by means of information technologies, to build a safer aviation system.

A range of possible product alternatives and delivery systems are possible to develop advanced cockpit weather information systems. But, it is not clear how researchers and product developers should identify the most promising technological systems to provide the needed consumer requirements and to achieve market success. A product development decision model was one possible tool to support resolution of this issue.

An important first step in weather information product development is the determination of customer needs for various characteristics. Ultimately, a method is needed to map this information into technical performance characteristics. In addition, the engineering management decisions in this market include a complex spectrum of advanced technology and information system product development. These requirements made this an excellent problem to apply the combined decision model approach developed in the previous chapter with this objective: *The identification of the most appropriate data links to develop new GA cockpit weather information systems based on customer needs by means of the combined model.*

This chapter applied the first five steps of the combined model methodology (Table 8) to this particular IS development problem. First, it developed a web-based Kano questionnaire using the results of a focus group study and the outcomes of a previous research. Then, it provided the survey analysis and identified Kano categories for CRs with 90% confidence level and calculated their absolute importance values. Finally, it developed four different product definitions that may reflect evolution of a life cycle of an advanced information product line: Basic product, entry-level product, advanced product, and high-end product.

The next chapter provides combined decision models for each product by applying the remaining steps of the methodology for two-level decision analysis. The first level ties DRs to CRs and the second level evaluates alternative data links based on the DRs. As a result, the most appropriate data links to meet customer requirements are identified for each product specification.

CHAPTER IV
COMBINED DECISION MODEL ANALYSIS

This chapter applies the remaining combined model steps (6 to 12) to the GA cockpit weather information systems development problem. The ultimate objective of this test case is to determine the most appropriate data links for these new systems based on customer needs, so that the information system providers can make product development decisions that potentially lead them to market success. To achieve this objective and test the model, a two-level appraoach is applied:

- The first level identifies the importance values of design requirements based on customer requirements, and
- The second level evaluates of the data links that can support the design requirements.

This methodology is then applied to each product level defined in the previous chapter (basic, entry-level, advanced, and high-end products) to determine the most capable data links for each product and to identify the existence of a data link that can support the entire life cycle.

Section 4.1 of this chapter executes the first level model for each product specification by applying steps 6 to 9:

6. Calculating the relative importance values of CRs.
7. Identifying the DR list and CR-DR relationship ratings.
8. Calculating the absolute importance values of DRs.
9. Finding the relative importance of DRs.

As a result, the first level model analysis helps the product developer to decide which DRs are more important than others in meeting customer requirements for the new cockpit weather information system design.

Section 4.2 provides the application of the second level analysis for each product specification via steps 10 to 12 and carries the impact of customer satisfaction to detailed design decisions:

10. Entering the DRs from the previous step to the new "whats" column in the second matrix together with their relative importance values as illustrated in Figure 4.

11. Identifying the new "hows" (data links) and relationship ratings between the data links and DRs.
12. Calculating the total score of the data links.

Accordingly, the second level model provides the product developer the most appropriate data link listing to provide the needed DRs that meet customer requirements. Therefore, the impact of customer satisfaction is carried through to detailed design decisions.

4.1 First Level Model Development

This section starts with the identification of the critical design requirements/attributes of the weather information system that will dictate the performance and ultimately how the customer accepts it. Results of a previous study (Sireli et al, 2001) and expert opinions from two electrical engineers who are knowledgeable on cockpit weather information systems identified a set of basic design requirements. They define the information system in terms of its physical characteristics and architecture:

- *User Data Rate*: Amount of data transferred per second by a communications channel or a computing or storage device.
- *Network Coverage:* Capability of covering enough area where the system can access to weather information.
- *Capacity:* Maximum possible data transfer rate of a communications channel under ideal conditions.
- *Connection Delay:* Time from when a message is ready to be transmitted to the time it receives access to the channel or when the connection is actually established.
- *Message Latency:* Elapsed interval from the time the message was transmitted to the time it was received.
- *Request/Reply Capability:* Capability of providing a two-way communication in flight for weather information.
- *Traffic Information Capability:* Capability of providing weather information via the same data link used for weather information in flight.
- *Position Reporting:* Ability to provide position-based weather information relevant to the current flight position and flight plan.

The next section analyzes the combined models for product definitions, relating these design requirements to the customer requirements classified in Chapter 3, and thus, completes the first level analysis by relating CRs to DRs.

4.1.1 Models for Design Requirements

The CR-DR relationship ratings for the set of design requirements previously selected were identified based on the opinions of the two electrical engineers mentioned in the previous section. Various design requirements have different impacts on the specific product produced, thus, they vary in importance for each of the product definitions formed in the previous chapter. The first level combined models for these four product definitions (basic, entry-level, advanced, and high-end products) are included in tables 16, 17, 18, and 19 respectively. The absolute and relative importance values for CRs and DRs are calculated based on the equations provided in the methodology discussed in Chapter 2 (Table 8), following steps 6 to 9. The paragraphs following these tables provide a comparative summary of DR relative importance values and discuss the related models according to product definitions.

Table 16. First level combined model for the basic product.

Consumer Requirement (CR_i)	*Kano category*	*Absolute Importance of CR_i*	*Relative Importance of CR_i (W_i)*	User Data Rate	Request / Reply Capability	Traffic Info Capability	Capacity	Network Coverage	Latency	Connection Delay	Position Reporting
				Design Requirements (DR_j)							
AIRMETs	I	42.9%	14.9%	1	1	0	1	1	1	1	1
Winds aloft	I	43.7%	15.2%	1	1	0	1	1	1	1	1
Turbulence	I	44.0%	15.3%	1	1	0	1	1	1	1	1
2 x 2 mi - 4 x 4 mi	I	39.1%	13.6%	9	9	0	1	1	9	3	9
10 – 20 minutes	I	40.8%	14.2%	1	9	0	1	1	0	0	0
Text on screen	I	42.0%	14.6%	1	0	0	0	0	1	1	0
Services	I	35.8%	12.4%	9	9	0	1	1	9	3	0
AI_j=Absolute (technical) importance rating of DR_j:				3.08	4.06	0.00	0.85	0.85	2.94	1.38	1.67
RI_j=Relative (technical) importance rating of DR_j:				**0.21**	**0.27**	0.00	0.06	0.06	**0.20**	0.09	0.11

Table 17. First level combined model for the entry-level product.

Consumer Requirement (CR_i)	*Kano category*	*Absolute Importance of CR_i*	*Relative Importance of CR_i (W_i)*	User Data Rate	Request / Reply Capability	Traffic Info Capability	Capacity	Network Coverage	Latency	Connection Delay	Position Reporting
				Design Requirements (DR_j)							
METARs	M	64.7%	9.5%	3	1	0	1	1	3	3	1
TAFs	M	58.1%	8.5%	3	1	0	1	1	3	3	1
Icing	M	62.3%	9.1%	3	1	0	1	1	3	3	1
Convective	M	68.0%	10.0%	3	1	0	1	1	3	3	1
Ceiling/Visibility	M	71.7%	10.5%	3	1	0	1	1	3	3	1
5 x 5 mi - 8 x 8 mi	I	42.0%	6.1%	3	3	0	1	1	3	3	3
5 – 10 minutes	M	54.5%	8.0%	3	1	0	3	3	3	3	0
Symbols on graph	I	48.8%	7.1%	3	1	0	1	1	1	1	0
Thunderstorm	M	86.4%	12.7%	3	0	0	0	0	3	0	0
Icing	M	66.1%	9.7%	3	0	0	0	0	3	0	0
Low visibility	M	60.4%	8.8%	3	0	0	0	0	3	0	0
AI_j=Absolute (technical) importance rating of DR_j:				3.00	1.95	0.00	0.85	0.85	2.86	1.92	0.66
RI_j=Relative (technical) importance rating of DR_j:				**0.25**	**0.16**	0.00	0.07	0.07	**0.24**	**0.16**	0.05

Table 18. First level combined model for the attractive product.

Consumer Requirement (CR_i)	*Kano category*	*Absolute Importance of CR_i*	*Relative Importance of CR_i (W_i)*	User Data Rate	Request / Reply Capability	Traffic Info Capability	Capacity	Network Coverage	Latency	Connection Delay	Position Reporting
				Design Requirements (DR_j)							
METARs	M	64.7%	8.6%	9	1	0	9	1	3	3	9
TAFs	M	58.1%	7.8%	9	1	0	9	1	3	3	9
Icing	M	62.3%	8.3%	9	1	0	9	1	3	3	9
Convective	M	68.0%	9.1%	9	1	0	9	1	3	3	9
Ceiling/Visibility	M	71.7%	9.6%	9	1	0	9	1	3	3	9
9 x 9 mi - 12 x 12 mi	I	43.0%	5.7%	1	0	0	1	1	1	1	0
5 – 10 minutes	M	54.5%	7.3%	3	1	0	3	3	3	3	0
Forecast maps	O	55.5%	7.4%	9	3	0	1	1	9	3	3
Thunderstorm	M	86.4%	11.5%	9	0	0	0	0	9	0	0
Icing	M	66.1%	8.8%	9	0	0	0	0	9	0	0
Heavy precipitation	O	57.8%	7.7%	9	0	0	0	0	9	0	0
Low visibility	M	60.4%	8.1%	9	0	0	0	0	9	0	0
AI_j=Absolute (technical) importance rating of DR_j				8.10	3.98	0.00	4.26	0.78	5.50	1.80	4.13
RI_j=Relative (technical) importance rating of DR_j				**0.28**	**0.14**	0.00	**0.15**	0.03	**0.19**	0.06	**0.14**

Table 19. First level combined model for the high-end product.

Consumer Requirement (CR_i)	*Kano category*	*Absolute Importance of CR_i*	*Relative Importance of CR_i (W_i)*	User Data Rate	Request / Reply Capability	Traffic Info Capability	Capacity	Network Coverage	Latency	Connection Delay	Position Reporting
				Design Requirements (DR_j)							
METARs	M	64.7%	7.3%	9	1	0	9	1	9	9	9
TAFs	M	58.1%	6.6%	9	1	0	9	1	9	9	9
Icing	M	62.3%	7.0%	9	1	0	9	1	9	9	9
Convective	M	68.0%	7.7%	9	1	0	9	1	9	9	9
Ceiling/Visibility	M	71.7%	8.1%	9	1	0	9	1	9	9	9
9 x 9 mi - 12 x 12 mi	I	43.0%	4.9%	1	0	0	1	1	1	1	0
0 – 5 minutes	A	59.4%	6.7%	9	1	0	3	3	9	9	3
Radar loop animation	O	71.2%	8.0%	9	9	0	1	1	9	9	9
Thunderstorm	M	86.4%	9.8%	9	0	0	0	0	9	0	0
Icing	M	66.1%	7.5%	9	0	0	0	0	9	0	0
Heavy precipitation	O	57.8%	6.5%	9	0	0	0	0	9	0	0
Low visibility	M	60.4%	6.8%	9	0	0	0	0	9	0	0
Turbulence	A	53.6%	6.1%	9	0	0	0	0	9	0	0
Traffic	A	63.0%	7.1%	0	0	9	0	0	0	0	0
AI_j=Absolute (technical) importance rating of DR_j				7.97	3.91	0.64	3.63	0.70	7.97	4.68	4.23
RI_j=Relative (technical) importance rating of DR_j				**0.24**	**0.12**	0.02	0.11	0.02	**0.24**	**0.14**	**0.13**

Table 20 includes a comparative summary of the DR relative importance ratings in descending order for each product definition and Figure 7 provides graphs of the DR rankings based on product specifications for better illustration. These provide the output of the first level of the combined model.

Table 20. Relative importance ratings of the DRs for product definitions (in descending order).

	BASIC PRODUCT		ENTRY-LEVEL PRODUCT		ADVANCED PRODUCT		HIGH-END PRODUCT	
DR #	**DR list**	**Relative importance of DRs (RI_j)**	**DR list**	**Relative importance of DRs (RI_j)**	**DR list**	**Relative importance of DRs (RI_j)**	**DR list**	**Relative importance of DRs (RI_j)**
1	Request/reply capability	**0.27**	User data rate	**0.25**	User data rate	**0.28**	User data rate	**0.24**
2	User data rate	**0.21**	Latency	**0.24**	Latency	**0.19**	Latency	**0.24**
3	Latency	**0.20**	Request/reply capability	**0.16**	Capacity	**0.15**	Connection delay	**0.14**
4	Position reporting	0.11	Connection delay	**0.16**	Request/reply capability	**0.14**	Position reporting	**0.13**
5	Connection delay	0.09	Capacity	0.07	Position reporting	**0.14**	Request/reply capability	**0.12**
6	Capacity	0.06	Network coverage	0.07	Connection delay	0.06	Capacity	0.11
7	Network coverage	0.06	Position reporting	0.05	Network coverage	0.03	Traffic info capability	0.02
8	Traffic info capability	0.00	Traffic info capability	0.00	Traffic info capability	0.00	Network coverage	0.02

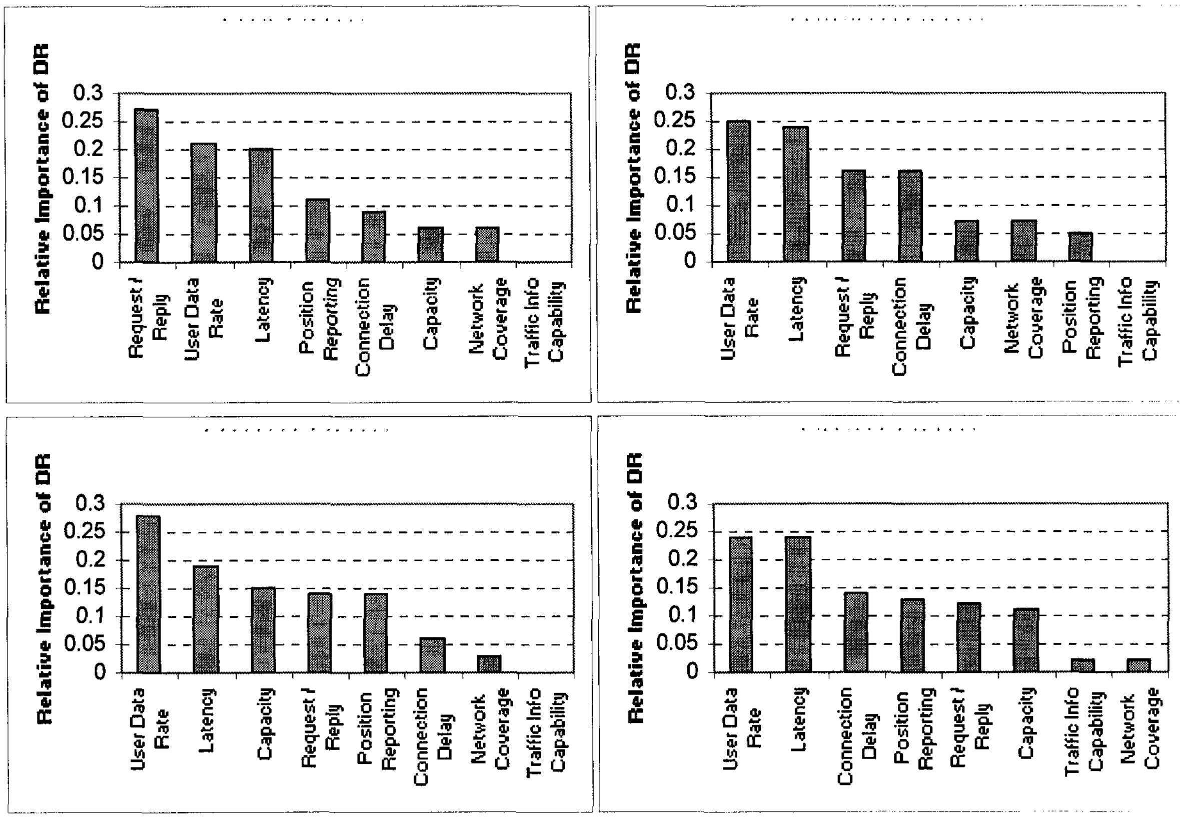

Figure 7. Comparative illustration of DR importance values for product definitions.

The comparative results in Table 20 and Figure 7 provide the output of the first level of the combined model and the following conclusions can be made for each product definition:

Basic Product: The relative importance ratings indicate that request/reply capability (0.27) is the most important technical characteristic for the basic product to meet customer requirements. User data rate (0.21) and latency (0.20) follow it with relative importance values 0.21 and 0.20 respectively. Position reporting, connection delay, capacity, network coverage and traffic information capability are the remaining DRs in descending order.

Entry-level Product: According to the output of the first level model, user data rate (0.25) is the most important DR for developing the entry-level product. Latency (0.24) is second while request/reply capability (0.16) and connection delay (0.16) share the third place. Capacity, network coverage, position reporting and traffic information capability follow them in descending order.

Advanced Product: User data rate (0.28) is the most important technical characteristic for the advanced product to meet customer needs and it is followed by latency (0.19), capacity (0.15), request/reply capability (0.14) and position reporting (0.14). Connection delay, network coverage and traffic information capability are the remaining DRs in descending order.

High-end Product: User data rate (0.24) and latency (0.24) are equally important DRs for developing the high-end product. Connection delay (0.14), position reporting (0.13) and request/reply capability (0.12) follows them, and capacity, traffic information capability and network coverage are the other DRs in descending order.

This section related the importance values of DRs to the product definitions, and consequently completed the first level analysis of the combined model. According to the results of the first level analysis, user data rate and latency are among the most important technical characteristics for all product definitions and will have a significant impact throughout the product life cycle. The rank-orders of other DRs change according to product specification. These results are used in the second level analysis of the model to achieve the ultimate outcome: The most appropriate data link list for each product definition.

Section 4.2 provides the application of the second level analysis for each product specification by executing the model development steps 10 to 12.

4.2 Second Level Model Development

Second level execution of the combined model involves evaluating the performances of the various data links against the identified design requirements. The relative importance values of the DRs were calculated in the previous section. This section assesses the candidate technologies and makes recommendations.

4.2.1 Data Links

The results of a previous study (Sireli et al, 2001), the opinions of two NASA aviation managers, and the recommendations of two electrical engineers (who have expertise on weather information systems) were combined to identify a set of candidate data links that may potentially support the major design requirements of future weather information systems. The data links considered are:

- ACARS (Aircraft Communication Addressing and Reporting System)
- VDL-2 (Very high frequency – VHF – Digital Link – Mode 2)
- VDL-B (VHF Digital Link – Broadcast)
- VDL-3 (VHF Digital Link – Mode 3)
- VDL-4 (VHF Digital Link – Mode 4)
- UAT (Universal Access Transceiver)
- Mode S
- Aircell
- EchoFlight (Low Earth Orbit – LEO – Satellite)
- WSI Inflight (Geo-synchronous – GEO – Satellite)

The next section evaluates these candidate technologies based on the design requirements summarized in Table 20 for each product definition.

4.2.2 Models for Data Links

The data links were scored against the design requirements based on a redefined 9-3-1-0 scale according to opinions of the same experts (Table 20):

- 9 High performance / High availability
- 3 Moderate performance / Restricted availability
- 1: Poor Performance / Insufficient availability
- 0: No provision

The second level combined models for the product definitions (basic, entry-level, advanced, and high-end products) are included in tables 21, 22, 23, and 24 respectively. The total scores of the data links are calculated based on the equations provided in the methodology section of Chapter 2 (Table 8, following steps 10 to 12). The paragraphs following these tables provide a comparative summary of the data links and discuss the relationships between their second level models and the product definitions.

Table 21. Second level combined model for the basic product.

		Data Links									
DRs	**RIj=Relative importance of DRs**	ACARS	VDL-2	VDL-B	VDL-3	VDL-4	UAT	Mode S	Aircell	EchoFlight (LEO Satellite)	WSI Inflight (GEO Satellite)
User Data Rate	0.21	1	3	9	3	3	9	1	3	3	9
Request / Reply Capability	0.27	9	9	0	9	3	0	1	9	9	0
Traffic Info Capability	0.00	1	1	3	1	9	9	9	0	1	3
Capacity	0.06	1	3	9	3	3	9	1	1	1	9
Network Coverage	0.06	3	3	3	3	3	3	3	3	9	9
Latency	0.20	1	1	3	3	3	9	3	3	1	1
Connection Delay	0.09	1	3	9	3	9	9	1	3	1	1
Position Reporting	0.11	9	3	0	3	9	9	9	3	9	0
	Total score:	4.21	4.25	3.99	**4.64**	4.23	**6.19**	2.41	**4.53**	**4.97**	3.19

Table 22. Second level combined model for the entry-level product.

		Data Links									
DRs	**RIj=Relative importance of DRs**	ACARS	VDL-2	VDL-B	VDL-3	VDL-4	UAT	Mode S	Aircell	EchoFlight (LEO Satellite)	WSI Inflight (GEO Satellite)
User Data Rate	0.25	1	3	9	3	3	9	1	3	3	9
Request / Reply Capability	0.16	9	9	0	9	3	0	1	9	9	0
Traffic Info Capability	0.00	1	1	3	1	9	9	9	0	1	3
Capacity	0.07	1	3	9	3	3	9	1	1	1	9
Network Coverage	0.07	3	3	3	3	3	3	3	3	9	9
Latency	0.24	1	1	3	3	3	9	3	3	1	1
Connection Delay	0.16	1	3	9	3	9	9	1	3	1	1
Position Reporting	0.05	9	3	0	3	9	9	9	3	9	0
	Total score:	2.87	3.49	**5.22**	3.97	**4.28**	**7.13**	2.05	3.83	3.78	3.89

Table 23. Second level combined model for the advanced product.

		Data Links									
DRs	**RIj=Relative importance of DRs**	ACARS	VDL-2	VDL-B	VDL-3	VDL-4	UAT	Mode S	Aircell	EchoFlight (LEO Satellite)	WSI Inflight (GEO Satellite)
User Data Rate	0.28	1	3	9	3	3	9	1	3	3	9
Request / Reply Capability	0.14	9	9	0	9	3	0	1	9	9	0
Traffic Info Capability	0.00	1	1	3	1	9	9	9	0	1	3
Capacity	0.15	1	3	9	3	3	9	1	1	1	9
Network Coverage	0.03	3	3	3	3	3	3	3	3	9	9
Latency	0.19	1	1	3	3	3	9	3	3	1	1
Connection Delay	0.06	1	3	9	3	9	9	1	3	1	1
Position Reporting	0.14	9	3	0	3	9	9	9	3	9	0
	Total score:	3.33	3.45	**5.12**	3.84	**4.25**	**7.58**	2.60	3.54	4.06	**4.40**

Table 24. Second level combined model for the high-end product.

DRs	RIj=Relative importance of DRs	ACARS	VDL-2	VDL-B	VDL-3	VDL-4	UAT	Mode S	Aircell	EchoFlight (LEO Satellite)	WSI Inflight (GEO Satellite)
		Data Links									
User Data Rate	0.24	1	3	9	3	3	9	1	3	3	9
Request / Reply Capability	0.12	9	9	0	9	3	0	1	9	9	0
Traffic Info Capability	0.02	1	1	3	1	9	9	9	0	1	3
Capacity	0.11	1	3	9	3	3	9	1	1	1	9
Network Coverage	0.02	3	3	3	3	3	3	3	3	9	9
Latency	0.24	1	1	3	3	3	9	3	3	1	1
Connection Delay	0.14	1	3	9	3	9	9	1	3	1	1
Position Reporting	0.13	9	3	0	3	9	9	9	3	9	0
	Total score:	2.97	3.18	**5.17**	3.66	**4.70**	**7.83**	2.67	3.42	3.57	3.71

Table 25 summarizes the outcomes of the second level models for product definitions in descending order, and Figure 8 illustrates the comparative analysis of the data link total scores depending on product level. These results present the final outcome of the combined model for each product definition.

Table 25. Total scores of the data links for product definitions (in descending order).

	BASIC PRODUCT		ENTRY-LEVEL PRODUCT		ADVANCED PRODUCT		HIGH-END PRODUCT	
DL #	**Data links**	**Total score**	**Data links**	**Total score**	**Data links**	**Total score**	**Data links**	**Total score**
1	UAT	6.19	UAT	7.13	UAT	7.58	UAT	7.83
2	EchoFl.*	4.97	VDL-B	5.22	VDL-B	5.12	VDL-B	5.17
3	VDL-3	4.64	VDL-4	4.28	WSI Infl.	4.40	VDL-4	4.70
4	Aircell	4.53	VDL-3	3.97	VDL-4	4.25	WSI Inf.	3.71
5	VDL-2	4.25	WSI Inf.	3.89	EchoFl.	4.06	VDL-3	3.66
6	VDL-4	4.23	Aircell	3.83	VDL-3	3.84	EchoFl.	3.57
7	ACARS	4.21	EchoFl.	3.78	Aircell	3.54	Aircell	3.42
8	VDL-B	3.99	VDL-2	3.49	VDL-2	3.45	VDL-2	3.18
9	WSI Inf.*	3.19	ACARS	2.87	ACARS	3.33	ACARS	2.97
10	Mode S	2.41	Mode S	2.05	Mode S	2.6	Mode S	2.67

* Echo Fl.: EchoFlight (LEO Satellite), WSI Inf.: WSI Inflight (GEO Satellite)

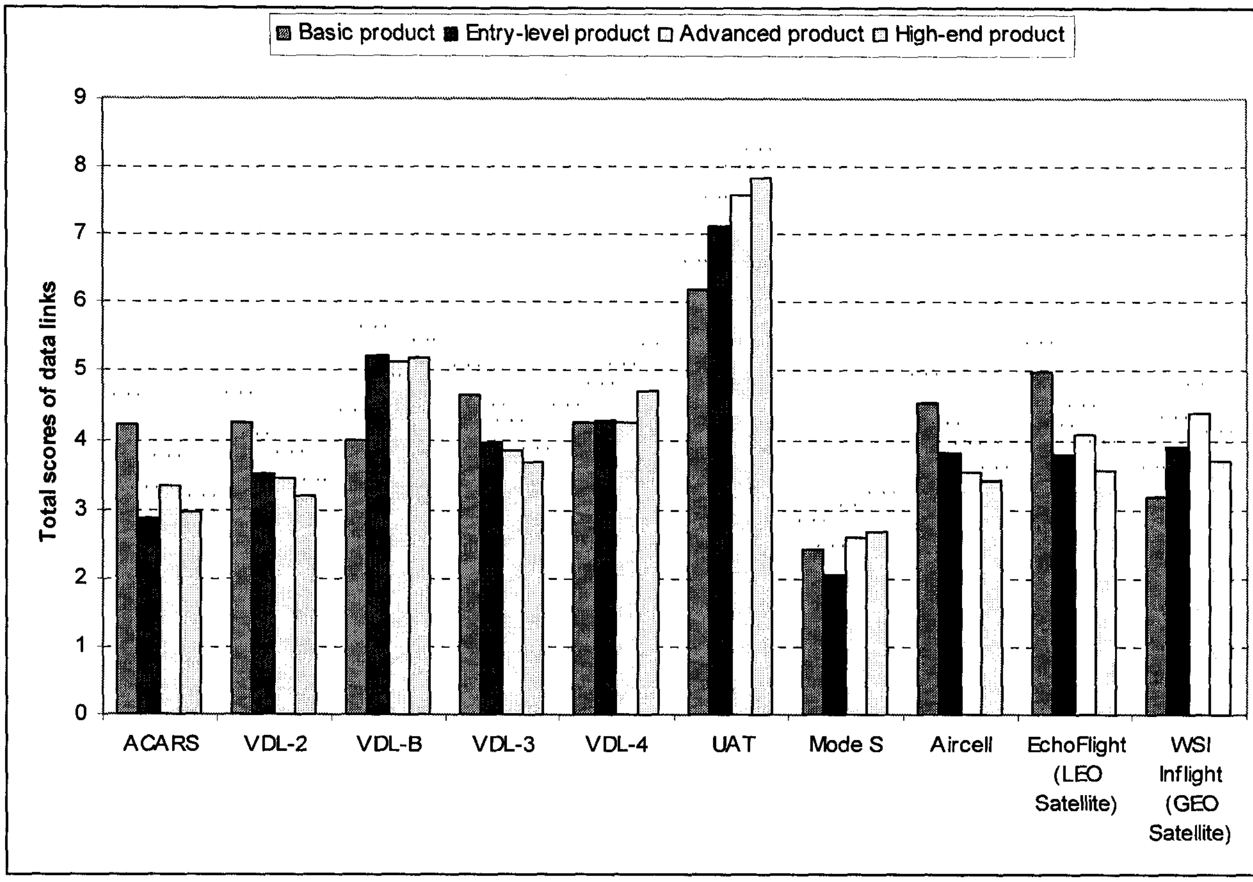

Figure 8. Data links in relation to product definitions.

According to the comparative results in Table 25 and Figure 8, the following conclusions can be reached for each product definition:

Basic Product: The total scores indicate that UAT (6.19) is the most capable data link to support the DRs. EchoFlight (LEO Satellite), VDL-3 and Aircell follow it with 4.97, 4.64 and 4.53 respectively. VDL-2, VDL-4, ACARS, VDL-B, WSI Inflight (GEO Satellite) and Mode S are the remaining data links in descending order.

Entry-level Product: UAT (7.13) is the most appropriate data link for developing the entry-level product. VDL-B (5.22) and VDL-4 (4.28) are also capable data links to provide the DRs. VDL-3, WSI Inflight (GEO Satellite), Aircell, EchoFlight (LEO Satellite), VDL-2, ACARS, and Mode S follow them in descending order.

Advanced Product: UAT (7.58) has the highest score for the advanced product development. It is followed by VDL-B (5.12), WSI Inflight (GEO Satellite) (4.40) and

VDL-4 (4.25) and the remaining data links are EchoFlight (LEO Satellite), VDL-3, Aircell, VDL-2, ACARS and Mode S in descending order.

High-end Product: The results of the combined model indicate that UAT (7.83) is the most capable data link to provide the DRs for the high-end product. VDL-B (5.17) and VDL-4 (4.70) are also appropriate data links for developing this product. WSI Inflight (GEO Satellite), VDL-3, EchoFlight (LEO Satellite), Aircell, VDL-2, ACARS and Mode S follow them in descending order.

This section demonstrated use of the second level analysis to provide the total score rankings for the candidate data links, and achieved the goal of the application exercise. It identified UAT as the most capable data link to support each product specified in this study. In essence, this data link is capable of supporting the entire life cycle. While the rank-orders of other data links change according to product specification, Modes S is the least appropriate data link to support any of these products and ACARS also has low scores in general. These results are consistent with the outcomes of another research study (Lockheed Martin, 1999), which employed a standard technical analysis to conclude that UAT was potentially very promising to uplink graphical weather data to the GA aircraft and Mode S was not capable of this task.

4.3 Summary

This chapter completed the testing of the combined model methodology (developed in Chapter 2) on the cockpit weather information system development problem, and suggested data links that can potentially support the design requirements (selected in Section 4.1) that meet the customer requirements (identified in Chapter 3). Consequently, the customer's voice was carried through to the identification of detailed design characteristics. Thus, the model test demonstrated capability to achieve the main objective of this research: to provide IS organizations with tools to make product development decisions that can reflect customer needs.

Based on identified design requirements, this chapter tested the combined models on the four different product definitions. The models identified the most important design requirements for each product by following the model application steps 6-9 developed in Chapter 2. User data rate, request/reply capability, latency, connection delay and position reporting were classified as the most important DRs depending on the product specification.

Next, candidate technologies were identified and methodology steps 10-12 were employed to estimate and compare the overall performance of alternative data links relative to the design requirements. This method identified UAT as the most capable data link candidate for the weather information product and its required technical characteristics. VDL-B, VDL-4, VDL-3, EchoFlight (LEO Satellite), WSI Inflight (GEO Satellite) and Aircell were other capable data links depending on the product definition.

The testing of the combined model developed in this research demonstrated that the model has the ability to distinguish product evolution and to support this progression. Employing this model added value to the problem of developing innovative GA cockpit weather information systems. It provided directions to engineering managers in weather information system organizations for developing different levels of products instead of simply identifying appropriate data links for a new system.

The next chapter includes model validation and sensitivity analysis before discussing the conclusions of this research.

CHAPTER V
MODEL VALIDATION

Validation examines whether the conceptual model is an accurate representation of the system under study. If a model is valid, then the decisions made using the model should be similar to those that would be made by physically experimenting with the actual system. According to Law and Kelton (1991), a model's validity can be achieved by:

- *Developing the model with high face validity.*
- *Performing sensitivity analysis.*
- *Identifying the accuracy of the output data.*

The following sections discuss the validation of the four combined models developed for the GA cockpit weather information systems based on these points.

5.1 Face Validity as a Product Development Model

The primary objective face validity is to assure that the model under development is reasonable to people who are knowledgeable about the system under study. Expert opinions are essential to identify the most critical components of a complex system and how they inter-relate, particularly if the system does not currently exist (Law and Kelton, 1991).

In a complex product development model, face validity must be integrated at each step. To achieve this goal, this study implemented a collaborative approach at every development stage of the combined model developed in Chapters 3 and 4.

For the identification of customer requirements and preparation of the customer survey, a focus group was assembled that included six pilots from varied professions, two NASA aviation managers with expertise on GA cockpit weather information systems, two electrical engineers who are knowledgeable on graphical weather products and weather data links, and two engineering managers who developed the model concept.

This study utilized the opinions of two electrical engineers who are knowledgeable on cockpit weather information systems for the selection of DRs and CR-DR relationship ratings in the first level model analysis.

In the second level analysis, two NASA aviation managers and two electrical engineers who are knowledgeable on weather information systems provided inputs for the identification of candidate data links and their performance ratings.

Consequently, the combined model had high face validity within the collaborative group who helped with developing it. The following section discusses the sensitivity analysis of the model.

5.2 Sensitivity Analysis

Sensitivity analysis determines if the output changes significantly when the value of an input parameter is changed. If the output is sensitive to a particular input of the model, then that aspect must be modeled carefully (Law and Kelton, 1991). Customer data may include errors due to data collection methods, and fairly small changes in these input data may affect the output of the model (Gustafsson, 2000; Thomas, 1993). The main inputs to the weather information system model are the customer requirements. The final outputs are the total scores of alternative data links. Therefore, the sensitivity of these outputs to changes in customer requirements should be examined.

The four product models encompass a large number of parameters. Law and Kelton (1991) recommend that if the number of model inputs is high, then the most important factors that might be capable of changing the outcome significantly should be selected for sensitivity analysis. For this reason, two highly rated inputs were selected for each model (basic, entry-level, advanced and high-end), and the output was observed according to –10%, +10%, -20% and +20% change in these inputs. The results are discussed below according to product definitions.

Basic Product:

The two important inputs selected for sensitivity analysis of the basic product model are "additional services" and "grid size (2x2 – 4x4 miles)" since these are the inputs with high relationship ratings in the house of quality. Thus, the absolute importance values of each input was changed between –20% and 20% of the original value while the other inputs remained constant as indicated in Table 26.

Table 26. Input changes for basic product.

Additional Services				
-20%	-10%	0%	+10%	+20%
28.6%	32.2%	35.8%	39.4%	43.0%
Grid Size (2x2 – 4x4 miles)				
-20%	-10%	0%	+10%	+20%
31.3%	35.2%	39.1%	43.0%	46.9%

Based on the changes in the absolute importance values of the "additional services", the data link list is observed as shown in Table 27:

For –10%, +10% and +20% input change: Minor changes occur in the data link scores (in the second decimal point), but the data link importance order does not change. Therefore, it can be concluded that the basic product model is insensitive to these input changes.

For –20% input change: Minimal changes occur in the data link scores (in the second decimal point). In the original data link list (0%), VDL-2, VDL-4 and ACARS are in the 5th, 6th and 7th place respectively. However, when the "additional services" input is changed –20%, these data links change places as indicated in the shaded areas of Table 27. Although the model shows slight sensitivity to the –20% input change, this does not affect the order of the most appropriate data links (UAT, EchoFlight, etc.) since the output score changes occur in less important data links.

Table 27. Observation of output based on the changes in additional services.

BASIC PRODUCT										
	-20%		-10%		0%		+10%		+20%	
DL #	Data links	Total score	Data links	Total score	Data links	Total score	Data links	Total score	Data links	Total score
1	UAT	6.18	UAT	6.19	UAT	6.19	UAT	6.19	UAT	6.19
2	EchoFl.	5.02	EchoFl.	4.99	EchoFl.	4.97	EchoFl.	4.95	EchoFl.	4.92
3	VDL-3	4.64	VDL-3	4.64	VDL-3	4.64	VDL-3	4.64	VDL-3	4.65
4	Aircell	4.52	Aircell	4.53	Aircell	4.53	Aircell	4.53	Aircell	4.53
5	VDL-4	4.27	VDL-2	4.25	VDL-2	4.25	VDL-2	4.24	VDL-2	4.24
6	ACARS	4.26	VDL-4	4.25	VDL-4	4.23	VDL-4	4.22	VDL-4	4.20
7	VDL-2	4.25	ACARS	4.23	ACARS	4.21	ACARS	4.19	ACARS	4.16
8	VDL-B	3.95	VDL-B	3.97	VDL-B	3.99	VDL-B	4.00	VDL-B	4.02
9	WSI Inf.	3.18	WSI Inf.	3.19	WSI Inf.	3.19	WSI Inf.	3.20	WSI Inf.	3.21
10	Mode S	2.46	Mode S	2.43	Mode S	2.41	Mode S	2.39	Mode S	2.37

Based on the changes in the absolute importance values of the "grid size (2x2 – 4x4 miles)", the data link list is observed as shown in Table 28:

For –10% and –20% input change: Minor changes occur in the data link scores (second decimal place), but the data link rank order does not change.

For +10% input change: Minimal changes occur in the data link scores (in the second decimal point) and VDL-4 and VDL-2 switch places compared to the original data (0%) as indicated in the shaded areas of Table 28. However, these two data links are among the less capable data links compared to UAT, EchoFlight, etc. Therefore, although the model shows slight sensitivity to a +10% input change, its impact on the most important outputs is not strong.

For +20% input change: Minor changes occur in the data link scores (in the second decimal point) and VDL-4, ACARS and VDL-2 change places as shown in the shaded portions of Table 28. However, these three are not among the strongest data links, thus, +20% input change does not cause a vital change in the model output.

Table 28. Observation of output based on the changes in grid size.

BASIC PRODUCT										
	-20%		-10%		0%		+10%		+20%	
DL #	Data links	Total score	Data links	Total score	Data links	Total score	Data links	Total score	Data links	Total score
1	UAT	6.13	UAT	6.16	UAT	6.19	UAT	6.21	UAT	6.24
2	EchoFl.	4.95	EchoFl.	4.96	EchoFl.	4.97	EchoFl.	4.98	EchoFl.	4.98
3	VDL-3	4.67	VDL-3	4.66	VDL-3	4.64	VDL-3	4.63	VDL-3	4.62
4	Aircell	4.55	Aircell	4.54	Aircell	4.53	Aircell	4.52	Aircell	4.51
5	VDL-2	4.28	VDL-2	4.26	VDL-2	4.25	VDL-4	4.25	VDL-4	4.27
6	VDL-4	4.19	VDL-4	4.21	VDL-4	4.23	VDL-2	4.23	ACARS	4.23
7	ACARS	4.18	ACARS	4.19	ACARS	4.21	ACARS	4.22	VDL-2	4.22
8	VDL-B	4.02	VDL-B	4.00	VDL-B	3.99	VDL-B	3.97	VDL-B	3.96
9	WSI Inf.	3.23	WSI Inf.	3.21	WSI Inf.	3.19	WSI Inf.	3.18	WSI Inf.	3.16
10	Mode S	2.35	Mode S	2.38	Mode S	2.41	Mode S	2.44	Mode S	2.47

Entry-level Product:

The two important inputs selected for the analysis of the entry-level product model are grid size (5x5 – 8x8 miles)" and "weather update interval (5-10 minutes)" since these are the inputs with high scores for relationship ratings in the house of quality of the basic product model (see Table 11). Thus, the absolute importance values of each input was changed between –20% and 20% of the original value while the other inputs remained constant as indicated in Table 29.

Table 29. Input changes for entry-level product.

Grid Size (2x2 – 4x4 miles)				
-20%	-10%	0%	+10%	+20%
33.6%	37.8%	42.0%	46.2%	50.4%
Weather Update Interval (5-10 minutes)				
-20%	-10%	0%	+10%	+20%
43.6%	49.1%	54.5%	60.0%	65.4%

Based on the changes in the absolute importance values of the "grid size" and "weather update interval", minor changes are observed in the second decimal place of the data link total scores, which do not affect the rank orders (Table 30 and Table 31). Since there are no significant changes in the output, it can be concluded that the entry-level model is insensitive to the changes in the absolute importance value of these inputs.

Table 30. Observation of output based on the changes in grid size.

ENTRY-LEVEL PRODUCT										
	-20%		-10%		0%		+10%		+20%	
DL #	Data links	Total score	Data links	Total score	Data links	Total score	Data links	Total score	Data links	Total score
1	UAT	**7.13**	UAT	**7.13**	UAT	**7.13**	UAT	**7.13**	UAT	**7.13**
2	VDL-B	**5.20**	VDL-B	**5.23**	VDL-B	**5.22**	VDL-B	**5.23**	VDL-B	**5.20**
3	VDL-4	**4.29**	VDL-4	**4.28**	VDL-4	**4.28**	VDL-4	**4.28**	VDL-4	**4.30**
4	VDL-3	3.98	VDL-3	3.97	VDL-3	3.97	VDL-3	3.96	VDL-3	3.97
5	WSI Inf.	3.86	WSI Inf.	3.91	WSI Inf.	3.89	WSI Inf.	3.91	WSI Inf.	3.88
6	Aircell	3.84	Aircell	3.82	Aircell	3.83	Aircell	3.82	Aircell	3.83
7	EchoFl.	3.79	EchoFl.	3.78	EchoFl.	3.78	EchoFl.	3.78	EchoFl.	3.80
8	VDL-2	3.50	VDL-2	3.49	VDL-2	3.49	VDL-2	3.49	VDL-2	3.50
9	ACARS	2.89	ACARS	2.86	ACARS	2.87	ACARS	2.86	ACARS	2.88
10	Mode S	2.06	Mode S	2.04	Mode S	2.05	Mode S	2.05	Mode S	2.06

Table 31. Observation of output based on the changes in weather update interval.

ENTRY-LEVEL PRODUCT										
	-20%		-10%		0%		+10%		+20%	
DL #	Data links	Total score	Data links	Total score	Data links	Total score	Data links	Total score	Data links	Total score
1	UAT	**7.13**	UAT	**7.13**	UAT	**7.13**	UAT	**7.13**	UAT	**7.13**
2	VDL-B	**5.23**	VDL-B	**5.21**	VDL-B	**5.22**	VDL-B	**5.21**	VDL-B	**5.24**
3	VDL-4	**4.27**	VDL-4	**4.28**	VDL-4	**4.28**	VDL-4	**4.29**	VDL-4	**4.28**
4	VDL-3	3.96	VDL-3	3.97	VDL-3	3.97	VDL-3	3.97	VDL-3	3.95
5	WSI Inf.	3.91	WSI Inf.	3.88	WSI Inf.	3.89	WSI Inf.	3.89	WSI Inf.	3.93
6	Aircell	3.82	Aircell	3.83	Aircell	3.83	Aircell	3.83	Aircell	3.81
7	EchoFl.	3.77	EchoFl.	3.79	EchoFl.	3.78	EchoFl.	3.79	EchoFl.	3.78
8	VDL-2	3.49	VDL-2	3.50	VDL-2	3.49	VDL-2	3.50	VDL-2	3.48
9	ACARS	2.85	ACARS	2.88	ACARS	2.87	ACARS	2.88	ACARS	2.85
10	Mode S	2.04	Mode S	2.05	Mode S	2.05	Mode S	2.06	Mode S	2.04

The same sensitivity analysis method was applied to the advanced model by changing the absolute importance value of the "ceiling/visibility" and "forecast maps" inputs, and to the high-end product models for "ceiling/visibility" and "radar loop animation" requirements. Similar to the entry-level model, no significant changes in the output was observed as indicated in Table 32, 33, 34, and 35 respectively.

Table 32. Observation of output based on the changes in ceiling/visibility.

ADVANCED PRODUCT										
	-20%		-10%		0%		+10%		+20%	
DL #	Data links	Total score	Data links	Total score	Data links	Total score	Data links	Total score	Data links	Total score
1	UAT	7.56	UAT	7.57	UAT	7.58	UAT	7.59	UAT	7.60
2	VDL-B	5.14	VDL-B	5.14	VDL-B	5.12	VDL-B	5.13	VDL-B	5.14
3	WSI Infl.	4.41	WSI Infl.	4.39	WSI Infl.	4.40	WSI Infl.	4.41	WSI Infl.	4.41
4	VDL-4	4.23	VDL-4	4.24	VDL-4	4.25	VDL-4	4.26	VDL-4	4.26
5	EchoFl.	4.06	EchoFl.	4.06	EchoFl.	4.06	EchoFl.	4.06	EchoFl.	4.06
6	VDL-3	3.85	VDL-3	3.85	VDL-3	3.84	VDL-3	3.83	VDL-3	3.82
7	Aircell	3.56	Aircell	3.55	Aircell	3.54	Aircell	3.53	Aircell	3.52
8	VDL-2	3.46	VDL-2	3.46	VDL-2	3.45	VDL-2	3.45	VDL-2	3.44
9	ACARS	3.33	ACARS	3.33	ACARS	3.33	ACARS	3.33	ACARS	3.33
10	Mode S	2.58	Mode S	2.59	Mode S	2.60	Mode S	2.60	Mode S	2.61

Table 33. Observation of output based on the changes in forecast maps.

ADVANCED PRODUCT										
	-20%		-10%		0%		+10%		+20%	
DL #	Data links	Total score	Data links	Total score	Data links	Total score	Data links	Total score	Data links	Total score
1	UAT	7.58	UAT	7.58	UAT	7.58	UAT	7.58	UAT	7.58
2	VDL-B	5.12	VDL-B	5.12	VDL-B	5.12	VDL-B	5.12	VDL-B	5.12
3	WSI Infl.	4.41	WSI Infl.	4.40	WSI Infl.	4.40	WSI Infl.	4.39	WSI Infl.	4.39
4	VDL-4	4.25	VDL-4	4.25	VDL-4	4.25	VDL-4	4.25	VDL-4	4.25
5	EchoFl.	4.07	EchoFl.	4.06	EchoFl.	4.06	EchoFl.	4.06	EchoFl.	4.05
6	VDL-3	3.84	VDL-3	3.84	VDL-3	3.84	VDL-3	3.84	VDL-3	3.83
7	Aircell	3.54	Aircell	3.54	Aircell	3.54	Aircell	3.54	Aircell	3.54
8	VDL-2	3.46	VDL-2	3.46	VDL-2	3.45	VDL-2	3.45	VDL-2	3.45
9	ACARS	3.34	ACARS	3.33	ACARS	3.33	ACARS	3.33	ACARS	3.32
10	Mode S	2.60	Mode S	2.60	Mode S	2.60	Mode S	2.60	Mode S	2.60

Table 34. Observation of output based on the changes in ceiling/visibility.

HIGH-END PRODUCT										
	-20%		-10%		0%		+10%		+20%	
DL #	Data links	Total score	Data links	Total score	Data links	Total score	Data links	Total score	Data links	Total score
1	UAT	7.81	UAT	7.82	UAT	7.83	UAT	7.84	UAT	7.85
2	VDL-B	5.16	VDL-B	5.17	VDL-B	5.17	VDL-B	5.18	VDL-B	5.19
3	VDL-4	4.68	VDL-4	4.69	VDL-4	4.70	VDL-4	4.70	VDL-4	4.71
4	WSI Inf.	3.71	WSI Inf.	3.71	WSI Inf.	3.71	WSI Inf.	3.72	WSI Inf.	3.72
5	VDL-3	3.67	VDL-3	3.66	VDL-3	3.66	VDL-3	3.65	VDL-3	3.65
6	EchoFl.	3.58	EchoFl.	3.57	EchoFl.	3.57	EchoFl.	3.56	EchoFl.	3.56
7	Aircell	3.44	Aircell	3.43	Aircell	3.42	Aircell	3.42	Aircell	3.41
8	VDL-2	3.19	VDL-2	3.19	VDL-2	3.18	VDL-2	3.18	VDL-2	3.17
9	ACARS	2.98	ACARS	2.97	ACARS	2.97	ACARS	2.97	ACARS	2.97
10	Mode S	2.67	Mode S	2.67	Mode S	2.67	Mode S	2.67	Mode S	2.67

Table 35. Observation of output based on the changes in radar loop animation.

HIGH-END PRODUCT										
	-20%		-10%		0%		+10%		+20%	
DL #	Data links	Total score	Data links	Total score	Data links	Total score	Data links	Total score	Data links	Total score
1	UAT	7.85	UAT	7.84	UAT	7.83	UAT	7.83	UAT	7.82
2	VDL-B	5.19	VDL-B	5.18	VDL-B	5.17	VDL-B	5.16	VDL-B	5.15
3	VDL-4	4.68	VDL-4	4.69	VDL-4	4.70	VDL-4	4.70	VDL-4	4.71
4	WSI Inf.	3.74	WSI Inf.	3.73	WSI Inf.	3.71	WSI Inf.	3.70	WSI Inf.	3.69
5	VDL-3	3.65	VDL-3	3.65	VDL-3	3.66	VDL-3	3.66	VDL-3	3.67
6	EchoFl.	3.54	EchoFl.	3.56	EchoFl.	3.57	EchoFl.	3.58	EchoFl.	3.59
7	Aircell	3.41	Aircell	3.42	Aircell	3.42	Aircell	3.43	Aircell	3.44
8	VDL-2	3.17	VDL-2	3.18	VDL-2	3.18	VDL-2	3.19	VDL-2	3.20
9	ACARS	2.94	ACARS	2.96	ACARS	2.97	ACARS	2.98	ACARS	3.00
10	Mode S	2.66	Mode S	2.67	Mode S	2.67	Mode S	2.67	Mode S	2.67

Consequently, although the basic model shows slight sensitivity to the changes in the absolute importance values of grid size and additional services, all four models applied to the weather information system development provided robust outputs.

5.3 Accuracy of the Output

The most definitive test of a model's validity is establishing that its output closely resembles the output that would be expected from the actual system (Law and Kelton, 1991). If there is not an existing system similar to the proposed system, it is necessary to have system experts review the model output data for reasonableness. This situation fits the cockpit weather information system test s since these products do not exist with all characteristics discussed in this study. There are two main outputs of the product development model:

1. Product definitions (basic, entry-level, advanced, and high-end) based on customer requirements and the Kano categories assigned to them.
2. Data link scores that enable quantitative ranking of technologies according to their capabilities to meet product specifications.

These two outputs were subjected to validation via two different surveys:

- An expert survey for the validation of the product definitions.
- A second expert survey for the validation of the data link scores.

Product Validation Survey:

This survey (in Appendix B) included 4 questions about the reasonableness of the feature combinations that characterize the basic, entry-level, advanced and high-end products. The survey offered 5 options to the participants for each question (5: very reasonable, 4: reasonable, 3: somewhat reasonable, 2: neutral, and 0: not reasonable). It produced 10 responses from GA pilots, and the results are given in Table 36. Since the sample size was small, a t-distribution mean test at the 90% confidence along with a 90% confidence interval for the mean (Equation set (12)) was applied to the responses.

$$\overline{X}(n) \pm t_{n-1,1-\alpha/2}\sqrt{S^2(n)/n}$$ Equation 12

$$S^2(n) = \frac{1}{n-1}\sum_{i=1}^{n}\left[X_i - \overline{X}(n)\right]^2$$

- $\overline{X}(n)$ is the sample mean,
- S(n) is the sample variance,
- $t_{n-1,1-\alpha/2}$ is the critical point for the t distribution, and
- n is the sample size.

Table 36. Product validation survey responses.

Question	Input Average	Confidence Interval (90%)	Upper Limit	Lower Limit
How reasonable are the basic product characteristics?	4.5	± 0.29	4.79	4.21
How reasonable are the entry-level product characteristics?	4.5	± 0.29	4.79	4.21
How reasonable are the advanced product characteristics?	4.5	± 0.29	4.79	4.21
How reasonable are the high-end product characteristics?	4.5	± 0.29	4.79	4.21

According to Table 36, customer inputs are consistent and show that the characteristic identification depending on the Kano categories present very reasonable product definitions with a 4.5 sample mean and 90% confidence interval for the actual mean of 4.21 to 4.79. This result validates the accuracy of the customer data gathered in the first step of the combined model development since that was the starting point of defining the four products and the product differentiation approach developed in this research.

Expert Validation Survey:

This survey, attached in Appendix C, included 4 questions about the degree of reasonableness of the data link rankings, output from the combined model. The survey offered 5 options to the participants for each question (5: very reasonable, 4: reasonable, 3: somewhat reasonable, 2: neutral, and 0: not reasonable). Four avionics and weather systems engineers from top aviation and weather information systems organizations completed the survey. The results are given in Table 37, which also contains 90% confidence intervals obtained by applying the t-distribution test (Equation (12)) to the survey responses.

Table 37. Expert survey responses.

Question	Input Average	Confidence Interval (90%)	Upper Limit	Lower Limit
How reasonable are the order of the data links for the development of the basic product?	4.75	± 0.37	5.12	4.38
How reasonable are the order of the data links for the development of the entry-level product?	4.75	± 0.37	5.12	4.38
How reasonable are the order of the data links for the development of the advanced product?	4.75	± 0.37	5.12	4.38
How reasonable are the order of the data links for the development of the high-end product?	4.75	± 0.37	5.12	4.38

The expert rankings are consistent and show that the data link scores depending on the product specification are very reasonable with a 4.75 sample mean and 90% confidence. Therefore, it can be concluded that the output of the four models present a very reasonable rank order of data links in terms of supporting the design requirements to meet customer needs.

Additional Validation for the Data Link Prioritization:

This study identified UAT as the most capable data link candidate for the weather information products and their required technical characteristics. It also concluded that Mode S is the least appropriate data link for these systems.

These results are consistent with the outcomes of a recent report by Lockheed Martin Aeronautical Systems (1999), which concluded that UAT is potentially very useful for cockpit weather applications since it has the theoretical bandwidth required for cockpit weather information systems due to its special capability to support ADS-B (Automated Dependent Surveillance - Broadcast) and complex weather graphics. The same study stated that Mode S is not adequate for delivering graphical weather to the cockpit and has high power requirements, thus, the general aviation industry does not favor this data link.

5.4 Summary

This chapter examined the validation of the combined models developed for four product definitions: basic, entry-level, advanced and high-end products, by employing Law and Kelton's (1991) validation approach including face validity, sensitivity analysis and accuracy of the output data.

Development of the combined model involved a collaborative approach in every step. The model development team included members who have expertise in a variety of areas related to GA cockpit weather information system development: pilots from different professions, electrical engineers, NASA aviation managers and engineering managers. As a result, it can be concluded that the combined model has face validity within the collaborative group who developed it.

Sensitivity analysis was applied to all four models by selecting two important inputs for each, and measuring the effects on model outputs to –10%, +10%, -20% and +20%

changes in these inputs. The basic model showed a slight sensitivity to the changes in the absolute importance values of grid size and additional services, but all four models were found to provide robust outputs and to be suitable for development of cockpit weather information systems.

In addition, the accuracy of the two main outcomes of the models was examined:

1. Product definitions based on customer requirements and the Kano categories assigned to them.
2. Data link scores that are the final outcome of the combined models depending on product specifications.

These two outcomes were subject to validation via two different surveys:

- A second customer survey for the validation of the product definitions,
- An expert survey for the validation of the data link scores.

Based on the customer validation survey results, it was concluded that the product characteristics are very reasonable. This result validated the accuracy of the customer data and the product differentiation approach developed in this research. The results of the expert validation survey indicated that the model produced a very reasonable rank order of data links in terms of supporting the design requirements to meet customer needs. Therefore, the data link scores are validated.

Additional validation was also provided by previous research: Lockheed Martin Aeronautical Systems (1999). Similar to the outcomes of the models developed in this research, Lockheed Martin concluded that UAT is potentially very useful for cockpit weather applications since it has the theoretical bandwidth required for cockpit weather information systems due to its special capability to support ADS-B (Automated Dependent Surveillance - Broadcast) and complex weather graphics. On the other hand, Mode S is not an appropriate data link for graphical weather due to its bandwidth limitations and high power requirements.

In summary, the combined model was tested on the GA cockpit weather information system development and developed valid results using Law and Kelton's (1991) approach. The next section concludes this research by summarizing key points.

CHAPTER VI
SUMMARY

Recent research emphasizes that the IS industry suffers from market failures due to inadequate decision-making in complex, innovative product development. Early user involvement and cross-functional collaboration are factors that can strongly contribute to solving this problem. Consequently, decision tools for gathering accurate customer data in the design phase and encouraging communication between R&D and marketing are important research areas to help information system product developers.

The primary objective of this research was to develop and demonstrate a product development decision model for the information systems industry that can contribute to IS product development success. A unique decision model was developed integrating customer needs and accurate market demand data into all phases of product development from the selection of product features to the identification of enabling technologies. The model provides a structure to evaluate proposed product characteristics against customer expectations and technical feasibility. It provides IS product developers with a tool capable of analyzing the market potential of specific product feature sets and promotes communication between R&D and marketing. The utility of the model was demonstrated by applying it to the challenging, multi-level problem of identifying the most appropriate data link technology for GA cockpit weather information systems. The goals set forth for this research were accomplished and exceeded when the data link rankings produced by the combined decision model were formally validated by experts. The following sections review the model development and testing results, accomplishments, and recommendations.

6.1 Model Development

IS product development presents unique challenges that the model addressed. As a starting point, this study developed selection criteria to choose a potentially useful decision model. It applied these criteria and evaluated six models: Perceptual mapping, expectancy value, preference regression, conjoint analysis, QFD, and Kano's customer satisfaction model.

QFD was the most promising decision model due to its ability to carry the effects of customer needs to detailed design decisions to identify enabling technologies, promoting collaboration between marketing and R&D, and providing multi-level decision analysis. However, this method has shortcomings in capturing the nuances of customer preference. As a result, QFD forecasts of the importance of technical characteristics of a product can be misleading.

Kano's model is potentially useful to overcome this issue since it has the ability to capture the nuances of the customer's purchasing decisions. This method classifies customer needs into six different categories: Attractive, one-dimensional, must-be, indifferent, reverse, and questionable requirements. QFD cannot capture these important details of customer needs. But, Kano's model does capture them and it can be used effectively to avoid potential inaccurate forecasts. To take advantage of this synergy, this research proposed a unique approach that integrated Kano's model into QFD to achieve an improved IS product development decision tool.

Practical decision models must have a structured implementation but be easily tailored to address specific applications. This study developed a 12-step methodology to integrate Kano's model into the QFD framework that extends Matzler and Hintenhuber's integration approach (1998) by adding significant improvements to address the IS industry needs. These improvements included:

- An improved scoring method to differentiate strong, moderate, and weak DR impacts on CRs that provides better identification of the most important technical characteristics of IS products.
- Elimination of negative ratings to achieve practical use of the model for promoting marketing and R&D interaction.
- Capabilities to integrate both the impact on customer satisfaction and the impact on customer dissatisfaction into the decision model in a way that encourages collaboration between marketing and R&D departments of IS organizations.
- Capability to define products based on Kano classifications to achieve customer-tailored products for innovative information systems and long-term product evolution.

- Use of statistical significance tests to classify CRs to improve credibility of the category selection and the IS product concept.
- Capability of multi-level decision analysis to carry the customer's voice into detailed design decisions from technical characteristics to enabling technologies.

The result is a unique methodology for developing a practical decision model that is suitable for multi-level product analysis and investigation of alternative technical characteristics of an IS product while integrating customer needs.

This new approach was tested on a current, advanced information system product development problem: GA cockpit weather information systems. This is summarized in the next section.

6.2 Model Test

The Aviation Weather Information (AWIN) element of NASA focuses on weather issues with a goal of promoting a safer aviation system a safer aviation system to pilots. A range of possible product alternatives and data link delivery systems are potentially suitable for GA weather information systems. But, it is not clear how researchers and product developers should identify the most promising technological systems that can provide the needed consumer requirements and achieve market success. A product development decision model was one possible tool to support resolution of this issue. This study tested a 12-step combined methodology on this particular IS development problem with this specific objective: *The identification of the most appropriate data links to develop new GA cockpit weather information systems and meet customer needs.*

As a result of previous research (Sireli et al, 2001, 2002), focus group recommendations and a customer survey, GA product characteristics were identified. Data analysis of a web-based Kano questionnaire identified Kano categories for CRs with 90% confidence level and calculated their absolute importance values. Based on Kano categorization, four different product specifications were defined for a cockpit weather information system: Basic product, entry-level product, advanced product, and high-end product, for which four different combined decision models were created. The first level analysis identified the importance levels of design requirements and the second level analysis prioritized alternative data links based on the design requirements from level one.

This analysis identified UAT as the most capable data link for the weather information product based on its technical characteristics. The UAT data link can support the entire life cycle of GA cockpit weather information products. VDL-B, VDL-4, VDL-3, EchoFlight (LEO Satellite), WSI Inflight (GEO Satellite) and Aircell were identified as alternative data links depending on the product definition. Mode S was labeled as the least appropriate data link for developing cockpit weather systems.

Next, the outcomes of the two-level combined model were validated based on Law and Kelton's (1991) three-point approach: creating a model with high face validity, performing sensitivity analysis and determining the accuracy of the output. Application of these three points concluded that all four models developed for different product definitions were valid.

As a result, this study demonstrated application of the combined model methodology on the cockpit weather information system development problem and created four useful and valid models for customer-tailored product specifications that potentially lead to market success. The application of the combined model developed in this research to the GA cockpit weather information system development added value to this problem by suggesting different levels of products to information system providers. They may consider these products as an evolution of a life cycle of a product line and as appealing to various groups of customers based on their organizations' budgetary and technical product development strategies.

6.3 Conclusions

This research created a combined product development decision model for IS development by integrating Kano's model into QFD. This model is able to make detailed product development suggestions based on customer needs from selecting product features to identifying enabling technologies by improving the following research areas:

- QFD's shortcomings in reflecting accurate customer preferences,
- The need for quantitative approaches to analyze the results of the Kano analysis, which is currently qualitative and subjective,

- The inadequacy of a uniform methodology to integrate Kano's model into QFD,
- The need for an application of an integrated model to complex and innovative products such as information system products.

This research successfully improved the areas stated above by extending a recent integration approach (Matzler and Hintenhuber, 1998) and it contributed to the following engineering management areas:

- *Methodology:* Creation of a unique methodology to form an combined decision model that identifies enabling technologies based on customer needs by quantitatively integrating the Kano model into QFD to mitigate the IS product development failures.
- *Application:* Demonstration of this model's usefulness and validity on a complex and innovative IS development problem, GA cockpit weather information system development, adding value to it by suggesting different levels of customer-tailored products to information system developers, which are potentially able to achieve market success.

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Appendix A. Customer survey questionnaire

SURVEY OF PILOTS

CHARACTERISTICS OF NEW COCKPIT WEATHER INFORMATION SYSTEMS

Welcome!

As a part of the Aviation Weather Information (AWIN) element of NASA's Aviation Safety Program, Old Dominion University and Virginia Tech are conducting a research led by NASA Langley Research Center, on providing advanced weather information to the aircraft cockpit. The goal of this program is to reduce weather related aviation accidents via new and improved cockpit weather information systems (WIS). A clear understanding of the potential users' (pilots') needs is critical for the development of these systems.

We would like you to take a few minutes to complete this 18-question survey that examines your views of the characteristics of these new systems. Your input is very important, and will provide valuable data for developing user-oriented advanced cockpit weather information systems.

Please contact Yesim Sireli (asireli@odu.edu) if you have questions or comments regarding this survey.

Thank you.

Your participation in this survey is completely voluntary. You do not need to give your name or contact information at any point.

This survey includes 10 sections and has a unique approach to measure your positive and negative opinions about the new cockpit weather information system. Most questions are two-part questions including one functional and one dysfunctional form. The functional question asks what you would feel if a feature were included in the new cockpit weather information system. On the other hand, the dysfunctional question asks what you would feel if the same feature were omitted from the new system. It is very important to read the questions carefully, and answer both of them accordingly.

SECTION 1: PROFESSION INFORMATION

1. Please describe your profession in this section (please check only one):

O Student
O Recreational
O Private
O Commercial
O Airline Transport
O Helicopter

SECTION 2: GRAPHICAL WEATHER

Graphical weather in the cockpit provides weather information to the pilot in graphical format. Please consider the en-route phase of flight for the questions in this section.

2A. A number of weather products in graphical format are possible to integrate into the new cockpit weather information system. Consider each choice one at a time and how you feel about the importance of including it. Please check only one for each row.

Wx products	**I like this weather product included**	**I need this weather product included**	**I am neutral about this weather product**	**I can live with including this weather product**	**I dislike including this weather product**
PIREPs (Pilot Reports)	O	O	O	O	O
AIRMETs (AIRman's METeorological Information)	O	O	O	O	O
METARs (Aviation Routine Weather Report)	O	O	O	O	O
TAFs (Terminal Aerodrome Forecast)	O	O	O	O	O
Winds Aloft	O	O	O	O	O
Icing	O	O	O	O	O
Convective	O	O	O	O	O
Turbulence	O	O	O	O	O
Ceiling/Visibility	O	O	O	O	O

2B. Please think again independently from the previous form of the question. The following weather products could be OMITTED from the new cockpit weather information system. Consider each choice one at a time and how you would feel if it was NOT included. Please check only one for each row.

Wx products	**I like this weather product omitted**	**I need this weather product omitted**	**I am neutral about this weather product**	**I can live with omitting this weather product**	**I dislike omitting this weather product**
PIREPs (Pilot Reports)	O	O	O	O	O
AIRMETs (AIRman's METeorological Information)	O	O	O	O	O
METARs (Aviation Routine Weather Report)	O	O	O	O	O
TAFs (Terminal Aerodrome Forecast)	O	O	O	O	O
Winds Aloft	O	O	O	O	O
Icing	O	O	O	O	O
Convective	O	O	O	O	O
Turbulence	O	O	O	O	O
Ceiling/Visibility	O	O	O	O	O

SECTION 3: GRID SIZE

3A. The following are possible minimum grid size (resolution) options for the graphical display of en-route long-range (not terminal) weather information. Consider each choice one at a time and how you feel about the importance of having it. Please check only one for each row.

Grid size options	I like this minimum grid size	I need this minimum grid size	I am neutral about this minimum grid size	I can live with this minimum grid size	I dislike this minimum grid size
2 x 2 mi - 4 x 4 mi	O	O	O	O	O
5 x 5 mi - 8 x 8 mi	O	O	O	O	O
9 x 9 mi - 12 x 12 mi	O	O	O	O	O

3B. Please think again independently from the previous form of the question. How do you feel about NOT HAVING the minimum grid size (resolution) options below for the graphical display? Consider each choice one at a time and how you would feel if it was NOT included. Please check only one for each row.

Grid size options	I do NOT like this minimum grid size	I do NOT need this minimum grid size	I am neutral about this minimum grid size	I can live with NOT having this minimum grid size	I dislike NOT having this minimum grid size
2 x 2 mi - 4 x 4 mi	O	O	O	O	O
5 x 5 mi - 8 x 8 mi	O	O	O	O	O
9 x 9 mi - 12 x 12 mi	O	O	O	O	O

SECTION 4: WEATHER UPDATE INTERVAL

Weather updates means the frequency of uploading new weather information to the cockpit. Please consider the en-route phase of flight for the questions in this section.

4A. The following are possible weather update options for the new cockpit weather information system. For a typical Graphical Weather Product such as a NEXRAD graph, what would be the most desirable weather update interval? Consider each choice one at a time and how you feel about the importance of having it. Please check only one for each row.

Weather update interval (en-route)	I like this weather update interval	I need this weather update interval	I am neutral about this weather update interval	I can live with this weather update interval	I dislike this weather update interval
0-5 minutes	O	O	O	O	O
5-10 minutes	O	O	O	O	O
10-20 minutes	O	O	O	O	O
20-30 minutes	O	O	O	O	O
30-60 minutes	O	O	O	O	O

4B. Please think again independently from the previous form of the question. How do you feel about NOT HAVING weather updates at the intervals given below for a typical Graphical Weather Product such as a NEXRAD graph? Consider each choice one at a time and how you would feel if it was NOT included. Please check only one for each row.

Weather update interval (en-route)	I do NOT like this weather update interval	I do NOT need this weather update interval	I am neutral about this weather update interval	I can live with NOT having this weather update interval	I dislike NOT having this weather update interval
0-5 minutes	O	O	O	O	O
5-10 minutes	O	O	O	O	O
10-20 minutes	O	O	O	O	O
20-30 minutes	O	O	O	O	O
30-60 minutes	O	O	O	O	O

SECTION 5: DISPLAY OF HAZARDOUS WEATHER

5A. A number of hazardous weather display presentations are possible to integrate into the new cockpit weather information system. Consider each choice one at a time and how you feel about the importance of including it. Please check only one for each row.

Display of hazardous weather	I like this display feature included	I need this display feature included	I am neutral about this display feature	I can live with including this display feature	I dislike including this display feature
Text on the screen	O	O	O	O	O
Voice on request	O	O	O	O	O
Symbols on the graph	O	O	O	O	O
Forecast maps	O	O	O	O	O
Radar loop animation	O	O	O	O	O

5B. Please think again independently from the previous form of the question. The following hazardous weather presentations could be OMITTED from the new cockpit weather information system. Consider each choice one at a time and how you would feel if it was NOT included. Please check only one for each row.

Display of hazardous weather	I like this display feature omitted	I need this display feature omitted	I am neutral about this display feature	I can live with omitting this display feature	I dislike omitting this display feature
Text on the screen	O	O	O	O	O
Voice on request	O	O	O	O	O
Symbols on the graph	O	O	O	O	O
Forecast maps	O	O	O	O	O
Radar loop animation	O	O	O	O	O

SECTION 6: WEATHER ALERT CONDITIONS

Weather alert is the capability of having weather warnings in the cockpit when unexpected hazardous weather conditions occur.

6A. A number of weather alert conditions are possible to integrate into the new cockpit weather information system. Consider each choice one at a time and how you feel about the importance of including it. Please check only one for each row.

Weather Alert Condition	I like this alert condition included	I need this alert condition included	I am neutral about this alert condition	I can live with including this alert condition	I dislike including this alert condition
Thunderstorm	O	O	O	O	O
Icing	O	O	O	O	O
Turbulence	O	O	O	O	O
Heavy precipitation	O	O	O	O	O
High winds	O	O	O	O	O
Low visibility	O	O	O	O	O

6B. Please think again independently from the previous form of the question. The following weather alert conditions could be OMITTED from the new cockpit weather information system. Consider each choice one at a time and how you would feel if it was NOT included. Please check only one for each row.

Weather Alert Condition	I like this alert condition omitted	I need this alert condition omitted	I am neutral about this alert condition	I can live with omitting this alert condition	I dislike omitting this alert condition
Thunderstorm	O	O	O	O	O
Icing	O	O	O	O	O
Turbulence	O	O	O	O	O
Heavy precipitation	O	O	O	O	O
High winds	O	O	O	O	O
Low visibility	O	O	O	O	O

SECTION 7: TRAFFIC INFORMATION

Traffic information means having traffic information on the same display as weather information. Assume that this will be provided by switching the content of the display to traffic information instead of weather.

7A. Traffic information is possible to integrate into the new cockpit weather information system. How do you feel about the importance of including it? Please check only one.

Traffic Information	I like it included	I need it included	I am neutral about it	I can live with including it	I dislike including it
Switched traffic & weather display	O	O	O	O	O

7B. Please think again independently from the previous form of the question. Traffic information could be OMITTED from the new cockpit weather information system. How you would feel if it was NOT included? Please check only one.

Traffic Information	**I like it omitted**	**I need it omitted**	**I am neutral about it**	**I can live with omitting it**	**I dislike omitting it**
Switched traffic & weather display	O	O	O	O	O

SECTION 8: ADDITIONAL SERVICES

Additional services are services such as Short Message Service (SMS) (the same service as in cell phone messaging), e-mail, Internet over the same data link as the weather information.

8A. Additional services are possible to integrate into the new cockpit weather information system. How do you feel about the importance of including them? Please check only one.

Services	**I like them included**	**I need them included**	**I am neutral about them**	**I can live with including them**	**I dislike including them**
Additional services	O	O	O	O	O

8B. Please think again independently from the previous form of the question. Additional services could be OMITTED from the new cockpit weather information system. How you would feel if they were NOT included? Please check only one.

Services	**I like them omitted**	**I need them omitted**	**I am neutral about them**	**I can live with omitting them**	**I dislike omitting them**
Additional services	O	O	O	O	O

ADDITIONAL COMMENTS (optional):

EMAIL ADDRESS (optional):

Appendix B. Customer validation survey questionnaire.

OLD DOMINION UNIVERSITY   NASA   VirginiaTech VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

FEEDBACK FOR COCKPIT WEATHER INFORMATION SYSTEMS

As a part of the Aviation Weather Information (AWIN) element of NASA's Aviation Safety Program, Old Dominion University and Virginia Tech have developed a decision model for new cockpit weather information systems: a research funded by NASA Langley Research Center. **The purpose of this model is to identify customer (pilot) requirements of a new and advanced cockpit weather information system.**

The requirements were gathered via a customer survey, and based on the survey analysis; the decision model developed four different product definitions that may reflect pilot needs at different levels:

- Basic product,
- Entry-level product,
- Advanced product, and
- High-end product.

You are one of the pilots who participated the customer survey that was used to develop this model. For this reason, you have been selected to provide your opinion on the outcomes of the model via this survey, which includes **only 4 questions**. Your input is very important, and will provide valuable data for developing user-oriented advanced cockpit weather information systems. Please contact Yesim Sireli (asireli@odu.edu) if you have questions or comments regarding this survey, and send it back to:

Attn: Yesim Sireli
By Email (preferred):
asireli@odu.edu
By Fax:
(757) 683-5655
By Mail:
Department of Engineering Technology,
Old Dominion University,
214 Kaufman Hall, Norfolk, VA 23529.

Organization of the Survey:

- This survey provides brief information about the outcomes of the decision model before each question offering 5 different choices.
- Please complete the survey by entering one of the following symbols next to the choice you would like to select: x, √, *, +. (If you prefer to use fax or mail, you can circle the choice you select).

This survey includes 6 questions and requires 5 minutes to complete.

Your participation in this survey is completely voluntary, and all surveys will be de-identified.

Basic Product

Pilots would see this product as a low-end, basic product: if the product met their cost expectations, they would buy the product. It includes the features in Table 1. *Please keep in mind that these results are based on 605 respondents that represent the aviation community characterized by the following professions:*

- *Private pilots (62%)* • *Commercial pilots (26%)* • *Airline pilots (8%)* • *Student pilots (4%)*

Table 1 Basic product characteristics

	Features included in the basic product	Customer preference based on survey analysis
Graphical weather products:	AIRMETs Winds aloft Turbulence	42.9% 43.7% 44.0%
Grid size:	2 x 2 miles - 4 x 4 miles	39.1%
Weather updates:	Every 10 – 20 minutes	40.8%
Display of hazardous weather:	Via text on screen	42.0%
Additional Services	e.g. Short Message Service (SMS), e-mail, or Internet	35.8%

1. In your opinion, how reasonable is the characteristics list in Table 1 for developing the basic product? (5:Very reasonable, 4: Reasonable, 3: Somewhat reasonable, 2: Neutral, 1: Not reasonable)

☐ **5** ☐ **4** ☐ **3** ☐ **2** ☐ **1**

COMMENTS (optional):

Entry-Level Product

This product is conceived as an advanced entry-level product, introduced in response to a competitors' initial market entry product. It includes the features in Table 2. *Please keep in mind that these results are based on 605 respondents that represent the aviation community characterized by the following professions:*

- *Private pilots (62%)* • *Commercial pilots (26%)* • *Airline pilots (8%)* • *Student pilots (4%)*

Table 2 Entry-level product characteristics

	Features included in the entry level product	Customer Preference based on survey analysis
Graphical weather products:	METARs TAFs Icing Convective Ceiling/Visibility	64.7% 58.1% 62.3% 68.0% 71.7%
Grid size:	5 x 5 miles - 8 x 8 miles	42.0%
Weather updates:	Every 5 – 10 minutes	54.5%
Display of hazardous weather:	Via symbols on graph	48.8%
Conditions for weather alert:	Thunderstorm Icing Low visibility	86.4% 66.1% 60.4%

2. In your opinion, how reasonable is the characteristic list in Table 2 for developing the entry-level product? (5:Very reasonable, 4: Reasonable, 3: Somewhat reasonable, 2: Neutral, 1: Not reasonable)

☐ **5** ☐ **4** ☐ **3** ☐ **2** ☐ **1**

COMMENTS (optional):

Advanced Product

This product is conceived as one generation beyond entry level. It includes the features in Table 3. *Please keep in mind that these results are based on 605 respondents that represent the aviation community characterized by the following professions:*

- *Private pilots (62%)* • *Commercial pilots (26%)* • *Airline pilots (8%)* • *Student pilots (4%)*

Table 3 Advanced product characteristics

	Features included in the level-3 product	Customer Preference based on survey analysis
Graphical weather products:	METARs	64.7%
	TAFs	58.1%
	Icing	62.3%
	Convective	68.0%
	Ceiling/Visibility	71.7%
Grid size:	9 x 9 miles - 12 x 12 miles	43.0%
Weather updates:	Every 5 – 10 minutes	54.5%
Display of hazardous weather:	Via forecast maps	55.5%
Conditions for weather alert:	Thunderstorm	86.4%
	Icing	66.1%
	Heavy precipitation	57.8%
	Low visibility	60.4%

3. In your opinion, how reasonable is the characteristic list in Table 3 for developing the advanced product? (5:Very reasonable, 4: Reasonable, 3: Somewhat reasonable, 2: Neutral, 1: Not reasonable)

□ **5** □ **4** □ **3** □ **2** □ **1**

COMMENTS (optional):

High-End Product

This product is conceived as a high-end, value added product. It includes the features in Table 4. *Please keep in mind that these results are based on respondents that represent the aviation community characterized by the following professions:*

- *Private pilots (62%)* • *Commercial pilots (26%)* • *Airline pilots (8%)* • *Student pilots (4%)*

Table 4 High-end product characteristics

	Features included in the level-4 product	Customer preference based on survey inputs
Graphical weather products:	METARs	64.7%
	TAFs	58.1%
	Icing	62.3%
	Convective	68.0%
	Ceiling/Visibility	71.7%
Grid size:	9 x 9 miles - 12 x 12 miles	43.0%
Weather updates:	Every 0 – 5 minutes	59.4%
Display of hazardous weather:	Via radar loop animation	71.2%
Conditions for weather alert:	Thunderstorm	86.4%
	Icing	66.1%
	Heavy precipitation	57.8%
	Low visibility	60.4%
	Turbulence	53.6%
Traffic	Air traffic info by switching the display to traffic	63.0%

4. In your opinion, how reasonable is the characteristic list in Table 4 for developing the high-end product? (5:Very reasonable, 4: Reasonable, 3: Somewhat reasonable, 2: Neutral, 1: Not reasonable)

□ **5** □ **4** □ **3** □ **2** □ **1**

COMMENTS (optional):

ADDITIONAL COMMENTS (optional):

PROFESSION OF THE PARTICIPANT (optional):

This concludes the survey. Thank you for your participation.

Appendix C. Expert validation survey questionnaire.

OLD DOMINION UNIVERSITY NASA VirginiaTech VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

A PRODUCT DEVELOPMENT MODEL FOR COCKPIT WEATHER INFORMATION SYSTEMS

As a part of the Aviation Weather Information (AWIN) element of NASA's Aviation Safety Program, Old Dominion University and Virginia Tech have developed a decision model for new cockpit weather information systems: a research funded by NASA Langley Research Center. **The purpose of this model is to identify customer (pilot) requirements of a new and advanced cockpit weather information system, and to determine the most appropriate data links for this product to meet those requirements.**

The requirements were gathered via a customer survey, and based on the survey analysis, the decision model developed four different product definitions that may reflect evolution of a life cycle of an advanced cockpit weather information product:

- Basic product,
- Entry-level product,
- Advanced product, and
- High-end product.

For each product definition, the model identified a data link list from the most appropriate to the least appropriate to develop that particular product. It also included cost analysis for three different market segments: private pilots, commercial pilots, and airline pilots.

You have been selected to provide your professional opinion on the outcomes of this model via this survey. We would like you to take a few minutes to complete this **4-question** survey that examines your views of the characteristics of these new systems and ideal data links to develop them. Your input is very important, and will provide valuable data for developing user-oriented advanced cockpit weather information systems. Please contact Yesim Sireli (asireli@odu.edu) if you have questions or comments regarding this survey, and send it back to:

Attn: Yesim Sireli
By Email:
asireli@odu.edu
By Fax:
(757) 683-5655
By Mail:
Department of Engineering Technology,
Old Dominion University,
214 Kaufman Hall, Norfolk, VA 23529.

Organization of the Survey:

- This survey provides brief information about the outcomes of the decision model before each question offering 5 different choices.
- Please complete the survey by entering one of the following symbols next to the choice you would like to select: x, √, *, +. (If you prefer to use fax or mail, you can circle the choice you select).

This survey includes 6 questions and requires 10 minutes to complete.

Your participation in this survey is completely voluntary, and all surveys will be de-identified.

Basic Product

Pilots would see this product as a low-end, basic product: if the product met their cost expectations, they would buy the product. It includes the features in Table 1.

Table 1 Basic product characteristics

	Features included in the basic product	Customer preference based on survey analysis
Graphical weather products:	AIRMETs Winds aloft Turbulence	42.9% 43.7% 44.0%
Grid size:	2 x 2 miles - 4 x 4 miles	39.1%
Weather updates:	Every 10 – 20 minutes	40.8%
Display of hazardous weather:	Via text on screen	42.0%
Additional Services	e.g. Short Message Service (SMS), e-mail, or Internet	35.8%

The decision model indicated a data link list to develop a product with the features given in Table 1. Figure 1 shows these data links from the most appropriate to the least appropriate with weights that the model assigned to each data link. For example, according to Figure 1, UAT is the first choice to develop the product that includes the characteristics listed in Table 1. EchoFlight (LEO Satellite) is the second, VDL-3 is the third, ACARS is the fourth choice of the model to develop the basic product, and so on. *Please keep in mind that this model assumes ideal conditions in terms of data link availability, and does not include a cost analysis or certification issues for data links.*

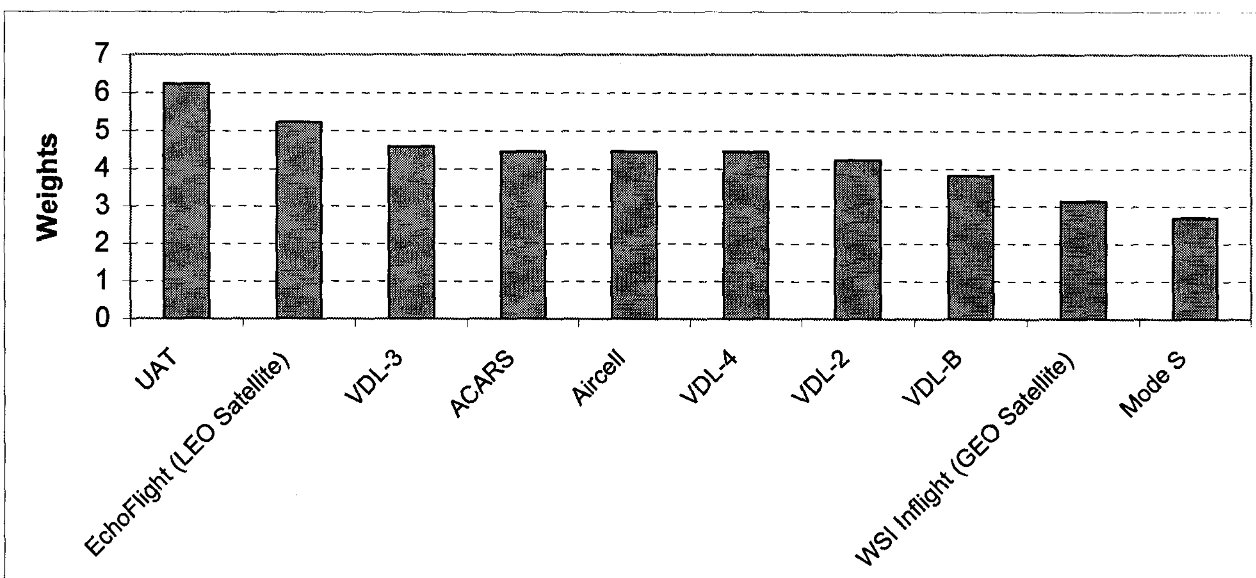

Figure 1 Data link list for basic product

1. In your opinion, how reasonable is the order of the data link choices (Figure 1) to provide the basic product characteristics? (5:Very reasonable, 4: Reasonable, 3: Somewhat reasonable, 2: Neutral, 1: Not reasonable)

☐ **5** ☐ **4** ☐ **3** ☐ **2** ☐ **1**

COMMENTS (optional):

Entry-Level Product

This product is conceived as an advanced entry-level product, introduced in response to a competitors' initial market entry product. It includes the features in Table 2.

Table 2 Entry level product characteristics

	Features included in the entry level product	Customer Preference based on survey analysis
Graphical weather products:	METARs TAFs Icing Convective Ceiling/Visibility	64.7% 58.1% 62.3% 68.0% 71.7%
Grid size:	5 x 5 miles - 8 x 8 miles	42.0%
Weather updates:	Every 5 – 10 minutes	54.5%
Display of hazardous weather:	Via symbols on graph	48.8%
Conditions for weather alert:	Thunderstorm Icing Low visibility	86.4% 66.1% 60.4%

The decision model indicated a data link list to develop a product with the features given in Table 2. Figure 2 shows these data links from the most appropriate to the least appropriate with weights that the model assigned to each data link. For example, according to this list, UAT is the first choice to develop the product that includes the characteristics listed in Table 2. VDL-B is the second, VDL-4 is the third, VDL-3 is the fourth choice of the model to develop the entry-level product, and so on. *Please keep in mind that this model assumes ideal conditions in terms of data link availability, and does not include a cost analysis or certification issues for data links.*

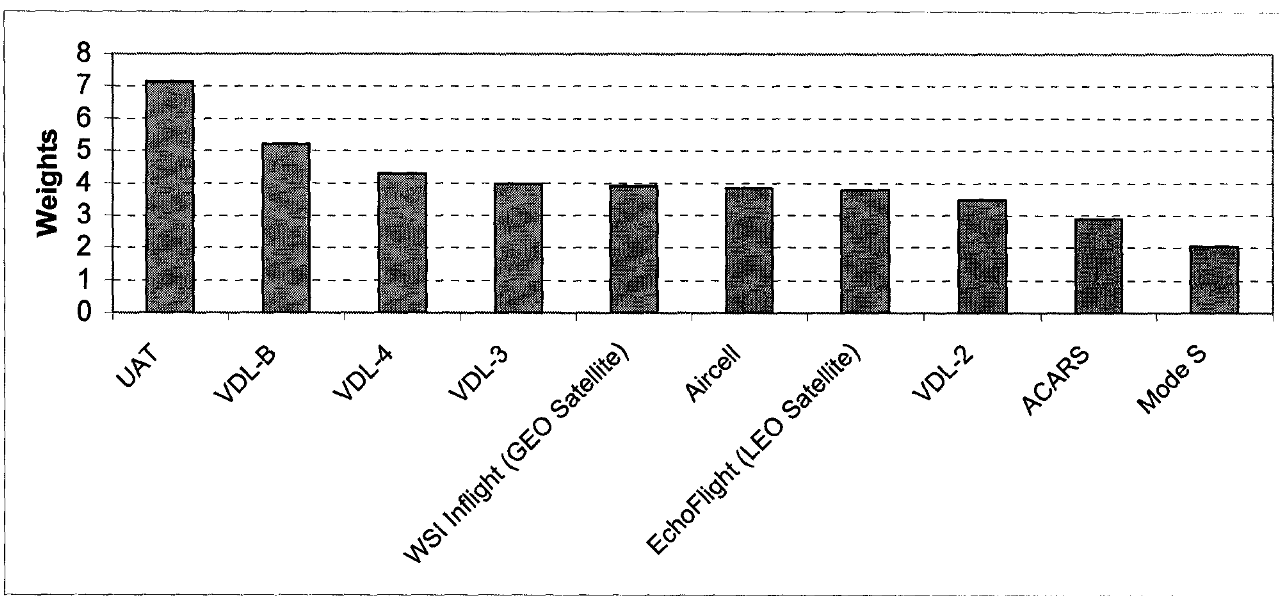

Figure 2 Data link list for entry-level product

2. In your opinion, how reasonable is the order of the data link choices (Figure 2) to provide the entry-level product characteristics? (5:Very reasonable, 4: Reasonable, 3: Somewhat reasonable, 2: Neutral, 1: Not reasonable)

☐ **5** ☐ **4** ☐ **3** ☐ **2** ☐ **1**

COMMENTS (optional):

Advanced Product

This product is conceived as one generation beyond entry level. It includes the features in Table 3.

Table 3 Advanced product characteristics

	Features included in the level-3 product	Customer Preference based on survey analysis
Graphical weather products:	METARs TAFs Icing Convective Ceiling/Visibility	64.7% 58.1% 62.3% 68.0% 71.7%
Grid size:	9 x 9 miles - 12 x 12 miles	43.0%
Weather updates:	Every 5 – 10 minutes	54.5%
Display of hazardous weather:	Via forecast maps	55.5%
Conditions for weather alert:	Thunderstorm Icing Heavy precipitation Low visibility	86.4% 66.1% 57.8% 60.4%

The decision model indicated a data link list to develop a product with the features given in Table 3. Figure 3 shows these data links from the most appropriate to the least appropriate with weights that the model assigned to each data link. For example, according to this list, UAT is the first choice to develop the product that includes the characteristics listed in Table 3. VDL-B is the second, VDL-4 is the third, WSI Inflight (GEO Satellite) is the fourth choice of the model to develop the advanced product, and so on. *Please keep in mind that this model assumes ideal conditions in terms of data link availability, and does not include a cost analysis or certification issues for data links.*

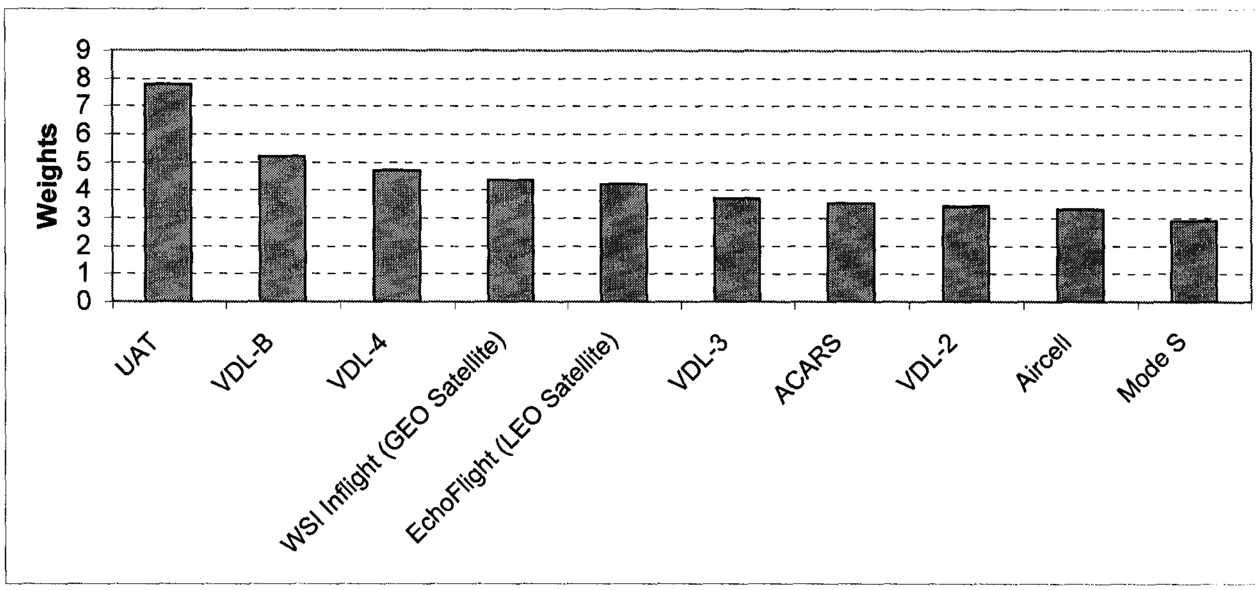

Figure 3 Data link list for advanced product

3. In your opinion, how reasonable is the order of the data link choices (Figure 3) to provide the advanced product characteristics? (5:Very reasonable, 4: Reasonable, 3: Somewhat reasonable, 2: Neutral, 1: Not reasonable)

☐ **5** ☐ **4** ☐ **3** ☐ **2** ☐ **1**

COMMENTS (optional):

High-End Product

This product is conceived as a high-end, value added product. It includes the features in Table 4.

Table 4 High-end product characteristics

	Features included in the level-4 product	Customer preference based on survey inputs
Graphical weather products:	METARs TAFs Icing Convective Ceiling/Visibility	64.7% 58.1% 62.3% 68.0% 71.7%
Grid size:	9 x 9 miles - 12 x 12 miles	43.0%
Weather updates:	Every 0 – 5 minutes	59.4%
Display of hazardous weather:	Via radar loop animation	71.2%
Conditions for weather alert:	Thunderstorm Icing Heavy precipitation Low visibility Turbulence	86.4% 66.1% 57.8% 60.4% 53.6%
Traffic	Air traffic info by switching the display to traffic	63.0%

The decision model indicated a data link list to develop a product with the features given in Table 4. Figure 4 shows these data links from the most appropriate to the least appropriate with weights that the model assigned to each data link. For example, according to this list, UAT is the first choice to develop the product that includes the characteristics listed in Table 4. VDL-B is the second, VDL-4 is the third, WSI Inflight (GEO Satellite) is the fourth choice of the model to develop the high-end product, and so on. *Please keep in mind that this model assumes ideal conditions in terms of data link availability, and does not include a cost analysis or certification issues for data links.*

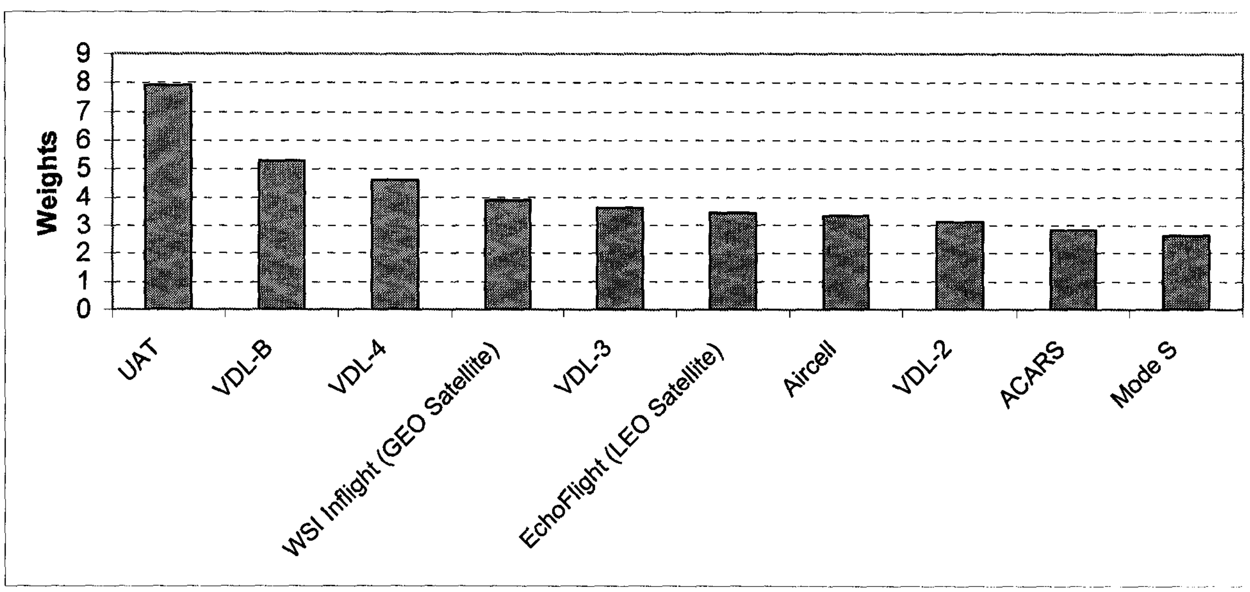

Figure 4 Data link list for high-end product

4. In your opinion, how reasonable is the order of the data link choices (Figure 4) to provide the high-end product characteristics? (5:Very reasonable, 4: Reasonable, 3: Somewhat reasonable, 2: Neutral, 1: Not reasonable)

☐ **5** ☐ **4** ☐ **3** ☐ **2** ☐ **1**

COMMENTS (optional):

ADDITIONAL COMMENTS (optional):

NAME AND PROFESSION OF THE PARTICIPANT (optional):

This concludes the survey. Thank you for your participation.

VITA

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EDUCATION: Master of Science
Electrical Engineering
Istanbul Technical University, Istanbul, Turkey, July 1992

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University of North Carolina at Charlotte

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January 1995 to November 1999
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Afife Yesim Sireli received her B.S. and M.S. degrees in Electrical Engineering from Istanbul Technical University, Istanbul, Turkey. Simultaneously, she worked as an R&D engineer for five years, prior to her Ph.D. education at the Department of Engineering Management & Systems Engineering at Old Dominion University. While working as a research assistant, she has been the project manager of numerous projects for NASA, NAVY, and Siemens. NASA projects mostly included market penetration and development of intelligent transportation systems and general aviation cockpit weather information systems. She is currently an assistant professor at the Engineering Management Program at the University of North Carolina, Charlotte. Her research interests include technology management, decision models, project management and product development.