A Product Development Decision Model for Cockpit Weather Information Systems

Research Sponsor:

NASA Aviation Weather Information Project (AWIN)

NASA Contract NAG-1-01097
ODURF Contract 101652

OLD DOMINION UNIVERSITY

Yesim Sireli
Paul Kauffmann
Old Dominion University

VirginiaTech
VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Surabhi Gupta
Pushkin Kachroo
Virginia Tech

Contents

List of Figures

List of Tables

Abstract

There is a significant market demand for advanced cockpit weather information products. However, it is unclear how to identify the most promising technological options that provide the desired mix of consumer requirements by employing feasible technical systems at a price that achieves market success. This study develops a unique product development decision model that employs Quality Function Deployment (QFD) and Kano's model of consumer choice. This model is specifically designed for exploration and resolution of this and similar information technology related product development problems.

1 Introduction

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. This study investigates this problem and develops a product development decision model specifically targeted at weather information systems for the GA market. In addition, this model also has broad implications for information system product development in general.

This study employs a consumer-centric modeling approach to select viable communication architectures and data links for weather information. Consumer opinions are captured in a survey that is designed to characterize product requirements and attach a level of importance to each. These consumer expectations for a specific service, preferences for bundled service packages, and requirement for value added services have significant implications for the communication requirements of the data link. Since data link technologies have varying capabilities and strengths in supporting different application requirements, there is not a uniform, preferred technology alternative. Based on choices of systems and service features to meet varying market segment needs, different data links will be preferred. This research demonstrates how it is possible to develop decision models that target technologies to specific applications by developing different product definitions and matching the supporting technology. Application of these models provides the potential to streamline and improve product development cycles in advanced technologies. This is particularly important since these systems have short life cycles.

This first chapter provides an overview of the project context, problem description, and a general outline of the paper organization.

1.1 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 (ref 1). 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 was to provide improved 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 (ref 2).

1.2 Problem Description and Paper Outline

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, human factors, and specialized aviation weather forecast products. The development of a complex information technology related system, such as AWIN, presents difficult challenges for technology managers. For example, over the last three decades there has been a significant increase in information technology investment worldwide (ref 3). However, many studies show that new product failures in the information systems market remain exceptionally high despite increasing efforts by academic and corporate researchers to develop new theories and approaches to reverse this trend (ref 4). A recent survey found that only 24% of implementations were considered successful and 64% of management had mixed feelings about the success of the projects with the remainder believing their projects were failures (ref 5). Other recent studies have shown similar results: projects come in years behind schedule, exceed budgets by millions, and fail to meet user needs once implementation is complete (ref 6). This research hopes to contribute to mitigation of these issues.

A specific example of the type of product development decision targeted by the model presented in this paper involves integration of decision aiding capabilities for weather information. Pilots have indicated this feature is essential to enhancing the quality and usefulness of weather information (Appendix A contains a pilot survey of and will be discussed in a later chapter). Implementation of decision aids requires advanced weather processing and display algorithms and the choice of placing this intelligence on-board the aircraft or on the ground is an important issue. With improvement in capabilities of data link and hardware, either alternative may be possible. Placing the intelligence processing on-board will increase the complexity and hence the cost of the hardware. However, on-board processing will enable simpler communication schemes (such as broadcasting) to be employed, since there is no need to send personalized information to different users. To add to the complexity of this decision, it must be made in a way that includes consideration of support for other system capabilities and features beyond decision aiding. This paper presents a model that will support complex product development decisions such as this.

The remaining chapters are organized in the following topical areas:

- Chapter 2 provides general information about cockpit weather information systems and data link alternatives for the general aviation (GA) segment.
- Chapter 3 develops the decision models used in this study and provides detailed examples.
- Chapter 4 provides results of a customer survey and uses this information to define four different cockpit weather information systems with different specifications.
- Chapter 5 presents application of the decision models developed based on these four product types.
- Chapter 6 concludes the report and discusses areas for future work on information system product development.

2 Weather Information in the GA Cockpit: Weather Products and Data Links

This chapter provides necessary technical background on current weather products and data link alternatives. 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 both strategic and tactical decisions affecting aviation safety (ref 7). Weather products have different attributes, such as the type of weather, geographic coverage area, and update rate, that affect how they are used in the cockpit and the supporting communication requirements. One of the key requirements for future weather products is the delivery and display of timely weather updates in graphical format while en-route. However, the inability to tailor weather products to the spatial and temporal needs of the aviation community has been identified as a critical deficiency (ref 7). An enabling technology to resolve this issue is the requirement for a high data rate, air-ground communication link with an efficient media access scheme. This study focuses on this general problem: determining the specific weather information needs of the aviation community coupled with selection of a communication system that can deliver and display the required advanced weather products.

Weather products are currently coded for distribution to ground based aviation weather service providers to minimize the bandwidth (BW) needed for ground communication systems. The service providers decode the weather messages and provide descriptions of observations or forecasts through verbal messages that can be understood by airborne users. The coded formats used for ground based distribution can serve as a starting point to estimate the data communication capability required to provide the same information over a digital air/ground network. Table 1 summarizes the amount of data produced and distributed for a number of prevalent weather products (ref 1) and Table 2 provides brief definitions of these weather products. This information provides a basic reference for evaluating requirements for future ground-to-air data link systems designed to provide weather information in digital format in addition to, or in lieu of, these current delivery systems. The next section examines various data link alternatives.

Table 1 Weather product characteristics

Products	Area covered	Number of product zones for USA	Number of products produced per day	Product life	Bytes per message (coded)
METAR/SPECI	Terminal	1700 +	24	1 hr	500-1,000
TAF	Terminal	526	4	24 hrs	500-1,000
Area forecast	Several states	6	3	12 hrs	3,000-10,000
AIRMET-Sierra	3000 square miles	6	As required by weather	6 hrs	500-1,000
AIRMET-Tango	3000 square miles	6	As required by weather	6 hrs	500-2,000
AIRMET-Zulu	3000 square miles	6	As required by weather	6 hrs	500-2,000
Domestic SIGMET	3000 square miles	6	As required by weather	4 hrs	500-1,000
Convective SIGMET	3000 square miles	3	As required by weather	2 hrs	1,000-5,000
International SIGMET	Atlantic/Pacific oceans	2	As required by weather	4 hrs	500-2,000
Winds Aloft	200 square miles	176	2	6/12/24 hrs	250-500
PIREP Distributed	1-5 miles	1	173	1 hr	250-500

Table 2 Weather product definitions

Weather Products	Definitions
PIREP	A PIREP (The Pilot Flight Report) is a report of meteorological phenomena encountered by aircraft in flight.
AIRMET	An AIRMET (AIRman's METeorological Information) advises of weather that may be hazardous, other than convective activity, to single engine, other light aircraft, and Visual Flight Rule (VFR) pilots.
SIGMET	A SIGMET (SIGnificant METeorlogical Information) advises of weather potentially hazardous to all aircraft other than convective activity.
METAR	A METAR (METeorological Aviation Routine Weather Report) is an hourly surface weather observation. Weather related information provided includes: wind, visibility, weather type, obstructions to visibility, sky conditions, temperature, dew point, and altimeter setting.
TAF	A TAF (Terminal Aerodrome Forecast) includes the expected meteorological conditions at an airport during a specified period (usually 24 hours).

2.1 Data Links for Weather Information in the Cockpit

Selection of a data link is a key decision in defining a marketable weather information system (WIS) since the capabilities of the WIS will largely be dependent on the data link. Several candidate communication systems and data link protocols are in the development and trial stages of deployment and these include VHF data links (VDL Mode 2, VDL Mode 3, VDL Mode 4), Universal Access Transceiver (UAT), and satellite communications (SATCOM). These communication schemes have different physical layers and network protocols which impact their ability to support the various types of aeronautical communication. For system development, the choice of data link technology must be made after detailed analysis of its operational and technical merits in terms of the functions it is required to fulfill.

A starting point for discussing the candidate data link systems is examination of options in the modes of communication.

2.1.1 Broadcast vs. Request Reply

Since most weather information products are not flight dependent, a large number of users can benefit from the same information. Consequently, broadcast is a natural choice for cockpit weather systems. Although focused, two-way communication promotes flexibility and targeted utility, the bandwidth required increases in proportion to the number of individual users and this precludes use of unlimited two-way schemes for wide scale weather data dissemination. To mitigate this issue, a request/reply communication scheme allows the pilot to request only specific information that may be pertinent to a specific fight plan and location. Since this information is geographically specific, it is also smaller in size. For example, a NEXRAD map showing only regional information will have a smaller data volume than a national NEXRAD image. However for a large region, the information may be at too large a scale to determine precisely what lies a few miles ahead. In this situation, a drawback with the request-reply method is that the pilot may not always have the knowledge or time to request a specific piece of information that may be critical for safe flight operations. In summary, broadcast is most suitable for disseminating general weather information (ref 8), however the merits of request-reply communications in certain application scenarios warrant further consideration.

A mix of broadcast and two-way can have a significant impact on reduction of the total bandwidth required for the data link. For example, the broadcast element may include a commonly used set of information. Based on pilot preference, other weather products may be obtained through request-reply and these products do not need to be included in the broadcast set, thus saving on bandwidth and achieving a more efficient architecture.

There is a third communication scheme that is a mixture of the two preceding techniques and involves a two-way link with a Geo-Positioning System (GPS). This system, applied to aviation weather, is called "Narrowcasting" and is currently offered by Avidyne Inc. It uses addressing similar to a request/reply communication link but unlike request/reply, it provides automatic transmission of data without requiring the user to make specific requests. In this scheme, subscribed aircraft have a unique address that identifies them on the communications network. The customer preferences for weather which include the type, frequency, resolution coverage area and other options are pre-entered into the system. These are then used when the aircraft is en-route to automatically provide weather information based on the route (GPS information) and preferences.

The next sections examine the physical characteristics, system architecture, implementation and policy issues of the candidate data link technologies to evaluate suitability for different weather information requirements. This information will be integrated into the decision model in later chapters.

2.1.2 VHF Data Links

The VHF band uses line-of-sight communications with a network of VHF ground stations and is a congested area of the spectrum since it is shared by many ground based systems. The VHF links currently considered for future applications (VDL Mode 2, VDL Mode 3 and VDL Mode 4) are digital and provide better use of spectrum and higher data rates. From a user perspective, the VHF data links are attractive options since they are standardized and will support future migration to new technology as it becomes available. Of concern to system developers is the ability of VHF links to support future growth in air traffic due to the limited amount of available spectrum.

In comparison with satellite networks, VHF links have better end-to-end latency and are therefore more suitable for two-way communications such as voice and air traffic control (ATC) applications. On the negative side, a drawback of VHF systems (e.g. in comparison to satellite systems) is the level of coverage (remote areas) and the line-of-sight restriction. For example, a GA related issue is that flights at low altitude may not be able to receive signals in flight regions that are not in the vicinity of a ground antenna. The characteristics of the VHF digital links, VDL Mode 2, VDL Mode 3, and VDL Mode 4 are further summarized in Table 3.

2.1.3 Universal Access Transceiver (UAT)

UAT is a system that has been proposed for ADS-B (Automated Dependent Surveillance - Broadcast), a traffic monitoring service. It is a broadband system, can support high data rates, and is capable of traffic, weather and surveillance functions. As a result, it is cost effective when multiple services are required. Although it is a bi-directional link, it is not designed as a request-reply system since the uplink and downlink behave as if they were separate broadcast channels. The development of a UAT terrestrial network requires a significant cost and time investment and full continental coverage will not be achieved in a near term time frame. However since UAT is also an ADS-B link, these infrastructure costs can be shared by the multiple data services that may be provided. The characteristics of UAT are further summarized in Table 4.

Table 3 VHF aeronautical weather data links

	VHF Digital Link Mode 2 (VLM2)	VHF Digital Link Mode 3 (VDLM3)	VHF Digital Link Mode 4 (VDLM4)
Description	VDL mode 2 is a data only link; there is a two-way mode and a broadcast mode (VDL-B).	VDL mode 3 is a two-way link that supports both voice and data communication and is designed to support Air Traffic Control (ATC) communications.	VDL mode 4 is multi channel ADS-B link providing ground-to-air, air-to-air connections. Some time slots can be reserved for FIS-B information.
Technical Characteristics	• Carrier Sense Multiple Access protocol • D8PSK, non-coherent detection (3 bits/symbol) • Can operate at a 31.5 kbps max data rate, 19.5 kbps 2-way, but effective throughput is much less.	• Time Division Multiple Access (TDMA) scheme, splitting each 25 kHz channel into 4 time slots using a GPS signal. • Same modulation as VDLM2. • Can support up to 31.5 kbps. But each time slot will carry less than ¼ of this BW.	• Self-organizing TDMA (STDMA). • GMSK modulation. • Total modulation data rate of 19.3 kbps split between the time slots.
Advantages	• Relatively high data rate. • It is the first network to be deployed and radio equipment is available from manufacturers.	• Support for prioritization of messages in the protocol, and the fixed access delay and latency provided by TDMA. • Supports all ATC messaging.	• Can very efficiently use the available spectrum. • For air-to-air, it does not need supporting ground infrastructure.
Disadvantages	• Throughput and delay degrade significantly when the channel is heavily loaded. • High CCI and ACI values that require large guard bands and waste spectrum. • Cannot be used for time-critical ATC messages due to non-deterministic delay of CSMA.	• Co-channel interference (CCI) much more than VDLM2). In-flight data collisions may occur. • Requires central control of ground station increasing infrastructure costs. • Radio more complex and hence more expensive than VDLM2. • Not planned to be deployed until 2008 – 2015 time frame.	• No spectrum allocated and potential for deployment in US is low. • In lower loading conditions offers less throughput than VDLM2. • Primarily an ADS-B link.

Various data in table from Ref. 1

Table 4 Non-VHF aeronautical weather data link: UAT

	UAT (Universal Access Transceiver)
Description	A MITRE developed broadband system proposed as an ADS-B link. Some time slots can be reserved for FIS broadcasts.
Technical Characteristics	• Single 2 MHz channel shared by TDMA scheme. • 3600 per channel net throughput. • Broadcast only, no addressed messages.
Advantages	• Offers the greatest single-channel throughput. • Has ample BW to provide ADS-B messages as well as complex weather graphics.
Disadvantages	• Not yet standardized. • Requires a large spectrum allocation. • A US-only system with its implementation dependent on it being chosen for ADS.

Various data in table from Ref. 1

2.1.4 Satellite Link

Satellite communications (Satcom) have certain unique advantages and a number of existing and upcoming satellite links have the capability of providing weather information. For example, Satcom methods are unequalled for broadcast applications (delivery of the same information to a large group of users) and they preclude the need for a large ground based network. In addition, coverage is excellent since aircraft operating at any altitude can receive the signals.

Satcom systems are classified based on the orbit characteristics: Low Earth Orbit (LEO), Medium Earth Orbit (MEO) and Geosynchronous Orbit (GEO). Each of these options presents various advantages and disadvantages as far as weather information. For example, LEO satellites are preferred by a number of data networks such as Globalstar and Teledesic since they have reduced power requirements for airborne applications. However, they require a phase array tracking antenna to keep in line-of-sight of the satellites as they move in their orbits. Due to the added complexity of the antenna, the hardware for LEO systems is comparatively more expensive than GEO, MEO or VHF systems.

There are currently five commercial satellite systems that provide communication services to aviation users: Globalstar, Orbcomm, Iridium, MSAT, and Inmarsat. Sireli et al. (ref 9) provide more detailed information on Globalstar and Inmarsat. Given the number and different types of constellations being deployed worldwide, there is increasing array of choices and cost options available in the Satcom area. Another factor that makes satellite systems attractive for aviation applications is the increasing availability of satellite - based phones that can be used on the ground as well as on the air. Increasing availability of dual mode phones (cellular equipped) will increase the functionality and affordability of a range of options based on reduced infrastructure costs. The characteristics of satellite links are further summarized in Table 5.

Table 5 Satellite link summary

	Satellite link
Description	Established providers of fixed communication services including wireless WANs (Wide Area Networks) and VSAT (Very Small Aperture Terminal) networks.
Technical Insight	Satcom systems: • Low Earth Orbit (LEO), • Medium Earth Orbit (MEO), • Geosynchronous Orbit (GEO).
Advantages	• Delivery of the same information to a large group of users is possible. • Increasing array of choices and reduced cost options available. • Available satellite based phones can be used on the ground as well as on the air.
Disadvantages	• LEO satellites are preferred over others due to reduced power requirements for airborne applications. • Expensive infrastructure.

2.1.5 Airborne Cellular

Cellular service has previously been denied to airborne users because of the 'frequency capturing effect' of the airborne terminals at high altitudes. However, one company, AirCell, provides airborne cellular voice and data capabilities. AirCell uses the existing cellular network infrastructure and specialized antennas at the cell sites coupled with proprietary technology to reduce interference from terrestrial users and provide coverage to high altitudes. These phones require dual mode operation with a satellite network to compensate for limited cellular coverage.

2.1.6 Cockpit Hardware Considerations

The on board or terminal unit is a key component of the weather information system and required capabilities determine both complexity and cost. Depending on the system architecture, the on-board unit will have various levels of storage, computation, and control requirements. Primarily, the hardware requirements depend on the amount of data processing required by the on-board unit. In general, standalone units (e.g. handheld) have less processing capacity compared to panel-mounted systems due to the physical constraints of the display. However they are cost effective when the information need is basic, such as in an advisory capacity. The current high-end displays are panel mounted and have weather overlaid onto navigation moving maps, providing a higher level of situational awareness and requiring more computational capability.

There is a relation between the bandwidth requirements of the data link and the weather processing coordination between the ground and in the air. More processing and intelligence on the ground as well as maintaining static information on-board (such as map databases) can reduce the amount of data required for transmission. Employing more on-board processing and memory (which raises non recurring cost) can further reduce the amount of data required to uplink pre-formatted, tailored weather products.

2.2 Summary

The delivery and display of timely weather updates in graphical format en-route is a key requirement of pilots for future weather products and this may require a high data rate air-ground communication link with an efficient media access scheme. This chapter provided basic information on current weather products, the modes of communication, and the trade offs involved in selection of data link options. This information is intended to serve as a general foundation for examining the general aviation cockpit weather information systems and the decision model described in following chapters and is not intended to provide a comprehensive technical analysis. The references mentioned in this chapter contain more detailed technical information on these options for interested readers.

The next chapter examines the decision model developed to select data links that support desired weather product characteristics.

3 Decision Models for a Cockpit Weather Information System

A starting point for a product development decision model is a thorough understanding of customer requirements. From literature and a previous survey (ref 10), the following general facts were known about pilot preferences related to weather information:

- Graphical products are preferred over voice briefs.
- Since weather data must be current, timely updates of real-time weather are important.
- Weather data must include the type and intensity of the weather phenomenon.
- Since cockpit space and system cost are significant constraints, multiple services should be integrated into the same display whenever possible.
- Automated notification of significant weather phenomena is important for safety.

Since pilot requirements for graphical cockpit weather information dictate the necessary capabilities of data link and/or hardware characteristics, a survey was developed and administered to better understand pilot needs. The goal of the pilot survey was to support prioritization of requirements by delving deeper into these preferences and expanding on this base of information. In turn, this increased understanding can identify the capabilities required of the candidate communication technologies employed to deliver the desired weather information characteristics.

Due to the wide geographical distribution of pilots and the possible impact of this diversity, a web based survey approach was employed to assure a geographically dispersed participant group. In addition, online surveys are easier for the participants to access and complete and provide flexibility that cannot be achieved by mail questionnaires (ref 11). Since a broad cross section of pilots visit the web sites of organizations such as the Aviation Magazine & News Service, Aircraft Owners and Pilots Association (AOPA), and National Business Aircraft Association, the cooperation of these groups was enlisted.

This chapter develops a tool to analyze the critical interface of translating survey data into actionable product development decisions. It proposes to achieve this task by integrating two models to analyze the survey data: Quality Function Deployment and Kano's models of customer satisfaction. The next sections describe these decision models and how they are integrated to support information system product development.

3.1 Quality Function Deployment

QFD is a systematic methodology for quality management and product development (ref 12) and assures consideration of the consumer requirements in the new product design phase. As a result, QFD is a proven tool to guide project teams and managers in developing products that meet user needs (refs 12, 13). The central element of the QFD model is the relationship matrix (often called the "house of quality") illustrated in Figure 1. The matrix lists the customer requirements (CRs or "whats") along the rows. Each of these requirements has an importance value elicited from the customer. 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-hand side of the house shows the comparative evaluation of competing alternative products. The central portion of the house consists of cells that describe the strength of the relationship of the design requirements to customer requirements.

The relationships between CRs and DRs are typically specified as "strongly related," "moderately related," "weakly related," or "not related" and the matrix cells often employ a scoring system based on 9, 3, 1, and 0 respectively for each relationship. 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 relationship strength of each design requirement to the customer requirements (ref. 14). These calculations are discussed in more detail in the next section.

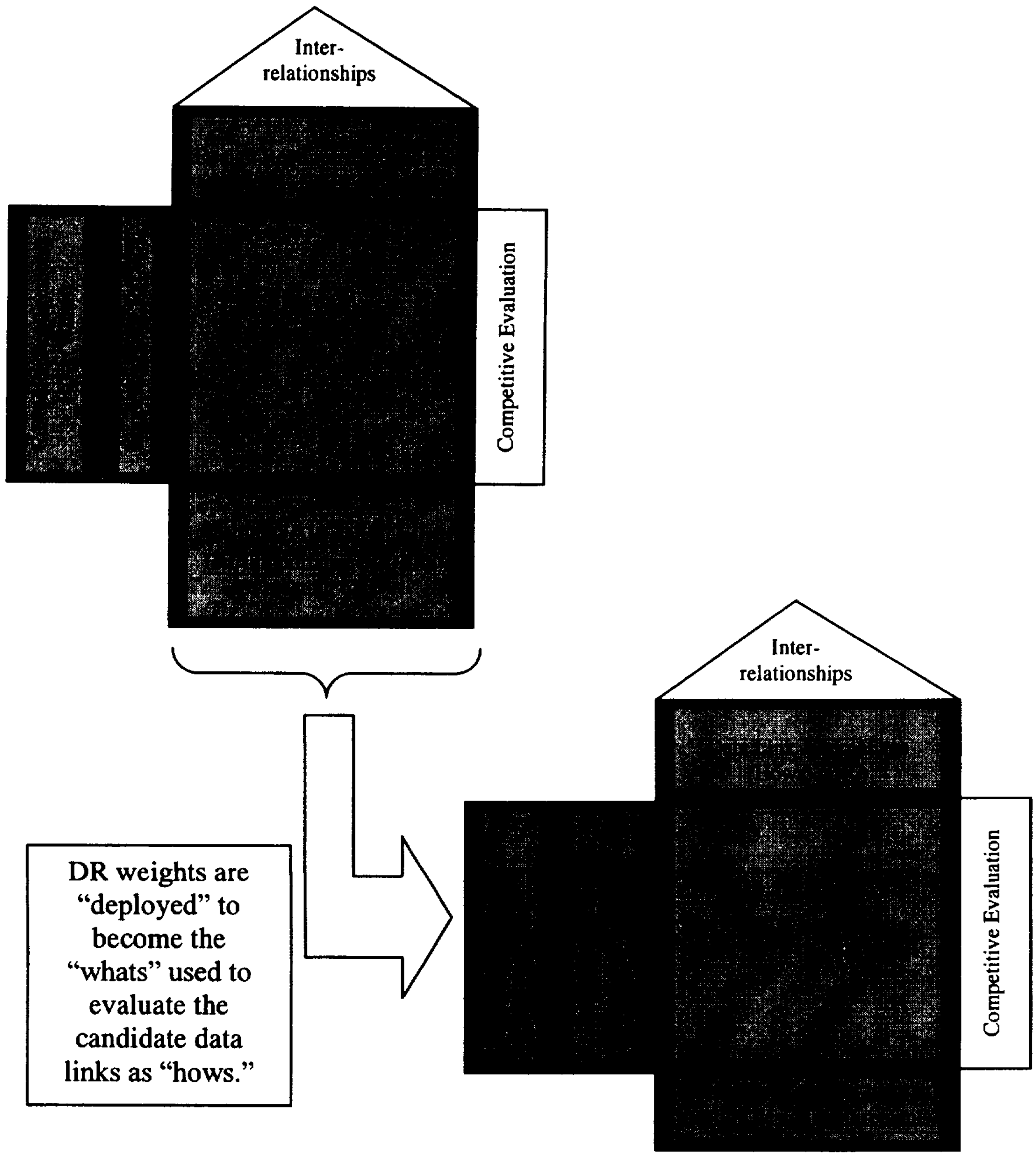


Figure 1 General framework of QFD's house of quality

The QFD application in this study does not utilize every feature of the QFD house of quality. For example, since there are no competitive products to the cockpit weather system, the competitive evaluation section is not used. In addition, since the design requirements were seen as essentially independent at this early stage in product development, the inter-relationship section in the roof was not employed. As a result, this model analysis includes only the shaded areas in Figure 1.

Figure 1 demonstrates the two level application of QFD that is envisioned for data link selection. Using the results of mapping customer requirements into general design requirements shown in the first house of quality, a successive mapping (deployment) evaluates the capabilities of the specific data links to meet the design requirements as shown by the importance ratings or weights. Quality functions may be deployed multiple times carrying "how to do" into the successive house of quality as "what to do (ref 15)."

3.1.1 QFD Calculations

The QFD model calculates the importance values of the DRs using matrix row and column operations (ref 13). For each DR, the absolute importance rating is computed using equation (1):

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

- 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 be transformed into the relative impact rating, RI_j, using equation (2):

$$RI_j = \frac{AI_j}{\sum_{j=1}^{n} AI_j} \qquad \text{Equation 2}$$

It is clear that 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 DR_j is in meeting customer requirements and this allows DRs to be prioritized based on these importance values.

Equation (1) and (2) 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 pilot preferences. To assure accurate portrayal of the importance of customer requirements, a unique version of QFD is proposed that integrates Kano's customer satisfaction model. The next section discusses Kano's model approach and its application in the decision model.

3.2 Kano's Customer Satisfaction Model

N. Kano and other researchers (ref 16) developed a unique and flexible model for characterizing customer needs. In the traditional customer satisfaction models, often employed in analysis of 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 (ref 17). However, increasing fulfillment of customer expectations does not always mean a proportional increase in customer satisfaction since this change also depends on the "type" of the expectation (ref 18).

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 (ref 19). 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 that could influence the AWIN QFD model: linearity of characteristic performance and the impact of dissatisfaction as well as satisfaction.

Figure 2 shows how the Kano model distinguishes three types of product requirements that influence customer satisfaction in different ways.

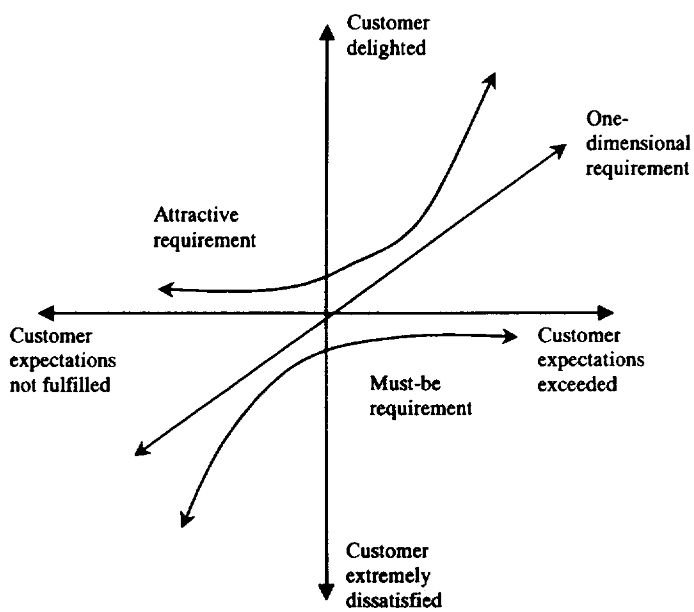


Figure 2 Kano's model of customer satisfaction

- Attractive requirements (A): These are the product criteria that have the highest influence on how satisfied a customer will be 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 (ref 20). Consequently, attractive requirements can differentiate the product from competitors. Attractive requirements are not static and market changes often force them to evolve towards one-dimensional and must-be requirements (discussed below) as competitors improve their product characteristics (ref 17).
- 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. Must-be requirements are a decisive competitive factor and, if they are not fulfilled, the customers will not be attracted to the product (refs 19, 20).
- One-dimensional requirements (O): These result in customer satisfaction when fulfilled, and dissatisfaction when not fulfilled (ref 19). The higher the level of fulfillment, the higher the customer's satisfaction, and vice versa (ref 20).

Attractive, must-be and one-dimensional requirements are identified by employing a specially designed Kano model 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 customers' 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 (ref 20). Both forms of the question include five different response options for the customer to select as shown in Table 6. For example, the Kano questionnaire used for this study included a question about dangerous weather conditions (such as thunderstorms, icing, turbulence, and high winds) and whether the respondents wanted to be alerted 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 the 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.

Analysis of the Kano questionnaire results in classification of the product characteristics into the three types of requirements defined above (A, M, and O). Since respondents may not rate all attributes included in the questionnaire in these categories, other classifications are possible: indifferent (I), questionable (Q), and reverse (R). Indifferent means that the customer is indifferent to this product attribute and does not care if it is present or not. A questionable rating indicates the question was phrased incorrectly, the customer misunderstood the question, or an incorrect response was provided. Reverse means that the customer expects the reverse of that product attribute (ref 20).

Table 6 shows an example of a Kano evaluation table developed during this study. The next section discusses the details of evaluating the responses to define these categories and develop a weight rating for the QFD model.

Table 6 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

3.2.1 Kano Calculations

Kano classification calculations begin with simple tabulation of the survey responses. The Kano requirement category for the CR (A, O, M, I, R, or Q) is identified 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. To distinguish between closely rated categories, the following equation determines if there is a statistically significant difference between the two most frequent observations (ref 21): If

$$|a-b| < 1.65\sqrt{\frac{(a+b)(2N-a-b)}{2N}} \quad , \qquad \text{Equation 3}$$

then the difference between the top two ratings 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.

Once Table 6 data is tabulated, it can determine the W_i (i.e. CR customer importance) for the QFD model by using the percentages of cell entries for each CR category. As a starting point, the impact on satisfaction and the impact on dissatisfaction for each CR are calculated using Equations (4) and (5) (ref 20):

Impact on satisfaction: $S_i = \frac{A_i + O_i}{A_i + O_i + M_i + I_i}$ Equation 4

Impact on dissatisfaction: $D_i = \frac{O_i + M_i}{A_i + O_i + M_i + I_i}$ Equation 5

A, O, M, and I represent the percentages of responses in the Table 6 cells for the CRs from i=1,...,m, where m is the total number of CRs. The absolute importance of each CR is selected as the highest of either the satisfaction or dissatisfaction value calculated using equation (4) and (5) above. There is no distinction between an importance value calculated by using S_i and an importance value calculated by using D_i since achieving higher customer satisfaction is as important as avoiding customer dissatisfaction.

S_i indicates how much the influence on customer satisfaction is increased by providing that CR and D_i indicates how much the influence on customer satisfaction is decreased by NOT providing that CR. These are explained in more detail in Figure 3 and 4. For example, Figure 3 shows that, if a consistent S_i satisfaction increase is achieved by including a requirement into the product to fulfill customer expectations:

- For an attractive requirement, an "A" increase in product performance is required to produce an S_i increase in customer satisfaction.
- For a one-dimensional requirement a "B" increase in product performance with B>A is needed for the same S_i improvement in satisfaction.
- For a must-be requirement, a "C" increase in product performance with C>B is needed to improve S_i by the same amount.
- Since C > B > A, if the requirement is attractive, a relatively small amount of performance increase (A) causes a S_i amount of satisfaction increase. If the requirement is one-dimensional, achieving the same amount of satisfaction increase requires higher performance (B). Finally, if the requirement is must-be, the same amount of satisfaction increase requires an even higher amount of performance increase (C), consistent with the definitions of Kano requirements.

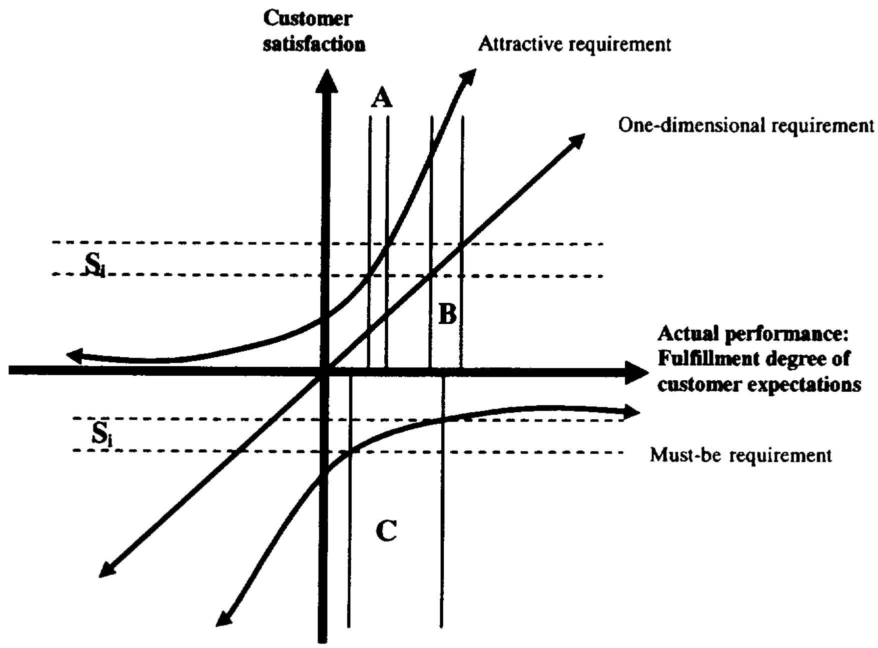


Figure 3 Satisfaction level vs actual performance

Similarly Figure 4 demonstrates the impact of D_i, the amount of satisfaction decrease (or dissatisfaction increase) resulting from not including a requirement into the product to fulfill customer expectations:

- For an attractive requirement, product performance decrease by the amount A′ causes D_i dissatisfaction.
- For a one-dimensional requirement, a B′ decrease in product performance causes Di dissatisfaction with A'>B'. Also, if D_i in Figure 4 equals S_i in Figure 3, B′ in Figure 4 equals B in Figure 3, since the relationship between customer satisfaction and product performance is linear for one-dimensional requirements, unlike attractive and must-be requirements.
- For a must-be requirement, a C′ decrease in product performance results in Di dissatisfaction.
- Since A′ > B′ > C?, if the requirement is must-be, a relatively small amount of performance decrease (C?) causes a D_i amount of satisfaction decrease. If the requirement is one-dimensional, a higher performance decrease (B?) causes the same amount of dissatisfaction. Finally, if the requirement is attractive, although the performance decrease is the largest (A?), the amount of dissatisfaction is still the same, consistent with the definitions of Kano requirements.

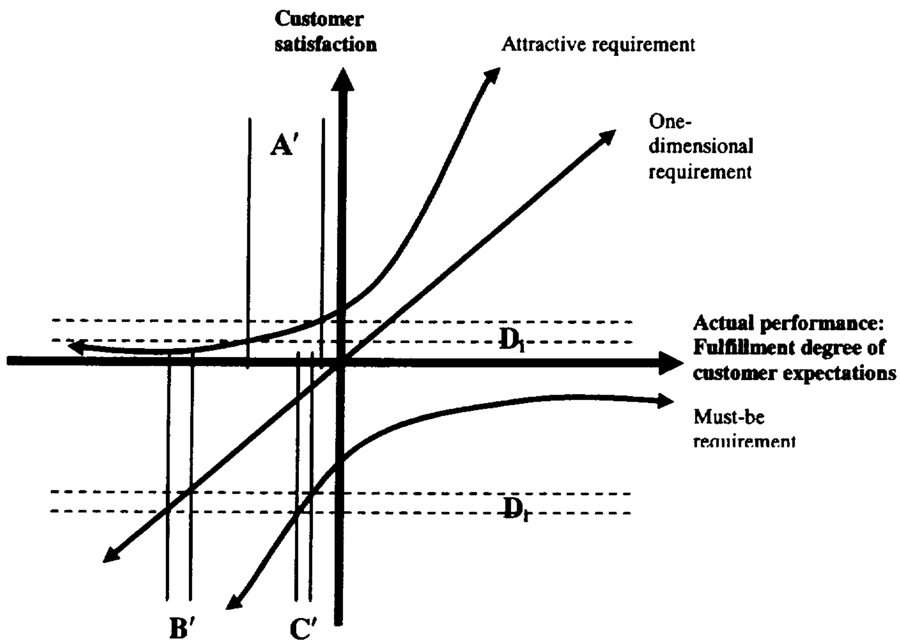


Figure 4 Dissatisfaction level vs actual performance

After calculating S_i and D_i values, the relative importance of each CR is found using Equation (6).

$$W_i = \frac{S_i}{\sum_{i=1}^{m} S_i} \quad \text{or} \quad W_i = \frac{D_i}{\sum_{i=1}^{m} D_i} \qquad \text{Equation 6}$$

This Wi value is used in the QFD model as noted in the previous discussion related to equation (1). The next section examines this integration of the QFD- Kano model and outlines the model relationships.

3.3 Combined Decision Model

This section summarizes how Kano's model of customer satisfaction and traditional QFD were combined to develop a decision tool for weather information product development. Figure 5 provides a schematic of the steps used to develop the example model:

1. The starting point is identification of candidate CRs by use of a literature search and informal interviews of experts.
2. The completed list of candidate CRs is used to develop a Kano type customer survey.
3. Survey responses are analyzed using Kano model equations.
4. Based on these results, a list of CRs and related importance weights are developed.
5. To establish the list of DRs and the relation of the DRs and CRs, a literature search on information systems was conducted.
6. Results are integrated into a combined QFD model to provide product development guidance and support deployment to a second level analysis as shown in Figure 1.

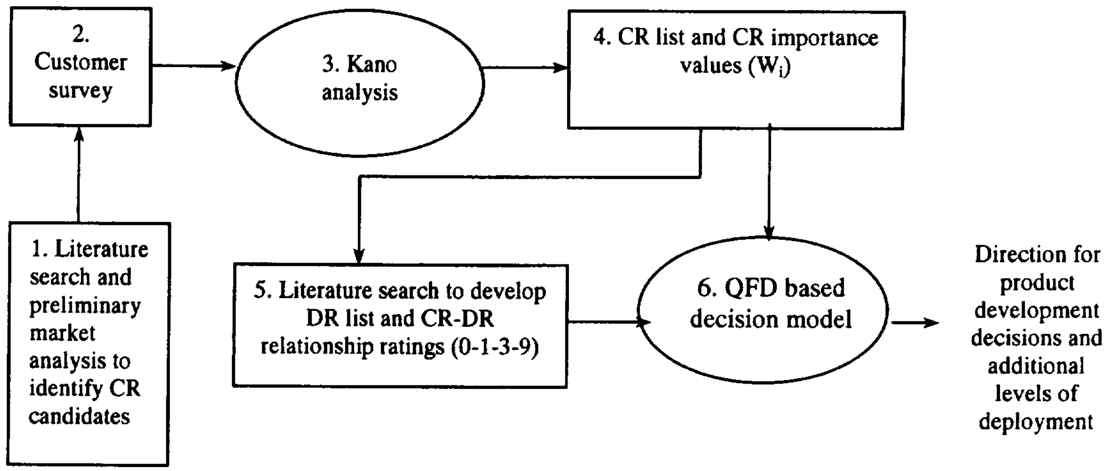


Figure 5 Integrated study methodology example

Table 7 presents results of developed from the integrated decision model for cockpit weather information systems. The customer requirements and importance values are identified via Kano analysis of 370 pilot survey responses; design requirements and the CR-DR relationship ratings are determined by expert opinions. Coupling these results into the combined model identifies the relative impact ratings for user data rate (0.23), latency (0.23), connection delay (0.16), and position reporting (0.15) as the most important technical characteristics for achieving the customer requirements for cockpit weather systems in the general aviation market. The model suggests that product developers should focus on these design requirements to fulfill 77% of customer product expectations.

Table 7 Decision model example - cockpit weather information system development

Customer requirements (CR_i)	Kano category	Absolute importance of CR	Relative importance of CR (W_i)	Design requirements (DR_j)							
				User data rate	Request / reply capability	Traffic info capability	Capacity	Network coverage	Latency	Communication delay	Position reporting
Graphical weather products included	M	57.6%	18.3%	9	1	0	9	1	9	9	9
2x2-4x4 mile-grid size	I	38.0%	12.0%	9	9	0	1	1	9	3	9
0-5 minute-weather update interval	A	53.2%	16.9%	9	1	0	3	3	9	9	3
Radar loop animation on display	O	73.6%	23.3%	9	3	0	1	1	9	3	3
Integrated weather and traffic display	A	60.5%	19.2%	9	1	9	3	3	9	9	9
Additional services (Internet, email, etc.)	I	32.6%	10.3%	9	9	0	1	1	9	3	0
Absolute impact rating of DR_j (AI_j)				9.00	2.33	1.73	3.18	1.72	9.00	6.26	5.66
Relative impact rating of DR_j (RI_j)				**0.23**	0.06	0.04	0.08	0.04	**0.23**	**0.16**	**0.15**

Table 7 presents a potential weather information system product, defined by selecting a combination of indifferent, must-be, one-dimensional, and attractive requirements. Other product definitions can be identified based on the Kano categories derived from the survey responses and sub groups in the GA market. For example, it is possible to define a product with only must-be features and identify the most important DRs for that particular product. This product can be defined as the basic market entry product. This conceptual capability is used in this study to define four different cockpit weather information systems that are explained in more detail in the next chapter.

3.4 Summary

This chapter explained how QFD and Kano's customer satisfaction model can be combined to create a product development decision tool for cockpit weather information systems. First, the QFD method was discussed along with the equations employed to calculate the absolute and relative importance values of design requirements. Then, Kano's customer satisfaction model was identified as a tool to compensate for possible deficiencies in the QFD approach related to employing linear customer satisfaction relationships. The Kano model segments customer requirement categories in greater detail based on inputs from survey responses and provides a methodology to identify calculations of satisfaction and dissatisfaction values that recognize non-linear relationships. Using this information, the importance of customer requirements can be categorized and the importance within those categories can be identified. Finally, a methodology was proposed to combine the QFD and Kano approaches into a combined, integrated decision model and the results of this model exercise were presented.

The next chapter discusses the survey results, their implications for weather information system product development, and identifies a number of potentially successful product concepts.

4 Customer Survey Analysis

As noted in the previous chapter and discussed related to Figure 5, a comprehensive survey of aviation weather users was conducted to develop more detailed information about customer preferences. This customer survey included the sections and topical questions described in Table 8 and ultimately produced a detailed list of customer requirements (CRs) along with an estimate of the degree of importance value for each CR. Although about 600 surveys were gathered, this report includes analysis of the first 370. Analysis of the remaining responses is continuing and will be published in the near future in an updated report and a forthcoming dissertation. A number of conference and journal papers are also anticipated.

Table 8 Customer survey sections

Survey Section	Survey Question Areas
Background information of survey participants	Certificate Is the participant an instructor? Instrument rating Aircraft type Is the participant current? The U.S. region where the participant flies the most
Specific questions on flight characteristics	Total cross-country hours Typical cruise altitudes Typical airspeeds Typical length of flight Total flight hours
Decision-aiding information	Desired ways to make weather information easier to assimilate and interpret
Customer requirements (CRs)	Graphical weather System characteristics Communication methods between the cockpit and the ground User-friendliness of the system Costs of the system

The next sections examine the areas in Table 8 and begin with participant characteristics.

4.1 Background Information of Survey Participants

This section describes the participant background information gathered from the survey and Table 9 summarizes the percentage responses for these sections.

- Section 1 asked the survey participants about their flying certificates: Student, recreational, private, commercial, or airline transport. Almost 63% of participants indicated they were private pilots.
- Section 2 asked about CFI, CFII, or MEI ratings. Responses indicate almost 82% are not in any of these categories. The rest (18%) are CFI, CFII, or MEI rated.
- Section 3 found that 69% were IFR (Instrument flight rule) rated and 31% VFR (visual flight rule). Figure 6 provides more detail on this response and indicates that 55% of respondents had 50 or less hours of actual instrument flying time.
- Section 4 found that 84% primarily fly a single engine piston aircraft with another 9% indicating multi engine piston. This was a one – choice question and serves as a reference for other questions later in the survey.
- Section 5 asked the pilot if he/she is current and almost 96% indicated they are current.
- Section 6 examined the geographic dispersion of respondents and found that the highest percentages were in the southeast (26%) and northeast (22%). The smallest response in the

continental US was from the Northwest (8%) and south central (10%). Figure 7 describes the states included in these geographical categories

Table 9 Background information summary

1. Certificate:	**Response percentage**	**5. Is the participant current?**	**Response percentage**
Student	3%	Yes	96%
Recreational	0%	No	4%
Private	63%	**6. Region:**	
Commercial	26%	Northwest	8%
Airline Transport	8%	North central	18%
2. Is the participant an instructor?		Northeast	22%
CFI, CFII, or MEI rated	18%	Southwest	14%
I am not rated/not an instructor	82%	South central	10%
3. Instrument rating:		Southeast	26%
Instrument rated	69%	Alaska	1%
VFR pilot	31%	Hawaii	1%
4. Aircraft type:			
Single engine piston	84%		
Multi engine piston	9%		
Single engine turboprop	1%		
Multi engine turboprop	2%		
Jet less than 20,000 lbs MTOW	0%		
Jet 20,000 to 100,000 lbs MTOW	3%		
Large transport	0%		
Helicopter	1%		

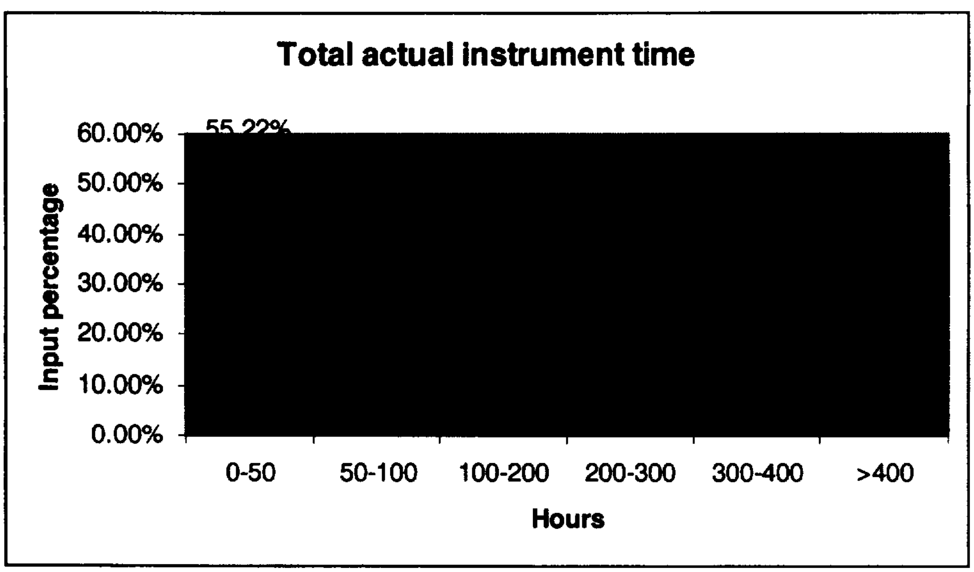
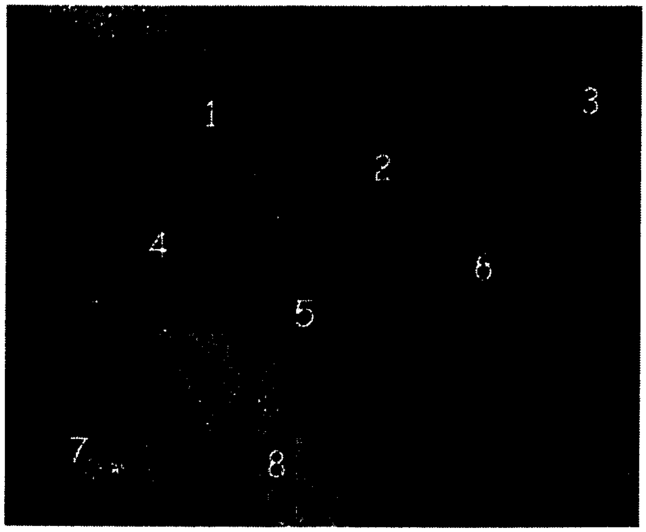


Figure 6 Total actual instrument time



1: Northwest
2: North central
3: Northeast
4: Southwest
5: South central
6: Southeast
7: Alaska
8: Hawaii

Figure 7 Definition of geographical regions

4.2 Specific Questions on Flight Characteristics

The survey questionnaire asked participants about the characteristics of their flying experience. Respondents were asked to answer these questions based on the aircraft type they previously selected as the primary piloted aircraft identified in Section 4 above.

- Total cross-country hours: Table 10 summarizes responses and indicates that 34% have 100 or less hours, 29% have 100- 500 hours and 9% have over 3,000 hours.
- Typical cruise altitudes: Table 11 indicates that 44% typically cruise at altitudes between 5000 – 8000 feet
- Typical airspeeds: Table 12 presents typical airspeed data and shows that about 70% of respondents fly at airspeeds less than 150 knots with 13% below 100.
- Typical length of flight: Table 13 indicates that the typical flight for 55% of respondents is 200 knots or less.
- Total flight hours: Table 14 summarizes responses on total flight hours and shows that 32% have over 1000 hours while 37% have less than 300 with 13% less than 100.

Table 10 Pilots' cross-country hours

What is your total cross-country hours?	Response percentage
0-100	33.61%
100-500	29.20%
500-1000	14.60%
1000-3000	13.77%
>3000	8.82%

Table 11 Typical flight altitudes

What are your typical cruise altitudes (feet)?	Response percentage
<=500	0.83%
500-5000	25.69%
5000-8000	43.37%
8000-15000	22.65%
>15000	7.46%

Table 12 Typical airspeeds

What are your typical cruise airspeeds (knots)?	Response percentage
<=100	13.13%
100-150	56.50%
150-200	19.55%
200-500	7.82%

Table 13 Typical length of flight

What is the typical length of your flights (nautical miles)?	Response percentage
<=200	55.22%
200-400	29.40%
400-600	9.89%
600-1000	4.67%
>1000	0.82%

Table 14 Pilots' total flight hours

What is your total flight hours?	Response percentage
<=100	13.41%
100-300	24.02%
300-600	17.04%
600-1000	13.69%
>1000	31.84%

4.3 Decision Aiding Information

An important aspect of a cockpit WIS is the ability to provide decision aids to the pilot. Decision aiding reduces the pilot workload by processing, correlating, and fusing disparate pieces of information for the pilot to use in making flight decisions, thus adding intelligence to the system. An example of decision aiding is an algorithm that links the intensity, the temporal and spatial coverage of the various weather phenomena to the aircraft speed and heading to compute the time when the aircraft will 'meet' the weather. Other cockpit weather aspects that can use decision aiding to make information easier to assimilate and interpret include:

- Identification of alternate safe airports
- Highlight of weather areas that have changed since the last update.
- Presentation of forecasts in a manner that will be easy to discern from the current conditions and present only the forecast that is within the flight time.

- Identification of information for the immediate vicinity of the flight path (e.g. for a 50 mile radius) that is updated more frequently than the information for a wider area, thus saving bandwidth.

The decision - aiding functions impact the hardware of the WIS in areas such as processing, formatting and display of information. For example, on-board units will require increased processing power, memory and advanced decision aiding algorithms to carry out decision - aiding functions. With a specified level of intelligence, these systems can provide continuous recommendations on the course, altitude, alternate routes and airport status based on the current and forecasted information received from the ground. The reliability and certification of such systems in safety-critical aeronautical applications is a limiting factor in their deployment.

To provide insight on this system element, the survey included an open-ended question asking the participants to describe one or more decision aiding function(s) that should be included in the WIS. The responses to this question showed that there is significant need for these capabilities and provided useful suggestions. Figure 8 describes the decision aids that the survey participants indicated are most needed in the cockpit based on 318 responses from the first 370 pilots who completed the customer survey. The largest segment (18%) indicated a need for decision aiding related to flight planning / routing / safe altitude selection according to weather conditions followed by weather movement at 9%. There was a number of decision aids that were selected in small volume and they are consolidated in the other decision aid category (32%) and listed in Table 15 in detail.

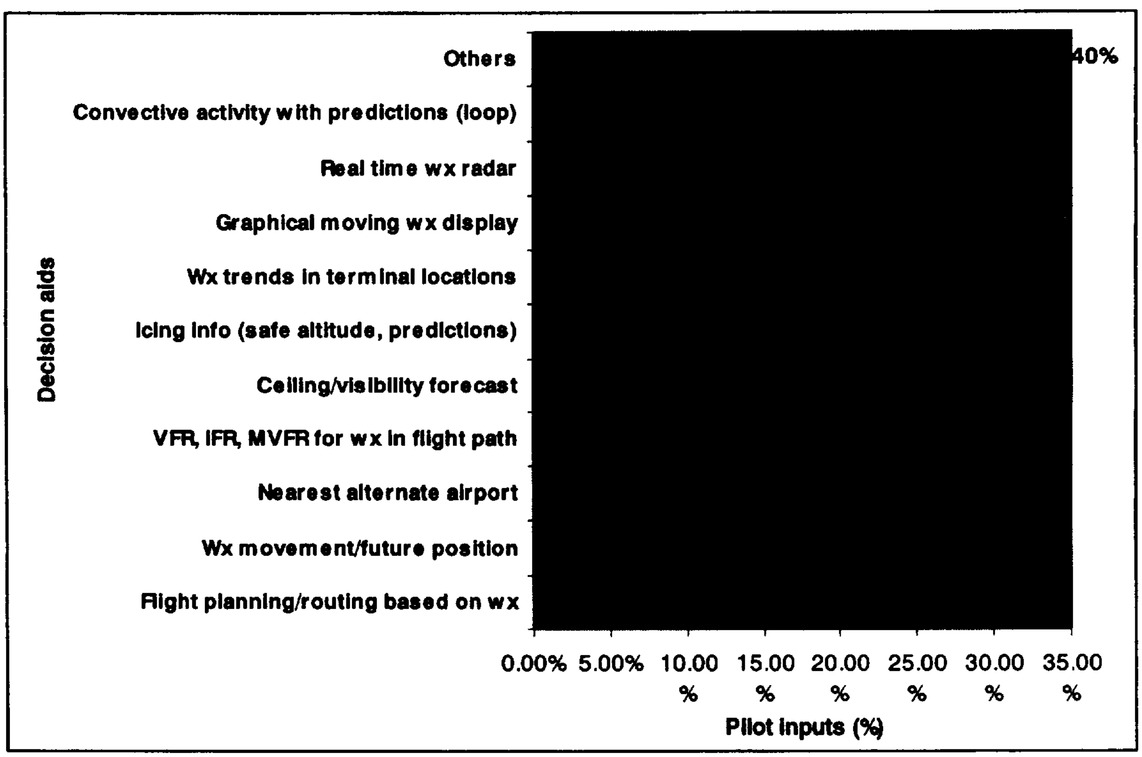


Figure 8 Decision aiding response summary

Table 15 Breakdown of other decision aids

Others	Response Percentage	Others	Response Percentage
Collision avoidance	3.8%	TAFs	0.9%
Fuel availability based on weather	2.5%	Emergency button to alert ATC	0.9%
Below personal minimums	1.9%	SIGMETs	0.6%
METARs	1.6%	NEXRAD	0.6%
PIREPs	1.6%	NOTAMs	0.6%
Winds aloft	1.6%	GPWS/TCAS functionality	0.6%
Lightning strikes	1.6%	Airport flow/airspace restrictions	0.6%
MVFR or IFR pilot reports	1.3%	Navaids not working alert	0.3%
AIRMETs	1.3%	Temporal selection	0.3%
Runway condition warning	1.3%	Text	0.3%
Heavy precipitation	1.3%	Turn anticipator function	0.3%
Raw data	1.3%	Clearances	0.3%
Aircraft location info	0.9%	Help with communications	0.3%
ATIS/AWOS	0.9%	Plain English, simple buttons	0.3%
TFRs and active special use airspace info	0.9%	En-route weather warnings	0.3%
Turbulence probability	0.9%	Dew point	0.3%

The definitions for the decision aids noted in Table 15 are expressed primarily using the exact words of the respondents. Together, Figure 8 and Table 15 indicate the responses on decision aids vary widely. Other than the need for flight planning based on weather conditions, the survey participants suggested a large variety of decision-aids and did not indicate a clear preference. However, it is apparent that the pilots want the capability of simple and effective (not distractive) decision-aiding information in the cockpit.

4.4 Kano Analysis of Customer Requirements

Using the Kano methodology and category definitions discussed in Chapter 3, Table 16 summarizes 370 survey results related to the customer requirement list, the Kano category, and the absolute importance values of each CR. 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 16 provides two measurements for each customer requirement: absolute importance and the type of the requirement (Kano category) as defined in Chapter 3. Absolute importance values are calculated by using Equations (4) and (5) and are indicated as (S_i) or (D_i) in the absolute importance column. Table 16 also includes significance calculations for each CR using Equation (3) and the last column concludes the significance of the Kano category for each CR.

For example both AIRMETs and METARs (defined in Chapter 2) are "must-be requirements" based on the responses obtained and summarized in a table similar to Table 6. Using Equations (4) and (5), the satisfaction levels were found to be 40.3% and 68.3% (in this case, both calculated by equation (5) - D_i). This result indicates these are base product requirements with a relative importance in this category of 40.3% or 68.3%. On the other hand, winds aloft is an "attractive requirement" meaning lack of inclusion will not disappoint the customer but inclusion will provide a high level of satisfaction if included with 42.8% impact value (calculated by equation (4) - S_i).

Table 16 Summary of customer requirements

	Customer Requirements (CRs)	Absolute Importance of CR_i	Kano Category	$\lvert a - b \rvert$		$1.65\sqrt{\frac{(a+b)(2N-a-b)}{2N}}$	Kano category statistically significant?
Graphical Weather	Graphical weather products:						
	PIREPs	55.6% (S_i)	O	**16**	<	**20.06**	*NO*
	AIRMETs	40.3% (D_i)	M	55	>	20.41	Yes
	METARs	68.3% (D_i)	M	38	>	21.17	Yes
	TAFs	59.7% (D_i)	M	42	>	20.62	Yes
	Winds Aloft	42.8% (S_i)	A	45	>	19.90	Yes
	Icing	62.7% (D_i)	M	63	>	20.64	Yes
	Convective	68.1% (D_i)	M	70	>	21.14	Yes
	Turbulence	44.1% (D_i)	M	33	>	20.14	Yes
	Ceiling/Visibility	76.4% (D_i)	M	56	>	21.72	Yes
Grid Size	2x2 mi – 4x4 mi	38.0% (S_i)	I	38	>	20.75	Yes
	5x5 mi – 8x8 mi	39.3% (D_i)	I	92	>	20.98	Yes
	9x9 mi – 12x12 mi	39.6% (D_i)	I	34	>	20.44	Yes
Characteristics	Weather update interval:						
	0-5 minutes	53.2% (S_i)	A	**5**	<	**19.35**	*NO*
	5-10 minutes	53.2% (D_i)	M	17	>	20.24	Yes
	10-20 minutes	38.2% (D_i)	I	18	>	21.07	Yes
	20-30 minutes	0.0%	R	130	>	22.17	Yes
	30-60 minutes	0.0%	R	253	>	22.27	Yes
	Display of hazardous weather:						
	Text on screen	43.1% (S_i)	I	55	>	19.82	Yes
	Voice on request	21.1% (S_i)	I	70	>	22.08	Yes
	Symbols on the graph	48.4% (D_i)	M	46	>	19.59	Yes
	Forecast maps	57.5% (D_i)	O	**16**	<	**20.49**	*NO*
	Radar loop animation	73.6% (D_i)	O	23	>	21.49	Yes
	Weather alert time:						
	Instantaneously	59.6% (S_i)	A	**5**	<	**18.44**	*NO*
	1-5 minutes	56.0% (D_i)	M	**4**	<	**18.86**	*NO*
	5-10 minutes	48.0% (D_i)	I	36	>	19.99	Yes
	10-20 minutes	0.0%	R	**8**	<	**20.53**	*NO*
	20-30 minutes	0.0%	R	74	>	21.10	Yes
	Weather alert conditions:						
	Thunderstorm	90.3% (D_i)	M	53	>	22.10	Yes
	Icing	66.9% (D_i)	M	26	>	20.87	Yes
	Turbulence	48.4% (S_i)	A	22	>	19.53	Yes
	Heavy precipitation	55.9% (D_i)	M	11	>	19.83	Yes
	High winds	49.3% (D_i)	M	26	>	19.05	Yes
	Low visibility	60.5% (D_i)	M	24	>	20.26	Yes
Other Characteristics	Traffic	60.5% (S_i)	A	**14**	<	**20.26**	*NO*
	Additional services	32.6% (S_i)	I	86	>	21.31	Yes
User-friendliness	Data entry:						
	Touch screen	61.1% (S_i)	O	55	>	19.24	Yes
	Bezel buttons	57.2% (D_i)	O	42	>	20.49	Yes
	Pen-based system with icons	0.0%	R	107	>	21.59	Yes
	Voice recognition	0.0%	R	**17**	<	**21.38**	*NO*
	Joystick	0.0%	R	26	>	21.56	Yes
	Trackball	0.0%	R	31	>	21.45	Yes
	Interpretation time for weather information:						
	0-25 seconds	44.2% (S_i)	I	39	>	18.40	Yes
	25-60 seconds	42.9% (D_i)	I	54	>	18.10	Yes
	1-2 minutes	36.2% (D_i)	I	74	>	18.77	Yes
	2-5 minutes	31.5% (D_i)	I	29	>	19.57	Yes
	5-10 minutes	0.0%	R	47	>	19.94	Yes
Costs	Non-recurring costs:						
	$1000 – 3000	78.2% (D_i)	O	119	>	21.17	Yes
	$3001 – 5000	43.4% (D_i)	I	57	>	19.57	Yes
	$5001 – 10000	0.0%	R	74	>	21.71	Yes
	$10001 – 20000	0.0%	R	275	>	21.82	Yes
	$20001 - 30000	0.0%	R	333	>	21.83	Yes
	Recurring costs:						
	$0 – 500	69.2% (D_i)	O	119	>	20.50	Yes
	$501 – 1000	0.0%	R	90	>	21.63	Yes
	$1001 - 1500	0.0%	R	297	>	21.85	Yes

As an example of distinguishing Kano categories using significance values in Table 16, PIREPS was labeled as a one-dimensional requirement since it was the Kano category with the most (110) inputs from the survey participants among weather products. However, the indifferent category was the second with 94 inputs. Using Equation (3), it was found that the difference between these two was not statistically significant. Therefore, we cannot be confident that PIREPS is actually a one-dimensional requirement.

The remaining sections of this chapter explain the technical implications of these customer requirements and then define four different products with different characteristics based on the Kano categories indicated in Table 16 as I (indifferent), M (must-be), O (one-dimensional), and A (attractive).

4.5 Technical Implications of Consumer Requirements

Success in achieving consumer requirements is dependent on the design attributes of the cockpit weather information system such as characteristics of the data link, the network configuration, and the system and terminal unit design. The consumer requirements will be analyzed in relation to the supporting design options in the next chapter. This section employs the survey responses to provide a basis for that discussion by establishing key relationships between the customer needs and the technical design options. This analysis will subsequently be used in identifying the most important design parameters for different product definitions.

4.5.1 Graphical Weather Products

One of the key requirements of pilots is the delivery and display of timely weather updates in graphical format while en-route. This requires a high data rate air-ground communication link with an efficient media access scheme. Many weather products are currently offered in graphical format and include color-coded radar imagery and symbolic representation of textual weather products such as the graphical TAFs and METARs. In the cockpit, the pilot will have a choice of various types of weather products to uplink and display but, due to bandwidth constraints, there is an upper limit to the number of graphical weather products that can be received. In addition, different types of graphical maps have varying data sizes. Maps that use symbolic representation, such as graphical METARs, have lower data sizes than a pixel representation, such as radar maps. The density of information affects the data size and some weather products, such as 'winds aloft' maps, inherently have a higher density of information. Support of a number of graphical products, such as radar and satellite imagery, winds aloft and turbulence maps, will require a data link with a data rate in excess of several kbps per user.

The survey obtained an indication of pilots' preferences for the different types of graphical weather products as summarized in Table 16. In general, all graphical weather products were considered to be "M- must be" requirements with the exception of PIREPS (O) and winds aloft (A). However, the results for PIREPs are not statistically significant and it is not possible to conclude this requirement is one-dimensional. AIRMETs, METARs, TAFs, icing, convective, turbulence, or ceiling/visibility features have relative importance ratings of 40.3%, 68.3%, 59.7%, 62.7%, 68.1, 44.1%, and 76.4% respectively. The ceiling/visibility weather product in the cockpit weather information system is the most important of these products followed by METARs and convective information.

4.5.2 Grid Size

The grid size defines the square area of the smallest graphic and preferences for grid size were a survey question area. The minimum grid size requirement has an effect on the data size of the graphic and hence the communication load. A smaller grid size is equivalent to increasing the resolution and is useful for pilots to obtain more detailed information for a given region. However, due to fast changing weather patterns and the lack of accuracy in predicting weather on a very small scale, the usefulness of a very small grid size is questionable. To compound this issue, a small grid size has to be coupled with a high update frequency to increase reliability of the small-scale information and to allow the system to keep up to date with the changing weather patterns. The grid size also varies based on the total area to be represented and the scale of the map. For example, to display a map of the entire United States, a grid size of 64km x 64km is sufficient while to display a specific terminal area, a smaller grid size (8km x 8km) may be needed. By using an appropriate grid size, bandwidth can be saved.

The survey examined preference for the following options in grid size range: (2x2 mi – 4x4 mi), (5x5 mi – 8x8 mi), and (9x9 mi – 12x12 mi). According to the first 370 replies, the majority for each grid size was in the Kano category of indifferent and there was no clear preference for the smaller grid sizes. This indicates that a smaller grid size is not considered necessary or desired by the users. Thus the survey indicates that bandwidth saving can be realized by having a larger grid size and this will not sacrifice customer satisfaction.

4.5.3 Weather Update Interval

The requirement for update rate is dependent on the particular weather product and often relates to an 'as required by weather' context. For example, frequent updates are needed to ensure that any changes in weather are tracked and that there is adequate forewarning of emerging bad weather. On the other hand, on a calm day the required update frequency is greatly reduced. The capability of the data link in areas such as the data rate and total capacity limit the update frequency. A broadcast link is better suited to support a high update frequency as the time to send a request is saved and the system can update several aircraft simultaneously.

The survey asked participants to select the most desirable weather update interval for a typical weather product such as a NEXRAD map. Although the responses favored a small update interval (i.e. a high update frequency) by selecting the lowest update interval of 0-5 minutes in the Kano category (A) attractive, the results for this option was not statistically significant. Therefore, it is not possible to conclude this requirement is attractive. The 5- 10 minute update interval was in the Kano category (M) must-be. All higher update intervals were either in the indifferent or reverse category.

4.5.4 Display of Direction and Rate of Movement of Hazardous Weather

Denoting the direction of movement and rate of movement of hazardous weather patterns are possible features of weather information systems. Since the different methods of presenting this information to the user will depend on the system design and capabilities, it is important for system designers to know user preferences for this requirement. The following display options were offered in the survey: 'text on the screen', 'voice on request', 'symbols on the graph', 'forecast maps' and '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 movement of weather. This method is bandwidth intensive and hence cannot be provided on a frequent basis. For example, radar loop animation requires several maps to be up linked and stored in the memory of the control and display unit (CDU). This implies a memory of at least 4 - 5 Mega Bytes with the inclusion of the rendering software's memory footprint. A display processor with sufficient processing speed to run the animation engine is also a requirement for radar loop animation. Forecasts and radar loops may benefit from a request/reply link since this method fits users who have specific needs with regard to the type of map.

According to the survey results (Table 16), providing text on screen or voice on request for the display of the hazardous weather are (I) indifferent characteristics. On the other hand, symbols on the graph is a (M) must be (impact of 48.4%) and forecast maps and radar loop are one-dimensional (impact of 57.5% and 73.6%). However, the forecast maps option was not statistically significant. Consequently, providing radar loop animation in the cockpit weather information system is the most important characteristic in the one - dimensional category.

4.5.5 Weather Alerts

It is important to the safety of flight operations to receive timely weather alerts en-route 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 concern with weather alerts is that they may be issued too frequently or to aircraft that are not affected by the particular weather alert, thus diminishing their impact or contributing to work overload of the pilot. This problem can be reduced by suitable selection of the communication scheme since certain communication architectures lend themselves to better dissemination of weather alerts. For example, a broadcast link that is capable of transmitting to a small geographical area will provide better alerting than request-reply systems and avoid several of the issues previously mentioned. Broadcast links that transmit information on very large scale, such as GEO satellite systems, may not be able to provide effective weather alerting since the alerts may be for too broad an area and information about localized activity may not be available.

The type of weather alert determines the region over which to issue the warning. For example turbulence warnings cannot be issued over a large region since it affects only a small area and the time over which the warning is valid may also be relatively small. For strategic flight planning purposes, warnings for weather phenomenon such as storm cells that are expected to last a long time, should be issued to aircraft over a wide area so that advance warning is available for important decisions.

According to the survey results (Table 16), providing turbulence alerts is an (A) attractive characteristic with an impact rating of 48.4%. Thunderstorm, icing, heavy precipitation, high winds, or low visibility alerts are rated as (M) must be with impact ratings of 90.3%, 66.9%, 55.9%, 49.3%, and 60.5% respectively. In summary, respondents indicated that providing thunderstorm alerts is the most important weather alert followed by icing and low visibility alerts at second and third place respectively.

4.5.6 Additional Services and Traffic

The term "additional services" encompasses certain non-aeronautical capabilities whose inclusion can add a higher level of utility and attractiveness to the weather information system. These services are currently being offered by some satellite links. For example, a number of satellite systems are being developed, which offer in-flight entertainment services to commercial carriers. Other value added services include Internet, e-mail and short message service (SMS). The implication of including these services is a data link whose data rate requirement may be in excess of 20 kbps, a rate preferable for two-way e-mail and mobile Internet services. The data link must also be capable of supporting either the TCP/IP or WAP Internet protocols.

The response of this particular group of participants of the survey to the inclusion of additional services was in the Kano category (I) indifferent with 32.6% impact rating if these services are provided in the product. This should be interpreted in the context that 84% of the participants fly single engine piston aircraft and these services mainly cater to the transport and business aviation sectors. Although providing traffic on weather display was in the attractive category, the results were not statistically significant. Therefore, it is not possible to conclude that this requirement is attractive.

4.5.7 Data Entry and Interpretation Time

The survey results indicated that the pilots rated two of the data entry options desirable: touch screen and bezel buttons were identified as significant (M) must be characteristics. Providing touch screen data entry to the system has a weight of 61.1% and bezel button data entry had an impact of 57.2%.

Interpretation time for weather information is the time the pilot would spend interpreting the weather data provided in the cockpit. According to the survey results, this category is mainly indifferent. However, it is clear that more pilots would like to spend less time for data interpretation since the importance values increase from the 2-5 minutes option to 0-25 seconds option. Additionally, the 5-10 minutes option is a reverse requirement, thus, is not desirable at all.

4.5.8 Costs

The general aviation market is price-sensitive and costs, especially recurring costs (annual fees), should be kept as low as possible. Participants identified both cost definitions (recurring and non recurring) as (O) *one-dimensional.* According to the survey results (Table 16), if non-recurring costs (hardware plus installation) are more than $3,000, the customer satisfaction impact (78.2%) will decrease. For recurring costs, a limit of $500 annually was identified as an (O) one-dimensional requirement with an impact rating of 69.2%.

4.6 Definitions of Products based on Customer Requirements

Based on the responses of survey participants, this section develops four different product definitions that may reflect evolution of a life cycle of and advanced information product: minimum expectation product, must be product, one dimensional product, and attractive product. To define the specifications of these products, we begin with the Kano categories primarily involving the must-be (M) category and then progressively add the one-dimensional (O) requirements to the product characteristics, finally adding the (A) attractive characteristics.

It is impossible to define a complete product using only M, O, and A requirements. For example, there must be at least one feature for each characteristic section and in some cases survey responses were (I) in all cases (e.g. grid size). Therefore, the product definitions employ a mixture of these requirements when necessary. For example data entry options are always one-dimensional and indifferent (I) requirements are employed for grid size. The product definition becomes more sophisticated by including higher CR importance values as the characteristics move from the minimum expectation product to the attractive product. In general, the four product definitions were defined using the following guidelines:

- Minimum expectation product: This product is conceived as a fundamental entry - level product and it is comprised primarily of indifferent requirements with the highest importance values from every feature category possible. However, it is not possible to define this product with only indifferent requirements for two reasons:
    1. A product with only indifferent requirements would not be very appealing to the customers.
    2. Some feature groups include only must-be or one-dimensional requirements.

  As a result, the minimum expectation product includes a mixture of I, M, and O requirements. Indifferent requirements with low importance values are not included in any product definition.
- Must-be product: This is conceived as an advanced entry-level product such as one that may follow a competitor's new product introduction. The highest rated must-be requirements are included in all feature categories possible. One-dimensional and indifferent requirements are included when there is no must-be requirement in that feature group.

- One-dimensional product: This is conceived as an improved product that may be one generation beyond entry level. The highest rated one-dimensional requirements are included in every feature category possible. Must-be and indifferent requirements are included when there is no one-dimensional requirement in that feature group.
- Attractive product: This is conceived as a premium product with high margins. Highly rated attractive requirements are included in any 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 17 summarizes how these definitions were categorized.

Table 17 Features included in products

Product definition	Number of Kano categories employed in product definition	Total number of features included in product
Minimum expectation	10 M, 5 I, 3 O	18
Must-be	13 M, 3 I, 3 O	19
One-dimensional	13 M, 4 I, 3 O	20
Attractive	13 M, 5 I, 3 O, 2 A	23

In this preliminary view, the features identified as statistically insignificant in Table 16 are not included in these product definitions since their Kano categories are not conclusive. When all 600 surveys are processed, a clearer difference between these product definitions may emerge and at that point it may be appropriate to include these characteristics.

The following sections describe the products in more detail.

Minimum expectation product

The minimum expectation product includes the combination of features that survey participants described as indifferent, must-be, and one-dimensional requirements. Pilots would see a product with these characteristics as a low-end, basic product: if the product met their cost expectations, they would buy the product, but they would not be impressed with it. Table 18 summarizes the product characteristics:

- Graphical weather (METARs, TAFs, icing, convective, and ceiling/visibility): There is no indifferent weather product in this group. Since this is a basic product, graphical weather products with only the highest importance values in the must-be category are selected.
- Grid size (9 x 9 miles – 12 x 12 miles): The maximum grid size is selected. Since the importance values of all grid size options are very close to each other, it is assumed that the grid size would decrease from the minimum expectation product to the attractive product. Therefore, the largest grid size is included in this product.
- Weather update interval (10-20 minutes): The indifferent interval is selected.
- Display of hazardous weather (Text on screen): The indifferent option with the highest importance value is selected.
- Weather alert conditions (Thunderstorm, icing, heavy precipitation, high winds, and low visibility): Since there is no indifferent category in this group, the must-be requirements are selected.
- Weather alert time (5-10 minutes): The indifferent interval is selected.
- Data entry option (Bezel buttons): Since there are only one-dimensional requirements in this group, the one-dimensional requirement with the lowest importance value is selected, leaving the other requirement with the higher importance to the one-dimensional product definition.
- Interpretation time of weather information (2-5 minutes): There are 5 options in this group with one classified as reverse and the other four as indifferent. The minimum expectation

product includes the indifferent option with the lowest importance value since the upcoming product definitions should include options with higher importance values.

- Non-recurring cost ($1,000-$3,000): This category includes a one-dimensional requirement since the minimum expectation product should cost lower than others since it is the low-end product.
- Recurring cost ($0-$500): This is a one-dimensional requirement, and pilots have no other preference for the recurring costs. Therefore, this category is the same for each product definition.

Table 18 Characteristics of the minimum expectation product

			Kano category
Graphical Weather	Graphical weather products:	METARs	M
		TAFs	M
		Icing	M
		Convective	M
		Ceiling/Visibility	M
	Grid size:	9 x 9 mi - 12 x 12 mi	I
Characteristics	Weather update interval:	10 - 20 minutes	I
	Display of hazardous weather:	Text on screen	I
	Weather alert conditions:	Thunderstorm	M
		Icing	M
		Heavy precipitation	M
		High winds	M
		Low visibility	M
	Weather alert time:	5 - 10 minutes	I
User-friendliness	Data entry option:	Bezel buttons	O
	Interpretation time of weather information:	2 - 5 minutes	I
Costs	Non-recurring cost:	$1,000 – 3,000	O
	Recurring cost:	$0 - 500	O

Must-be product

Table 19 summarizes the characteristics of the must-be product and includes the features that the survey participants described as must-be (or expected), one-dimensional and indifferent requirement. This product is conceived as an advanced entry level product, introduced in response to a competitors initial market entry product.

The must-be product has the following improvements compared to the minimum expectation product:

- Weather product AIRMETs
- Smaller grid size (5 x 5 miles - 8 x 8 miles)
- More frequent weather updates (5-10 minutes)
- Symbols on the graph for the display of hazardous weather instead of text
- Smaller data interpretation time for the pilot (1-2 minutes)

The non-recurring costs are selected the same as for the minimum expectation product, leaving the higher option for the one-dimensional and attractive products.

Table 19 Characteristics of the must-be product

			Kano category
Graphical Weather	Graphical weather products:	AIRMETs	M
		METARs	M
		TAFs	M
		Icing	M
		Convective	M
		Ceiling/Visibility	M
	Grid size:	5 x 5 mi - 8 x 8 mi	I
Characteristics	Weather update interval:	5 - 10 minutes	M
	Display of hazardous weather:	Symbols on the graph	M
	Weather alert conditions:	Thunderstorm	M
		Icing	M
		Heavy precipitation	M
		High winds	M
		Low visibility	M
	Weather alert time:	5 - 10 minutes	I
User-friendliness	Data entry option:	Bezel buttons	O
	Interpretation time of weather information:	1 - 2 minutes	I
Costs	Non-recurring cost:	\$1,001 – 3,000	O
	Recurring cost:	\$0 - 500	O

One-dimensional product

The characteristics of this product are summarized in Table 20 below. It is conceived as one generation beyond entry level and is differentiated from the must be product as follows:

- Turbulence weather product
- Radar loop animation for the display of hazardous weather instead of symbols on the graph
- Touch screen data entry instead of bezel buttons since touch screen has the highest importance value in this category
- Smaller data interpretation time for the pilot (25-60 seconds)

The non-recurring costs are higher than the first two products since this product has more advanced features.

Table 20 Characteristics of the one-dimensional product

Graphical Weather	Graphical weather products:		Kano category:
		AIRMETs	M
		METARs	M
		TAFs	M
		Icing	M
		Convective	M
		Turbulence	M
		Ceiling/Visibility	M
Characteristics	Grid size:	5 x 5 mi - 8 x 8 mi	I
	Weather update interval:	5 - 10 minutes	M
	Display of hazardous weather:	Radar loop animation	O
	Weather alert conditions:	Thunderstorm	M
		Icing	M
		Heavy precipitation	M
		High winds	M
		Low visibility	M
	Weather alert time:	5 - 10 minutes	I
User-friendliness	Data entry option:	Touch screen	O
	Interpretation time of weather information:	25 - 60 seconds	I
Costs	Non-recurring cost:	\$3,001 – 5,000	I
	Recurring cost:	\$0 - 500	O

Attractive product

The attractive product is conceived as a high end, value added product and is comprised o attractive characteristics when ever possible. Attractive requirements are the product criteria that have the highest influence on how satisfied a customer will be with a given product. The customer does not necessarily expect them, but fulfilling them leads to a more than proportional level of satisfaction. From a competitive advantage view, fulfillment of attractive requirements result in a product that will stand out in the market. The characteristics of this product are stated in Table 21.

The attractive product has the following improvements compared to the one-dimensional product:

- Weather product winds aloft
- Smaller grid size (2 x 2 miles - 4 x 4 miles)
- Turbulence as a weather alert
- Smaller data interpretation time for the pilot (0-25 seconds)

The non-recurring costs are the same as the one-dimensional product since it is the highest option possible according to pilot responses.

Table 21 Characteristics of the attractive product

Graphical Weather			Kano category:
	Graphical weather products:	AIRMETs	M
		METARs	M
		TAFs	M
		Winds aloft	A
		Icing	M
		Convective	M
		Turbulence	M
		Ceiling/Visibility	M
	Grid size:	2 x 2 mi - 4 x 4 mi	I
Characteristics	Weather update interval:	5 - 10 minutes	M
	Display of hazardous weather:	Radar loop animation	O
	Weather alert conditions:	Thunderstorm	M
		Icing	M
		Heavy precipitation	M
		High winds	M
		Low visibility	M
		Turbulence	A
	Weather alert time:	5 - 10 minutes	I
Other Characteristics		Additional services	I
User-friendliness	Data entry option:	Touch screen	O
	Interpretation time of weather information:	0 - 25 seconds	I
Costs	Non-recurring cost:	\$3,001 – 5,000	I
	Recurring cost:	\$ 0 – 500	O

4.7 Summary

An important first step in weather information product development is determination of customer needs and desires for various characteristics and identification of a methodology for discriminating between these factors and the level of performance. Ultimately, a method must be established to map this information into product requirements and the technical performance characteristics that achieve them. This chapter proposed and demonstrated a methodology to achieve this based on integration of QFD with Kano's model of customer satisfaction.

This chapter analyzed a customer survey that provided information on backgrounds of the survey participants, their flight characteristics, and requirements for wide range of decision-aids. It applied the model methodology to identify the degree of importance values for product characteristics based on Kano formatted questions and analytical methods. Results of the comprehensive survey contributed to understanding of the requirements of cockpit weather systems in the GA market and allowed definition of four different cockpit weather information systems based on the Kano categories described by the survey participants.

The next chapter takes these customer requirements and applies them to a set of design requirements (DRs) and explains how these DRs are matched to the four products specification definitions based on the CRs.

5 QFD-based Decision Model

This chapter discusses identification of the design requirements that are potential technical characteristics (hows) to support the customer requirements (whats) that were identified in the previous chapter. It demonstrates the use of the QFD-Kano model to relate the design and customer requirements for the four different product specifications defined in the previous chapter. Finally, it suggests an evaluation method to apply this approach for selecting data links for these product alternatives.

5.1 Definitions of Design Requirements (DRs)

Design requirements are those attributes of the weather information system that will dictate the performance of the system and ultimately how the customer base accepts it. A literature search on information systems identified a set of basic design requirements that define the information system in terms of its physical characteristics and architecture: user data rate, network coverage, capacity, connection delay, message latency, request-reply capability, traffic information capability, and position reporting. Based on this set of design requirements, the CR-DR relationship ratings were also identified for the QFD matrix as discussed in Chapter 3. These design requirements dictate the performance characteristics of the system as viewed by the user. Various design requirements will have different levels of importance based on the specific product produced. For example, the design requirements described above will vary in importance for each of the product definitions identified in the previous chapter. Design requirements are assumed independent of one another in this preliminary concept study. Their definitions are as follows:

- *Data Rate:* Data rate is an important design requirement since it affects the type and quality of services provided. For example, a low data rate service such as ACARS cannot support a large number of graphical products or high-resolution graphics. Data rates may be variable or fixed depending on the access protocol. Fixed data rates are provided by communication schemes such as FDMA (Frequency Division Multiple Access) and are applicable to critical safety services which need a guaranteed data rate. The advantage with variable bit rate (VBR) schemes is that the data rates can be changes based on the demand or type of service requested as well as the number of users accessing the channel. This results in better efficiency.
- *Connection Delay:* Connection delay is defined as the 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:* Message latency is defined as the elapsed interval from the time the message was transmitted to the time it was received.
- *Traffic Information Capability:* Some data links have capability to support multiple aeronautical functions such as communication, navigation, or surveillance. This is particularly useful for general aviation aircraft that do not have the means or interest to equip with separate specialized data links especially if investment in one system can solve multiple needs.
- *Request/Reply Capability:* Request/reply is particularly useful if voice capability or flight-specific weather information is needed.
- *Position Reporting:* This feature is essential when location based weather information is required. The ability to receive position-based information reduces the workload of the pilot, since it presents only information relevant to the current flight position and flight plan.

The next section relates these design requirements to the product definitions derived from the customer survey.

5.2 Design Requirement Analysis for the Product Definitions

The product definitions in Chapter 4 dictate performance characteristics of the weather information system's hardware and communication link. To more precisely define this relationship, the QFD matrix establishes values for the relationships between the customer requirements and design requirements. Each design attribute is important to the consumer requirement in varying degrees depending on the extent the consumer requirement is needed for that product definition. As discussed in Chapter 4, the QFD method assigns a value of 0, 1, 3, or 9 to assess the weighting for this relationship. The analysis for the complete WIS (i.e. the data link, the hardware, and the cost) identifies the system attributes (or DRs) that are important to the product definitions. Table 22 summarizes a general description of the design requirements for the different product definitions.

Table 22 Design requirement analysis according to product definitions

[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	Channel loading is minimum due to low update frequency and large grid size. Hence data rate and latency are not important design characteristics. A two-way link is more suitable than broadcast since the user does not need frequent updates and can request them on a per-need basis. Does not have to pay for information that he/she does not use.
	[illegible]	Integrated with another communication unit or with a wireless enabled hand-held computer.
	[illegible]	Due to the low non-recurring cost requirements, it will be attractive for the consumer if this system is an add-on to another system rather than a WIS only. Thus the hardware cost would also be shared and the customer would be willing to make the initial investment. The pricing plan should be per usage and not fixed monthly as the usage is low.
[illegible]	[illegible]	In the 'Must-be' WIS product definition, there are a moderate number of graphical weather products and increased update and grid size requirements. A system that meets this requirement has a data rate in the region of a few kbps and may be two-way or broadcast.
	[illegible]	A graphics capable CDU DEFINE with basic hardware capabilities. The graphics are simple therefore high color depth and resolution are not needed.
[illegible]	[illegible]	This product definition has E-PIREPs capability hence position reporting or a two-way link is an important system characteristic. It has a bigger suite of weather products and forecast weather products hence data rate has to be high and latency small. The connection delay is an important design requirement since frequent, periodic access to the channel for down linking the electronic pilot reports is needed.
	[illegible]	Touch screen display. Moderate graphics capability and a means to distinguish between forecast and observations.
[illegible]	[illegible]	The attractive product definition has all the 'bells and whistles' and the design requirements of data rate, latency, and connection delay are the most important due to the large number of graphical weather products and high update frequency. To enable all weather, traffic and other services, a broadband system is needed. It may be an asymmetrical link for more efficient use of bandwidth.
	[illegible]	Advanced graphics with vector processing is needed to display radar loop animation. Moving map display may be needed for traffic information capability.

5.3 QFD Models for Product Definitions

Tables 23, 24, 25, and 26 show the QFD models for the four product definitions: minimum expectation, must-be, one-dimensional, and attractive products respectively. All calculations are based on the formulas and methods discussed in Chapter 3. The average importance value for the graphical weather products in the tables are simply the average of the absolute importance values of the graphical weather products in that product category. For example, in the minimum expectation product QFD model (Table 23), the average importance value for the graphical products section is the average of the absolute importance values of METARs, TAFs, icing, convective, and ceiling/visibility.

These QFD models include customer requirements only in the following categories: graphical weather products, grid size, weather update interval, hazardous weather display, and (only in the attractive product decision model) additional services. The reason for this distinction is that the selected design characteristics are specifically data link related for meeting the customer requirements.

For the minimum expectation product, the relative importance ratings in the bottom line of Table 23 indicate that request/reply capability (0.33) and user data rate (0.15) are the most important technical characteristics. User data rate is followed closely by capacity, network coverage, latency, and connection delay. Traffic information and position reporting are not important. If this product can meet the cost expectations, the customer will buy it with the expectations for basic, functional performance. This product can be conceived as a first entry product.

Table 23 QFD model for the minimum expectation product

Design Requirements (DRj)

[redacted]	User Data Rate	Request / Reply Capability	Traffic Info Capability	Capacity	Network Coverage	Latency	Connection Delay	Position Reporting
	1	1	0	1	1	1	1	1
	1	0	0	1	1	1	1	0
	1	9	0	1	1	0	0	0
	1	0	0	0	0	1	1	0
AI_j=Absolute importance rating of DR_j	1.00	2.19	0.00	0.77	0.77	0.80	0.80	0.36
RI_j=Relative importance rating of DR_j	**0.15**	**0.33**	0.00	0.12	0.12	0.12	0.12	0.05

The relative importance ratings in Table 24 indicate that user data rate (0.22), latency (0.19), and connection delay (0.19) are the most important technical characteristics for the must-be product definition. This product can be conceived as an improved version as competitors enter the market.

Table 24 QFD model for the must-be product

	Design Requirements (DRj)							
	User Data Rate	Request / Reply Capability	Traffic Info Capability	Capacity	Network Coverage	Latency	Connection Delay	Position Reporting
[illegible]	3	1	0	1	1	3	3	1
[illegible]	3	3	0	1	1	3	3	3
[illegible]	3	1	0	3	3	3	3	0
[illegible]	3	1	0	1	1	1	1	0
AI_j=Absolute (technical) importance rating of DR_j	3.00	1.39	0.00	1.52	1.52	2.52	2.52	0.89
RI_j=Relative (technical) importance rating of DR_j	**0.22**	0.10	0.00	0.11	0.11	**0.19**	**0.19**	0.07

The relative importance ratings in Table 25 indicate that user data rate (0.21), position reporting (0.19), latency (0.15) and connection delay (0.15) are the most important technical characteristics for a one-dimensional product. For these products, a higher level of fulfillment of the customer requirements results in a proportionally higher customer satisfaction, and vice versa. This product can be conceived as a higher end product with value added features that will support higher margins.

Table 25 QFD model for the one-dimensional product

	Design Requirements (DRj)							
[redacted]	User Data Rate	Request / Reply Capability	Traffic Info Capability	Capacity	Network Coverage	Latency	Connection Delay	Position Reporting
	9	1	0	9	1	3	3	9
	3	3	0	1	1	3	3	3
	3	1	0	3	3	3	3	0
	9	9	0	1	1	9	9	9
AI_j=Absolute (technical) importance rating of DR_j	6.54	3.95	0.00	3.59	1.47	4.95	4.95	5.84
RI_j=Relative (technical) importance rating of DR_j	**0.21**	0.13	0.00	0.11	0.05	**0.16**	**0.16**	**0.19**

The relative importance ratings in Table 26 indicate that user data rate (0.25), latency (0.25), connection delay (0.16), and position reporting (0.14) are the most important technical characteristics for an attractive product. This product is conceived as the top of the line and the product will stand out in the market. The product developer has the flexibility to include the feature bundles (characteristics) based on cost or margin targets and market strategy. For example, if including a specific attractive requirement into the system results in unreasonably high cost (or reduced margins) that the high - end customer will not support, alternative "A" characteristics should be considered. However, if that characteristic does not cause an unreasonable cost increase and can support higher margins, including it would provide the company a competitive edge and market success.

Table 26 QFD model for the attractive product

[redacted]	User Data Rate	Request / Reply Capability	Traffic Info Capability	Capacity	Network Coverage	Latency	Connection Delay	Position Reporting
	9	1	0	9	1	9	9	9
	9	9	0	1	1	9	3	9
	9	1	0	3	3	9	9	3
	9	3	0	1	1	9	3	3
	9	9	0	1	1	9	3	0
AI_j=Absolute (technical) importance rating of DR_j	9.00	2.64	0.00	3.23	1.42	9.00	5.61	4.87
RI_j=Relative (technical) importance rating of DR_j	**0.25**	0.07	0.00	0.09	0.04	**0.25**	**0.16**	**0.14**

Design Requirements (DRj)

Table 27 summarizes the relative importance ratings of the DRs for each product definition discussed previously. It can be concluded that user data rate is important for all four products, and product developers should give priority to this characteristic in product design. Request/reply capability is very important to develop a minimum expectation product. Traffic information capability is not an important design characteristic for any product. Capacity has moderate importance for each product. Network coverage is a moderately important characteristic for the minimum expectation and must-be product and less important for one-dimensional and attractive products. Latency and connection delay are particularly important for must-be, one-dimensional and attractive products. Position reporting is less important for minimum expectation and must-be products, but should be a priority for one-dimensional and attractive products. In summary, product developers should give the highest priority to:

- Request/reply capability to develop a minimum expectation product.
- User data rate to develop a must-be or one-dimensional product.
- Latency or user data rate to develop an attractive product.

Table 27 Relative importance ratings of the DRs for product definitions

DRs	Minimum expectation product	Must-be product	One-dimensional product	Attractive product
User Data Rate	**0.15**	**0.22**	**0.21**	**0.25**
Request / Reply Capability	**0.33**	0.10	0.13	0.07
Traffic Info Capability	0.00	0.00	0.00	0.00
Capacity	0.12	0.11	0.11	0.09
Network Coverage	0.12	0.11	0.05	0.04
Latency	0.12	**0.19**	**0.16**	**0.25**
Connection Delay	0.12	**0.19**	**0.16**	**0.16**
Position Reporting	0.05	0.07	**0.19**	**0.14**

5.4 Evaluation of Data Links for Various Product Definitions

The QFD model's competitive analysis involves evaluating the performances of the various data links against the identified design requirements. The design requirements that are important to the product definitions have been identified, and based on the assessment of candidate technologies, recommendations are made in this section.

The data links were rated or scored against the design requirements and the results are shown in Table 28, employing the QFD approach identified in Figure 1 and discussed in Chapter 3. The project team determined the ratings in the example based on the team's knowledge of the data link systems. Hardware cost was not taken into account in this analysis.

Table 28 Data Link Performance Matrix

	WIS Data Links									
DRs	ACARS	VDL-2	VDL-B	VDL-3	VDL-4	UAT	Mode S	Aircell	EchoFlight (LEO Satellite)	WSI Inflight (GEO Satellite)
User Data Rate	1	3	9	3	3	9	1	3	3	9
Request / Reply Capability	9	9	0	9	3	0	1	9	9	0
Traffic Info Capability	1	1	3	1	9	9	9	0	1	3
Capacity	1	3	9	3	3	9	1	1	1	9
Network Coverage	3	3	3	3	3	3	3	3	9	9
Latency	1	1	3	3	3	9	3	3	1	1
Connection Delay	1	3	9	3	9	9	1	3	1	1
Position Reporting	9	3	0	3	9	9	9	3	9	0

Explanation of the Ratings: *9 Best; Available*
3 Moderate Performance; Restricted Availability
1: Poor Performance; Insufficient
0: No provision

Using the QFD scoring method and the ratings in Table 28, the various data links can be evaluated in comparison with the requirements of the four conceptual products. The resulting relative importance values of the design requirements (RI_j) are shown in tables 29, 30, 31, and 32. The total score of each data link was calculated using:

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

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

Table 29 Data link scoring for the minimum expectation product

		WIS 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	0.15	1	3	9	3	3	9	1	3	3	9
Request / Reply Capability	0.33	9	9	0	9	3	0	1	9	9	0
Traffic Info Capability	0	1	1	3	1	9	9	9	0	1	3
Capacity	0.12	1	3	9	3	3	9	1	1	1	9
Network Coverage	0.12	3	3	3	3	3	3	3	3	9	9
Latency	0.12	1	1	3	3	3	9	3	3	1	1
Connection Delay	0.12	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:	4.29	4.77	4.23	5.01	4.05	**5.4**	1.89	4.77	5.31	3.75

Table 30 Data link scoring for the must-be product

		WIS 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	0.22	1	3	9	3	3	9	1	3	3	9
Request / Reply Capability	0.1	9	9	0	9	3	0	1	9	9	0
Traffic Info Capability	0	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	0.11	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	0.19	1	3	9	3	9	9	1	3	1	1
Position Reporting	0.07	9	3	0	3	9	9	9	3	9	0
	Total score:	2.57	3.19	5.58	3.57	4.53	**7.35**	2.15	3.35	3.67	4.34

Table 31 Data link scoring for the one-dimensional 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)
		WIS Data Links									
User Data Rate	0.21	1	3	9	3	3	9	1	3	3	9
Request / Reply Capability	0.13	9	9	0	9	3	0	1	9	9	0
Traffic Info Capability	0	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	0.05	3	3	3	3	3	3	3	3	9	9
Latency	0.16	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	0.19	9	3	0	3	9	9	9	3	9	0
	Total score:	3.67	3.49	4.95	3.81	5.13	**7.62**	2.95	3.59	4.39	3.65

Table 32 Data link scoring for the attractive 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)
		WIS Data Links									
User Data Rate	0.25	1	3	9	3	3	9	1	3	3	9
Request / Reply Capability	0.07	9	9	0	9	3	0	1	9	9	0
Traffic Info Capability	0	1	1	3	1	9	9	9	0	1	3
Capacity	0.09	1	3	9	3	3	9	1	1	1	9
Network Coverage	0.04	3	3	3	3	3	3	3	3	9	9
Latency	0.25	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	0.14	9	3	0	3	9	9	9	3	9	0
	Total score:	2.76	2.92	5.37	3.42	4.8	**8.13**	2.7	3.24	3.5	3.83

Figure 9 shows a summary of the data link scores in relation to product definitions. According to the analysis described in tables 29, 30, 31, and 32, UAT is the first choice for supporting an integrated spectrum of weather information products (without cost consideration). The first four data link preferences for each product definition is as follows:

- For the minimum expectation product, UAT has the highest score (5.4),and EchoFlight (LEO Satellite) and VDL-3 closely follows it with 5.31 and 5.01 respectively. VDL-2 and Aircell score equally at 4.77.
- For the must-be product, UAT has the highest score (7.35) and VDL-B, VDL-4, and WSI Inflight (GEO Satellite) follow with 5.58, 4.5, and 4.34 respectively.
- For the one-dimensional product, UAT has the highest score (7.62) and VDL-4, VDL-B, and EchoFlight (LEO Satellite) follow with 5.13, 4.95, and 4.39 respectively.
- For the attractive product, UAT has the highest score (8.13) and VDL-B and VDL-4 follow with 5.37 and 4.80 respectively. WSI Inflight (GEO Satellite) has the fourth highest score as 3.83.

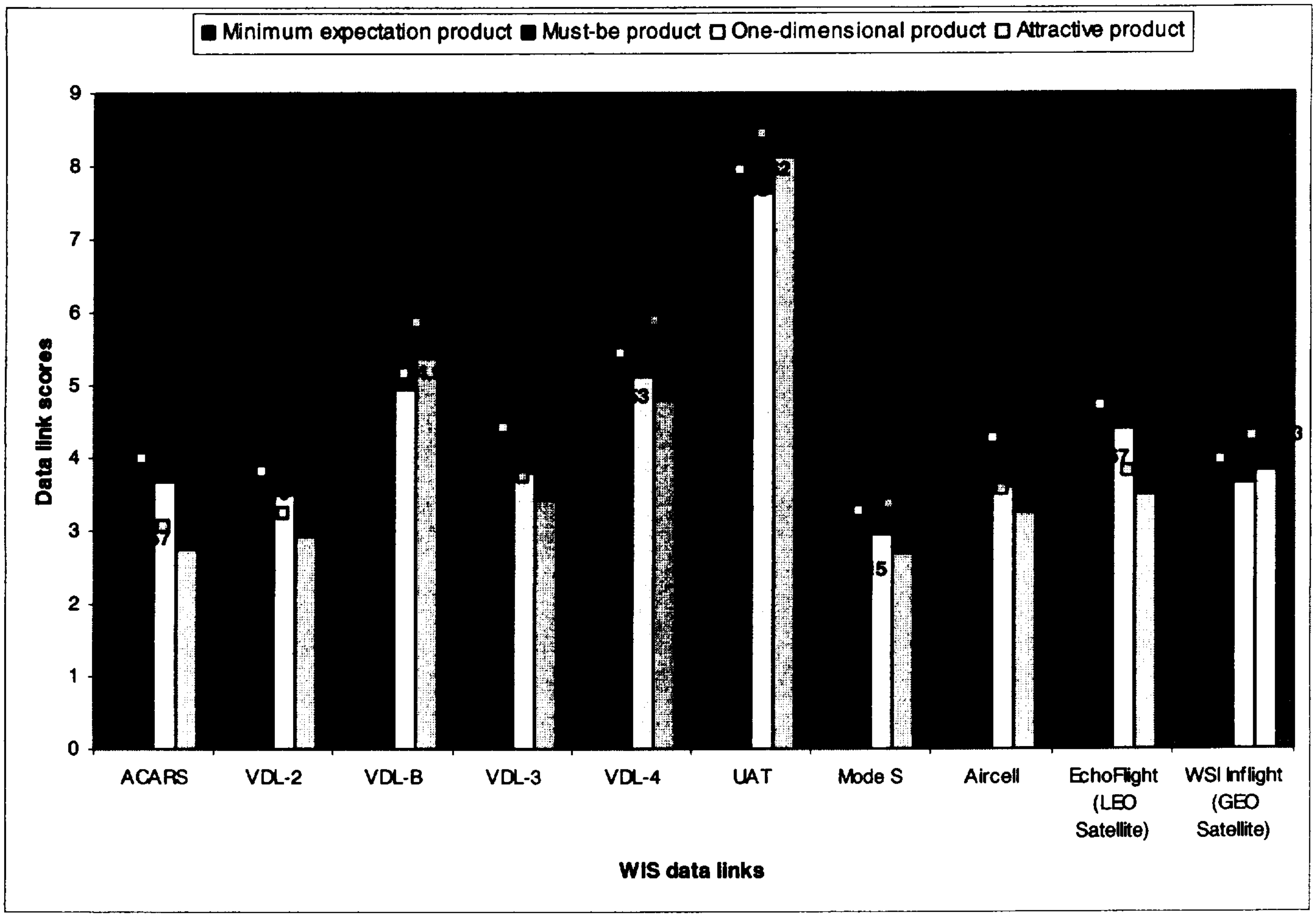


Figure 9 WIS data links in relation to product definitions

It is important to emphasize that this selection of data link preference is primarily a demonstration of the model methodology and applies only to the particular set of criteria used in this study. The performance of technologies is based on numerous factors and different conditions so there should be a comprehensive process of eliciting information from subject matter experts. This was beyond the scope of this first step in developing a conceptual model. Furthermore improvements and evolution of the technologies are always taking place and the correct measure of performance can only be obtained after detailed simulations and trials.

5.5 Summary

This chapter first defined possible design requirements for use in the QFD matrix. Then, it developed QFD models for four different product definitions, which were discussed in Chapter 4, and identified the most important design requirements for each product based on equations (1) and (2). It concluded that, in order to meet customer expectations, product developers should give the highest priority to:

- Request/reply capability to develop a minimum expectation product,
- User data rate to develop a must-be or one-dimensional product, and
- Latency or user data rate to develop an attractive product.

Next, a QFD scoring method was employed to estimate and compare the overall performance of alternative data links based on the design requirements. This method identified UAT as the most capable data link candidate for the weather information product and its required technical characteristics. Although this is a conceptual model, this result is consistent with a recent report by Lockheed Martin (ref. 1), which concluded that UAT is potentially very useful for cockpit weather since it has the theoretical bandwidth for advanced cockpit weather information systems due to its special capability to support ADS-B (Automated Dependent Surveillance - Broadcast) and complex weather graphics.

However, the Lockheed Martin report also concluded that UAT does not yet have an officially assigned frequency and is behind VDL4 in terms of technical development of standards. Product developers would need to take these issues into consideration in the product timetables. If these issues are solved, UAT is an attractive data link for cockpit weather. As alternatives, the VDL data links were also rated highly to support a cockpit weather information system that meets pilot needs.

6 Conclusions and Future Work

This study focused on developing decision models to improve information system product development with specific focus on cockpit weather information systems. In summary, it developed a decision method that demonstrated credible results in linking customer needs to technical requirements and evaluating data links to meet these requirements. First, it provided background information on graphical weather products and data links. Then, QFD and Kano's modeling approaches were explained and identified as complementary tools suitable for information technology product development. They were then integrated into a combined decision model that rated the importance of technical characteristics in achieving product characteristics.

To demonstrate the capabilities of the model to provide advanced product development information, a detailed customer survey was executed and analyzed to provide detailed information about customer requirements and their importance values. This survey data was used to define four different levels or generations of potential products that spanned expected life cycles of products from introduction to advanced value added. Using the survey results and the combined QFD-based decision models, the most important design requirements for these four product definitions to meet customer needs were determined. Finally, individual data link alternatives were rated to examine their potential to support these design requirements.

A critical test for any hypothesized model is producing credible results and the preliminary findings met this test. Based on 370 survey responses, the model identified data rate as important for all four products and weather information product developers should give priority to this design characteristic. Importance of other design requirements varied based on the level of the product. For example, request/reply capability is very important to serve as a market entry basis for the minimum expectation product. Traffic information capability is not an important design characteristic for any product. On the higher end of products, latency and connection delay are particularly important for must-be, one-dimensional and attractive products. Position reporting is not important for minimum expectation and must-be products but should be a priority for one-dimensional and attractive products. In summary, the model found that product developers should give the highest priority to:

- Request/reply capability to develop a minimum expectation product,
- User data rate to develop a must-be or one-dimensional product, and
- Latency or user data rate to develop an attractive product.

This study also employed the results of prioritizing the design characteristics using the integrated model with a QFD scoring method to measure and compare the projected overall performance of alternative data links to fulfill the design requirements of the four hypothesized products. This two level method identified UAT as the most capable data link across the product spectrum. This indicates this alternative has the potential to support long - term weather product evolution of the customer requirements. VDL data links, EchoFlight (LEO Satellite), WIS Inflight (GEO Satallite) and Aircell also demonstrated varying degrees of potential to support cockpit weather information system development. The QFD-based decision model matched survey - identified customer needs to technical characteristics that are achievable by using data links selected via a scoring method.

Although over 600 survey responses were gathered, this report includes information from 370. Analysis of the remaining responses is continuing and will focus on determining differences in required product characteristics in areas such as pilot characteristics or geography. In addition, sensitivity of the model to various input changes will be explored along with approaches to integrate cost analysis. These results will be published in the near future in an updated report, a forthcoming dissertation and a number of conference and journal papers.

References

1. Lockheed Martin Aeronautical Systems, AvCS, Inc., "Data Communications Requirements, Technology and Solutions for Aviation Weather Information Systems," Phase 1 and 2 Reports, Aviation Weather Communications Requirements, NASA Contract N66001-97-C-8605, March 1999.

2. Stough, Paul, "Aviation Weather Information Distribution and Presentation," NASA report, NASA Langley Research Center, August 6, 1998.

3. Tam, K. Y. and Hui, K. L., "Price Elasticity and the Growth of Computer Spending," IEEE Transactions on Engineering Management, vol. 46, no. 2, pp. 190, May 1999.

4. Berggren, E. and Nacher, T., "Introducing New Products Can Be Hazardous to Your Company: Use the Right New-Solutions Delivery Tools," The Academy of Management Executive, vol. 15, no. 3, pp. 92-101, Briarcliff Manor, August 2001.

5. Jiang, J. J. and Klein, G., "Information System Success as Impacted by Risks and Development Strategies," IEEE Transactions on Engineering Management, vol. 48, no. 1, pp. 46-54, February 2001.

6. Gallagher, S., "Beat the Systems Management Odds," Information Week, vol. 675, pp. 61-76, March 30, 1998.

7. Keel M. B., et al., "Aviation Weather Information Requirements Study," Georgia Tech Research Institute, NASA CR-2000-210288, June 2000. Intelligent Transportation Society of America web page: http://www.itsa.org.

8. Gallagher Ball, J. W., et al., "Data Communications Requirements, Technology and Solutions for Aviation Weather Information Systems," Lockheed Martin Aeronautical Systems, Phase II Report for NASA Glenn Research Center, March 2000.

9. Sireli, Yesim, Surabhi Gupta, Paul Kauffmann, and Pushkin Kachroo, "Implications of Automotive and Trucking On-Board Infromation Systems for General Aviation Cockpit Weather Systems," NASA report, NASA Langley Research Center, October 2001.

10. Sireli, Yesim, and Paul Kauffmann, "Future Trends for General Aviation In-Cockpit Weather Information Systems," SAE General Aviation Technology Conference & Exhibition, April 16-18, 2002, Wichita, KS.

11. Sireli, Yesim, Paul Kauffmann, and Erol Ozan, "A Quality Function Deployment Decision Model for the Information Systems Market," American Society for Engineering Management National Conference, October 2-5, 2002, Tampa, FL.

12. Shen, X. X., Tan, K. C., and Xie, M., "Benchmarking in QFD for Quality Improvement," Benchmarking, vol. 7, no. 4, pp. 282-291, Bradford, 2000.

13. Park, T. and Kim, K. J., "Determination of an Optimal Set of Design Requirements Using House of Quality," Journal of Operations Management, Volume 16, Issue 5, pp. 569-581, October 1998.

14. Presley, A., Sarkis, J., and Liles, D. H., "A Soft-Systems Methodology Approach for Product and Process Innovation," IEEE Transactions on Engineering Management, vol. 47, no. 3, pp. 379-392, August 2000.

15. Ho, E. S. S. A., Lai, Y. J., and Chang, S. I., "An Integrated Group Decision-Making Approach to Quality Function Deployment," IIE Transactions, vol. 31, pp. 553-567, 1999.

16. Kano, N., Seracu, N., Takahashi, F., and Tsuji, S., "Attractive quality and must-be quality," Hinshitsu: The Journal of Japanese Society for Quality Control, vol. 14, pp. 39-48, April 1984.

17. Huiskonen, J. and Pirttila, T., "Sharpening logistics customer service strategy planning by applying Kano's quality element classification," International Journal of Production Economics, vol. 56-57, pp. 253-260, 1998.

18. Matzler, K., Hinterhuber, H. H., Bailom, F., and Sauerwein, E., "How to delight your customers," Journal of Product and Brand Management, vol. 5, pp. 6-18, 1996.

19. Tan, K. C. and Shen, X. X., "Integrating Kano's model in the planning matrix of quality function deployment," Total Quality Management, vol. 11, p. 1141, December 2000.

20. Matzler, K. and Hinterhuber, H. H., "How to make product development projects more successful by integrating Kano's model of customer satisfaction into quality function deployment," Technovation, vol. 18, no. 1, pp. 25-38, 1998.

21. Fong, D., "Using the Self-Stated Importance Questionnaire to Interpret Kano Questionnaire Results," Center for Quality of Management Journal, vol. 5, no. 3, Winter, 1996.

Appendix A. Customer Survey Questionnaire

This survey questionnaire was prepared by a focus group of 6 pilots from various backgrounds.

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 (y_sireli@yahoo.com) 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 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.

BACKGROUND INFORMATION

Please describe your aviation background in this section.

Certificate (please check only one):

? Student
? Recreational
? Private
? Commercial
? Airline Transport

Instructor:

? I am CFI, CFII, or MEI rated

Instrument Rating:

? I am instrument rated
? I am a VFR pilot
Total actual instrument time:
Total cross country hours:

Which aircraft type do you usually fly? Please check only one as the reference for completing the remainder of the survey.

? Single engine piston
? Multi engine piston
? Single engine turboprop
? Multi engine turboprop
? Jet less than 20,000 lbs MTOW (e.g. Cessna CJ1, Beechjet, etc.)
? Jet 20,000 to 100,000 lbs MTOW (e.g. Hawker 800, Falcon, etc.)
? Large transport (e.g. Boeing BBJ, Airbus ACJ)

What are your typical cruise altitudes and airspeeds? _________ altitude _________ airspeed in knots

What is the typical length of your flights? _________ nautical miles

What is your total flight hours? _________

Are you current? ? Yes ? No

Which region of the U.S. do you usually fly?

? Northeast ? Southeast ? Northwest ? Southwest ? North-central ? South-central

IMPORTANT! Throughout this survey, assume that each feature you select may require additional costs for the system. Please prioritize your choices by keeping this in mind.

This section examines your preferences for various weather products as a part of the new cockpit weather information system.

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.

1A. 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)	?	?	?	?	?
AIRMETs (AIRman's METeorological Information)	?	?	?	?	?
METARs (Aviation Routine Weather Report)	?	?	?	?	?
TAFs (Terminal Aerodrome Forecast)	?	?	?	?	?
Winds Aloft	?	?	?	?	?
Icing	?	?	?	?	?
Convective	?	?	?	?	?
Turbulence	?	?	?	?	?
Ceiling/Visibility	?	?	?	?	?

1B. Please clear your mind, and think again independent 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)	?	?	?	?	?
AIRMETs (AIRman's METeorological Information)	?	?	?	?	?
METARs (Aviation Routine Weather Report)	?	?	?	?	?
TAFs (Terminal Aerodrome Forecast)	?	?	?	?	?
Winds Aloft	?	?	?	?	?
Icing	?	?	?	?	?
Convective	?	?	?	?	?
Turbulence	?	?	?	?	?
Ceiling/Visibility	?	?	?	?	?

Minimum grid size (resolution) for the graphical display.

2A. 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	?	?	?	?	?
5 x 5 mi - 8 x 8 mi	?	?	?	?	?
9 x 9 mi - 12 x 12 mi	?	?	?	?	?

2B. Please clear your mind, and think again independent 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	?	?	?	?	?
5 x 5 mi - 8 x 8 mi	?	?	?	?	?
9 x 9 mi - 12 x 12 mi	?	?	?	?	?

IMPORTANT! Throughout this survey, assume that each feature you select may require additional costs for the system. Please prioritize your choices by keeping this in mind.

CHARACTERISTICS OF THE SYSTEM

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.

3A. 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	?	?	?	?	?
5-10 minutes	?	?	?	?	?
10-20 minutes	?	?	?	?	?
20-30 minutes	?	?	?	?	?
30-60 minutes	?	?	?	?	?
Or Specify:......	?	?	?	?	?

3B. Please clear your mind, and think again independent 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	?	?	?	?	?
5-10 minutes	?	?	?	?	?
10-20 minutes	?	?	?	?	?
20-30 minutes	?	?	?	?	?
30-60 minutes	?	?	?	?	?
Or Specify:......	?	?	?	?	?

Direction and movement rate of hazardous weather is information about where and how fast the hazardous weather is moving.

4A. 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	?	?	?	?	?
Voice on request	?	?	?	?	?
Symbols on the graph	?	?	?	?	?
Forecast maps	?	?	?	?	?
Radar loop animation	?	?	?	?	?
Or Specify:......	?	?	?	?	?

4B. Please clear your mind, and think again independent 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	?	?	?	?	?
Voice on request	?	?	?	?	?
Symbols on the graph	?	?	?	?	?
Forecast maps	?	?	?	?	?
Radar loop animation	?	?	?	?	?
Or Specify:......	?	?	?	?	?

Location-Aware Weather Information is the automatic receipt of weather updates that are specific to the course of the aircraft or based on the current location of the aircraft. This may be a feature used by future weather delivery systems to provide more detailed information for a limited area. It is possible only with a two-way system and Global Navigation Satellite System integration e.g. GPS. Please consider the en-route phase of flight for the questions in this section.

5. Please tell us your preference for either of the following two modes of operation to provide location-aware information and select only ONE of the following choices. Please leave it blank if no preference.

? Based on your current geographical location, the weather information system uplinks localized weather updates to you. (You can also receive weather information for another area or on wider scale by making a request).

? The weather information system broadcasts the wide-scale weather information for a large geographical area and you use the on-board system to select the area of interest.

Broadcast vs. Request / Reply. Data can be uplinked from the ground station to the aircraft in one direction with a broadcast, but if the pilot wishes to have a return link to request specific information, a two-way link or request/ reply capability is required.

6. Which method (broadcast or request / reply) do you prefer for the following graphical weather products? Please consider the en-route phase of flight for this question.

Wx products	Broadcast	Request / Reply
PIREPs	?	?
AIRMETs	?	?
METARs	?	?
TAFs	?	?
Winds Aloft	?	?
Icing	?	?
Convective	?	?
Turbulence	?	?
Ceiling/Visibility	?	?

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

7A. 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	?	?	?	?	?
Icing	?	?	?	?	?
Turbulence	?	?	?	?	?
Heavy precipitation	?	?	?	?	?
High winds	?	?	?	?	?
Low visibility	?	?	?	?	?
Or Specify:………	?	?	?	?	?

7B. Please clear your mind, and think again independent 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	?	?	?	?	?
Icing	?	?	?	?	?
Turbulence	?	?	?	?	?
Heavy precipitation	?	?	?	?	?
High winds	?	?	?	?	?
Low visibility	?	?	?	?	?
Or Specify:………	?	?	?	?	?

Weather alert time is the earliest time warning that you get weather alert information before you encounter the weather.

8A. The following are possible weather alert time intervals for the new cockpit weather information system. 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 alert time interval warning	I like this weather alert interval	I need this weather alert interval	I am neutral about this weather alert interval	I can live with this weather alert interval	I dislike this weather alert interval
Instantaneously	?	?	?	?	?
1 - 5 minutes warning	?	?	?	?	?
5 - 10 minutes warning	?	?	?	?	?
10 - 20 minutes warning	?	?	?	?	?
20 – 30 minutes warning	?	?	?	?	?
Or Specify:………	?	?	?	?	?

8B. Please clear your mind, and think again independent from the previous form of the question. How do you feel about NOT HAVING the weather alert time warning intervals below for 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 time interval warning	I do NOT like this weather alert interval	I do NOT need this weather alert interval	I am neutral about this weather alert interval	I can live with NOT having this weather alert interval	I dislike NOT having this weather alert interval
Instantaneously	?	?	?	?	?
1 - 5 minutes warning	?	?	?	?	?
5 - 10 minutes warning	?	?	?	?	?
10 - 20 minutes warning	?	?	?	?	?
20 – 30 minutes warning	?	?	?	?	?
Or Specify:………	?	?	?	?	?

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.

9A. 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	?	?	?	?	?

9B. Please clear your mind, and think again independent 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	?	?	?	?	?

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.

10A. 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	?	?	?	?	?

10B. Please clear your mind, and think again independent 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	?	?	?	?	?

IMPORTANT! Throughout this survey, assume that each feature you select may require additional costs for the system. Please prioritize your choices by keeping this in mind.

COMMUNICATION

Weather Information via Voice and Data Communication. In order to get weather information, the pilot in the cockpit may communicate with the flight service station or the air traffic controllers via *voice*, or *data*, or *both voice and data*. *Voice communication provides* communication with the flight service station or air traffic controllers through a voice radio or another voice link. *Data communication* is the exchange of textual data and/or graphical weather information through the flight service station or air traffic controllers or through broadcast.

11A. Select your preference for the mode of communication of weather information (Voice, Data, or Both voice and data) in each of the following scenarios. Consider one scenario at a time and check one for each row.

Communication Scenario	The most appropriate mode is:	My opinion about this mode for this scenario is:				
		I like this communication mode for this scenario	I need this communication mode for this scenario	I am neutral about this communication mode for this scenario	I can live with this communication mode for this scenario	I dislike this communication mode for this scenario
In case of emergency	Voice ? Data ? Both ?	?	?	?	?	?
For confirmation / clarification	Voice ? Data ? Both ?	?	?	?	?	?
For take-off and landing	Voice ? Data ? Both ?	?	?	?	?	?
Requesting weather routing information	Voice ? Data ? Both ?	?	?	?	?	?
For all weather information	Voice ? Data ? Both ?	?	?	?	?	?
Or Specify:......	Voice ? Data ? Both ?	?	?	?	?	?

11B. Please clear your mind, and think again independent from the previous form of the question. How do you feel about NOT HAVING the mode of communication you selected (for each scenario) for the new cockpit weather information system? Consider one scenario at a time and check one for each row.

Communication Scenario	**As the most appropriate mode you selected:**	**My opinion about this mode for this scenario is:**				
		I do NOT like this communication mode for this scenario	**I do NOT need this communication mode for this scenario**	**I am neutral about this communication mode for this scenario**	**I can live with NOT HAVING this communication mode for this scenario**	**I dislike NOT HAVING this communication mode for this scenario**
In case of emergency	Voice ? Data ? Both ?	?	?	?	?	?
For confirmation / clarification	Voice ? Data ? Both ?	?	?	?	?	?
For take-off and landing	Voice ? Data ? Both ?	?	?	?	?	?
Requesting weather routing information	Voice ? Data ? Both ?	?	?	?	?	?
For all weather information	Voice ? Data ? Both ?	?	?	?	?	?
Or Specify:......	Voice ? Data ? Both ?	?	?	?	?	?

IMPORTANT! Throughout this survey, assume that each feature you select may require additional costs for the system. Please prioritize your choices by keeping this in mind.

User friendliness involves features that make the cockpit weather information system easier to use.

USER-FRIENDLINESS

System data entry describes the means to interface with the display unit and to select various functions.

12A. A number of data entry options 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.

Data entry options	**I like this data entry option included**	**I need this data entry option included**	**I am neutral about this data entry option**	**I can live with including this data entry option**	**I dislike including this data entry option**
Touch screen	?	?	?	?	?
Bezel buttons	?	?	?	?	?
Pen-based system with icons	?	?	?	?	?
Voice recognition	?	?	?	?	?
Joystick	?	?	?	?	?
Trackball	?	?	?	?	?
Or Specify:………	?	?	?	?	?

12B. Please clear your mind, and think again independent from the previous form of the question. The following data entry options 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.

Data entry options	**I like this data entry option omitted**	**I need this data entry option omitted**	**I am neutral about this data entry option**	**I can live with omitting this data entry option**	**I dislike omitting this data entry option**
Touch screen	?	?	?	?	?
Bezel buttons	?	?	?	?	?
Pen-based system with icons	?	?	?	?	?
Voice recognition	?	?	?	?	?
Joystick	?	?	?	?	?
Trackball	?	?	?	?	?
Or Specify:………	?	?	?	?	?

Decision-aiding information. The system should provide processed, useful, and relevant weather information to the pilot (not raw data).

13A. What decision-making functions would you like to have on this system? Please enter them into the decision making functions column below. Consider each choice one at a time and how you feel about the importance of including it. Please check only one for each row.

Decision making functions	I like it included	I need it included	I am neutral about it	I can live with including it	I dislike including it
	?	?	?	?	?
	?	?	?	?	?
	?	?	?	?	?
	?	?	?	?	?
	?	?	?	?	?
	?	?	?	?	?
	?	?	?	?	?

13B. Decision aids will help the pilot interpret weather information. Different amounts of time may be required to interpret weather information on the new system. Consider each interval one at a time and how you feel about the importance of it. Please check only one for each row.

Time required for the interpretation of weather info	I like this interval to interpret weather information	I need this interval to interpret weather information	I am neutral about this interval to interpret weather information	I can live with this interval to interpret weather information	I dislike this interval to interpret weather information
0 – 25 seconds	?	?	?	?	?
25 – 60 seconds	?	?	?	?	?
1-2 minutes	?	?	?	?	?
2-5 minutes	?	?	?	?	?
5-10 minutes	?	?	?	?	?
Or Specify:………	?	?	?	?	?

13C. Consider the time interval options for the interpretation of weather information once more. Tell us how you feel about them again, using the table below. Consider each choice one at a time and check one for each row.

Time required for the interpretation of weather info	I do NOT like this interval to interpret weather information	I do NOT need this interval to interpret weather information	I am neutral about this interval to interpret weather information	I can live with NOT HAVING this interval to interpret weather information	I dislike NOT HAVING this interval to interpret weather information
0 – 25 seconds	?	?	?	?	?
25 – 60 seconds	?	?	?	?	?
1-2 minutes	?	?	?	?	?
2-5 minutes	?	?	?	?	?
5-10 minutes	?	?	?	?	?
Or Specify:………	?	?	?	?	?

IMPORTANT! Throughout this survey, assume that each feature you select may require additional costs for the system. Please prioritize your choices by keeping this in mind.

COSTS

14. If this system were available now, who would pay for it? Please check one.

? You (out of your pocket)
O Your business. Define your business:......................................

Non-recurring costs are one-time costs for purchase and installation of the system (hardware plus installation).

15A. The non-recurring cost of the new cockpit weather information system could be one of the following amounts. Consider each choice one at a time and how you feel about the importance of paying that amount. Please check only one for each row.

Non-recurring costs	I am comfortable about paying this amount	I am willing to pay this amount	I am neutral about this amount	I can live with paying this amount	I dislike paying this amount
$1,000 – 3,000	?	?	?	?	?
$3,001 – 5,000	?	?	?	?	?
$5,001 – 10,000	?	?	?	?	?
$10,001 – 20,000	?	?	?	?	?
$20,001 – 30,000	?	?	?	?	?
Or Specify:.........	?	?	?	?	?

15B. Consider the non-recurring cost options for the new system once more. Tell us how you feel about them again, using the table below. Consider each choice one at a time and check one for each row.

Non-recurring costs	This amount is unreasonable	I do not like to pay this amount	I am neutral about this amount	I would consider paying this amount	I am willing to pay this amount
$1,000 – 3,000	?	?	?	?	?
$3,001 – 5,000	?	?	?	?	?
$5,001 – 10,000	?	?	?	?	?
$10,001 – 20,000	?	?	?	?	?
$20,001 – 30,000	?	?	?	?	?
Or Specify:.........	?	?	?	?	?

Recurring costs are annual costs for the services of the system.

16A. The annual recurring cost of the new cockpit weather information system could be one of the following amounts. Consider each choice one at a time and how you feel about the importance of paying that amount. Please check only one for each row.

Recurring costs (per year)	**I am comfortable about paying this amount**	**I am willing to pay this amount**	**I am neutral about paying this amount**	**I can live with paying this amount**	**I dislike paying this amount**
\$0 – 500	?	?	?	?	?
\$501 – 1,000	?	?	?	?	?
\$1,001 – 1,500	?	?	?	?	?
Or Specify:……..	?	?	?	?	?

16B. Consider the annual recurring cost options for the new system once more. Tell us how you feel about them again, using the table below. Consider each choice one at a time and check one for each row.

Recurring costs (per year)	**This amount is unreasonable**	**I do not like to pay this amount**	**I am neutral about this amount**	**I would consider paying this amount**	**I am willing to pay this amount**
\$0 – 500	?	?	?	?	?
\$501 – 1,000	?	?	?	?	?
\$1,0 01 – 1,500	?	?	?	?	?
Or Specify:……..	?	?	?	?	?

Time to market means the time (beginning from now) until the new product is introduced to the market.

17. Assume that the system whose features you determined by selecting the options above will exist in the future. Based on your current need to have this system, "how soon" would you like it to be in market?

Already in the market	0-3 months	3-6 months	6 months – 1 year	1-2 years	2 – 3 years	Or Specify
?	?	?	?	?	?	

18. If you selected the "already in the market" option above, please specify the product:………

This concludes the survey. Thank you for your participation.