Longitudinal Study of the Market Penetration of Cockpit Weather Information Systems

Final Report

Prepared for

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Executive Summary

The purpose of the longitudinal research of the market penetration of cockpit weather information systems (CWIS) is to contribute to the body of knowledge on modeling advanced technology feasibility in aviation by tracking and analyzing the market adoption of CWIS over a three year period. This research takes advantage of a previous study, conducted by Dr. Paul Kauffmann in 2000, which demonstrated an integrated and cost effective approach to evaluate advanced technology feasibility, examining the feasibility of CWIS in five market segments: transport, commuter, general aviation, business, and rotorcraft.

The longitudinal research consists of two consecutive studies and produced two reports. The first report was submitted in August 2003 and included general market analysis about the CWIS products in the market at the time, identified their characteristics and examined developing market dynamics. This report is the second and final report, concluding the longitudinal research by accomplishing the following:

- Provide a bird's-eye view of the current state of the CWIS mapping the relationships between hardware and weather data providers.
- Develop surveys to collect data from CWIS hardware manufacturers and weather data providers to examine the level of CWIS market adoption in 2004, and to predict future growth.
- Acquire historical data on CWIS sales over the past years to predict future adoption rates.
- Update Kauffmann's original study by focusing on product characteristics that are required by the pilots who participated in a customer survey.

- Predict market penetration from 2005 to 2025. To accomplish this, conduct a literature search to select or create the most appropriate market penetration model for CWIS products, as well as a wider product group called Information Systems (IS).
- Compare future predictions achieved by the new model with the predictions of the original study.

As a result, this study concludes that the actual market adoption rates of GA and business segments from year 2000 to 2004 are within the original study's prediction interval. That is to say, the original study provided statistically correct predictions for these segments in this time frame.

This study follows FAA's GA segment definition and uses the term "overall GA segment" to describe GA aircraft including private, business and rotorcraft segments. It also creates a new market adoption model to forecast market penetration curves of information systems (IS) including CWIS as a sub-group. By using the new model, it finds that the predicted market adoption rate for year 2014 for the overall GA segment is almost 44%. This rate is given as 42% in the original study, which indicates that the predictions of both studies for 2014 are very close.

This study also finds that the maximum market penetration rate in 2025 is 52%. This was found as 53% in the original study, leaving only 1% difference between the two maximum penetration forecasts. According to the predicted penetration curve in this study, CWIS in the overall GA segment starts entering maturity around 2014. On the other hand, from the shape of the original study's curve the maturity stage seem to start a few years later, probably around 2018. As a result, this study predicts a somewhat faster developing market penetration curve compared to the original, and it also forecasts a slightly lower market adoption in 2025.

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1 Introduction

The purpose of the longitudinal research of the market penetration of cockpit weather information systems (CWIS) has been contributing to the body of knowledge on modeling advanced technology feasibility in aviation by tracking and analyzing the market adoption of CWIS over a three year period. This research took advantage of a previous study, conducted by Dr. Paul Kauffmann in 2000, which demonstrated an integrated and cost effective approach to evaluate advanced technology feasibility, examining the feasibility of CWIS in five market segments: transport, commuter, general aviation, business, and rotorcraft [1]. The results of this study were well received by the industry.

CWIS developers started to release their products into the aviation market in early 2000s [2]. Since various aviation market segments began to adopt these products over the past few years, comparing the original study model and its predictions with the actual market influences and adoption rates has been one of the goals of the longitudinal research. Examining the accuracy of the original predictions and refining the model or using a new model to make further predictions on CWIS market penetration was another goal of this research.

The longitudinal research consisted of two consecutive studies and produced two reports. The first report was submitted in August 2003 and included general market analysis about the CWIS products in the market at the time, identified their characteristics and examined developing market dynamics [3]. This report is the second and final report, concluding the longitudinal research.

As indicated in the first report [1], CWIS products are usually introduced to the market via partnerships between hardware manufacturers and weather data providers. Various weather products are available on these systems including NEXRAD, METARs, TAFs, SIGMETs, PIREPs, etc. Traffic information is also provided in some products and is optional in others. The user is able to obtain weather information via multi function color displays (MFD) with moving map or push-button capability. As of year 2003, the non-recurring costs for these systems ranged from $2,745 to $13,661 depending on the provider and the features included in the system. They also included various amounts of recurring costs (from $9.95 to $25.95 + 99 cents per minute). The first project report also provided a comparative summary of various CWIS products including UPSAT MX20 I-O, Anywhere WEATHER, Bendix/King KMD 550 + KDR 510, Garmin GNS 530 + GDL 49, and Echo Flight Cheetah FL 270.

The objectives of this second and final study are to:

- Update the first report [3] with a bird's-eye view of the current state of the CWIS mapping the relationships between hardware and weather data providers.
- Develop surveys to collect data from CWIS hardware manufacturers and weather data providers to examine the level of CWIS market adoption in 2004, and to predict future growth.
- Acquire historical data on CWIS sales over the past years to predict future adoption rates.
- Update Kauffmann's original study [1] by focusing on product characteristics that are required by the pilots who participated in a customer survey.

- Predict market penetration from 2005 to 2025. To accomplish this, conduct a literature search to select or create the most appropriate market penetration model for CWIS products, as well as a wider product group called Information Systems (IS).
- Compare future predictions achieved by the new model with the predictions of the original study [1].

This report discusses the implementation of these objectives in the following sections:

Section 2: Briefly summarizes related parts of Kauffmann's 2000 study [1] that predicted the market adoption of CWIS.

Section 3: Extends the original report by more detailed examination of most important CWIS characteristics in the United States in general, as well as in six different regions in the country.

Section 4: Investigates the recent circumstances of the CWIS market penetration by including current partnerships, sales data and adoption levels. It also compares this information with the predictions of the original study [1].

Section 5: Includes a literature search for the existing most appropriate market adoption models for IS products that contain CWIS as a subgroup. After that, it creates a new diffusion model used to predict future penetration of CWIS. Finally, it predicts CWIS market penetration from 2005 to 2025 by means of the new model, and compares it with the original study [1].

Section 6: Concludes the report.

2 Results of the Original Study

Kauffmann [1] studied the following questions in his original report in 2000 when companies were in the planning phase of CWIS product development:

1. What are the general product characteristics of the cockpit weather systems that eventually will achieve success in the target markets?
2. How quickly in the future will the market segments adopt cockpit weather systems?

These questions were directed to industry experts and the inputs were grouped in five market segments: transport, commuter, general aviation (GA) (included GA aircraft without business and rotorcraft), business, and rotorcraft. Kauffmann [1] identified some of the necessary characteristics for the market success of CWIS as:

- Combining weather information with moving map GPS.
- 5 weather data categories: Turbulence / shear, winds aloft, icing, moisture / precipitation, thunderstorm / convection, and ceiling / visibility.
- Weather updates every 10-14 minutes.

Kauffmann also predicted that CWIS would achieve their maximum market penetration levels till 2025 and 50% of these levels between 2008 and 2011. Figure 1 shows the market penetration curves estimated in the original report, for each market segment.

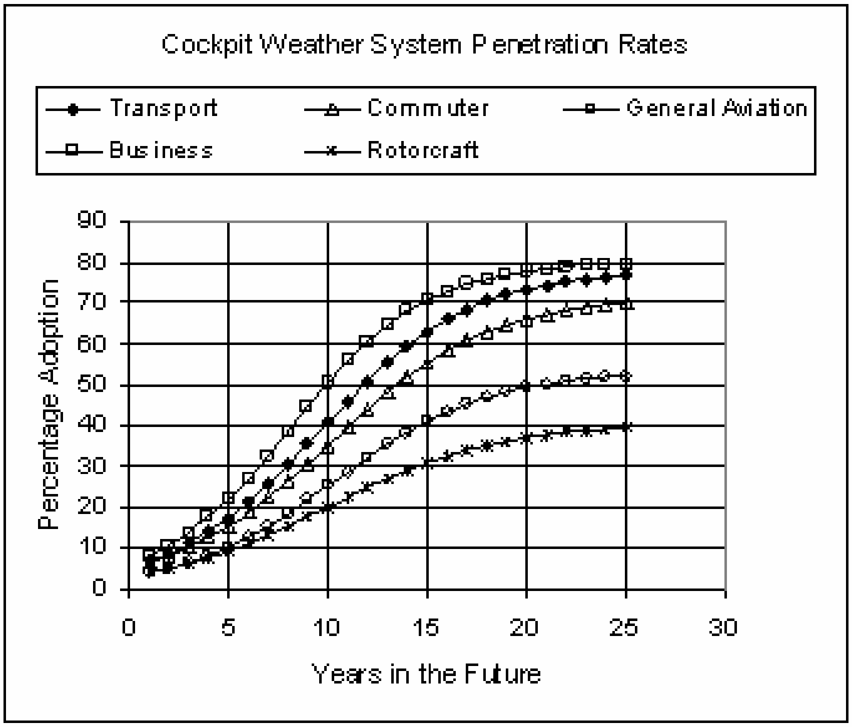

Figure 1. CWIS penetration estimates (March 2000).

The following predictions can also be drawn according to this graph:

- The transport segment will achieve near 80% market penetration in 2025 in its maturity phase.
- The penetration level for the commuter segment will be around 70% in 2025 in its maturity phase.
- The GA segment will achieve a little above 50% market penetration in 2025 as it enters the maturity phase.
- Market adoption in the business segment is predicted to increase faster than the other segments, and will reach 80% adoption rate in 2025.
- Rotorcraft is the slowest segment and only achieves 40% adoption rate in 2025 in its maturity phase.

The following sections discuss how this study expands Kauffmann's report in terms of new/modified product characteristics, the actual growth of the CWIS market in 2004, and how it attempts to predict market penetration from 2005 to 2025.

3 Extended Analysis on CWIS Characteristics

Either new product characteristics were added to the important CWIS characteristics list or the existing ones were modified since the time of the original study as research progressed [4, 5]. For example, a previous survey of 605 pilots included the characteristics below, organized under three categories (other characteristics are not mentioned here) [5]: The weather products category consists of 9 alternatives; weather update interval contains 3 different intervals, and the alert condition group includes 6 alternatives. The importance of these features is investigated in the following sub-sections, and the inputs were analyzed according to general preferences in the United States as well as in different regions of the country.

Weather Products (Weather information that pilots need in the cockpit):

- PIREPs
- AIRMETs
- METARs
- TAFs
- Winds aloft
- Icing
- Convective
- Turbulence
- Ceiling/Visibility

Weather Update Interval (Frequency of weather updates by means of CWIS):

- 0-5 minutes
- 5-10 minutes

- 10-15 minutes

Weather Alert Conditions (Weather conditions that pilots need to be alerted about):

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

3.1 Preferred CWIS Characteristics in the U.S.

A previous customer survey received 605 inputs from U.S. participants, 96% of which were current pilots [5]. Other background information about these pilots is as follows:

- *Professions:* 61.3% of the participants were private pilots, 26.2% were commercial pilots, as opposed to 8.1% airline transport, 3.8% student, and 0.6% helicopter pilots.
- *Typical altitude:* 69.9% of the participants fly up to 8,000 feet, while the rest fly in higher altitudes.
- *Aircraft type:* 84.3% fly single-engine piston aircraft. The rest fly multi-engine piston (8.7%), jet 20,000 to 100,000 lbs MTOW (3.0%), multi-engine turboprop (2.2%), single-engine turboprop (0.8%), helicopter (0.6%), and jet less than 20,000 lbs MTOW and large transport aircraft (0.2% each).
- *Instrument rating:* 68.2% of the participants are instrument rated, while the rest are VFR pilots.

- *Total flight hours:* 54.4% of the participant pilots' total flight hours are up to 600 hours. The rest have more flight hours.

Based on the inputs received, Table 1 contains the relative importance values of each product characteristic (the total percentage for each category is 100%) and Figure 2 illustrates these values on a graph for each feature category (weather products, update interval, and alert conditions). Table 2 includes related rankings per category for simplicity, where it is assumed that the weather product that has the highest relative importance value is ranked #1, and the product with the lowest value is ranked #9 in the weather products group. Similarly, the update interval with the highest relative importance value is assumed to be ranked #1, and the interval with the lowest value is ranked #3. In the weather alert condition category, the condition with the highest value is considered to be ranked #1, and the one with the lowest value is ranked #6.

Table 1. Relative importance values of CWIS characteristics.

Weather Products	Relative importance in general
PIREPs	10.4%
AIRMETs	8.4%
METARs	12.7%
TAFs	11.4%
Winds Aloft	8.6%
Icing	12.2%
Convective	13.4%
Turbulence	8.7%
Ceiling/Visibility	14.1%
Weather Update Interval	**Relative importance in general**
0-5 minutes	38.4%
5-10 minutes	35.3%
10-20 minutes	26.4%
Weather Alert Condition	**Relative importance in general**
Thunderstorm	23.1%
Icing	17.7%
Turbulence	14.3%
Heavy precipitation	15.5%
High winds	13.2%
Low visibility	16.2%

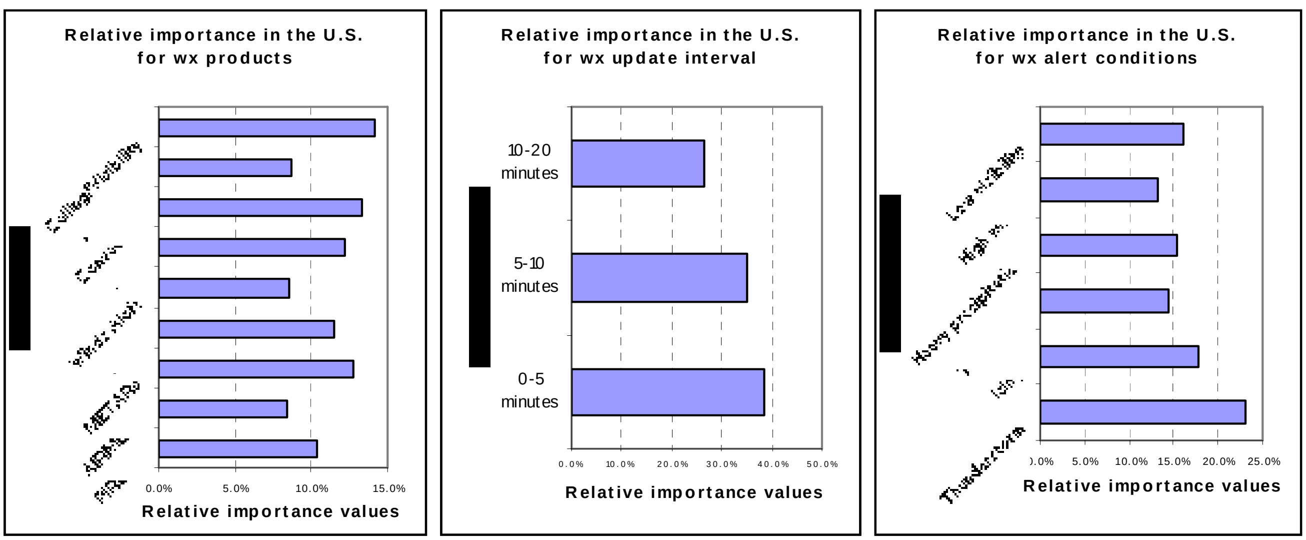

Figure 2. Relative importance of CWIS characteristics in three categories.

Table 2. Rankings of CWIS characteristics in three categories.

Weather Products	Rankings in general
Ceiling/Visibility	1
Convective	2
METARs	3
Icing	4
TAFs	5
PIREPs	6
Turbulence	7
Winds Aloft	8
AIRMETs	9
Weather Update	**Rankings in general**
0-5 minutes	1
5-10 minutes	2
10-20 minutes	3
Weather Alert	**Rankings in general**
Thunderstorm	1
Icing	2
Low visibility	3
Heavy precipitation	4
Turbulence	5
High winds	6

According to Table 2, *ceiling / visibility* is the most important weather product in general in the U.S. while *AIRMETs* is the least important. *Convective, METARs, icing, TAFs, PIREPs, turbulence*, and *winds aloft* are #2, 3, 4, 5, 6, 7, and 8 respectively. Most pilots would like weather updates every *0-5 minutes*. The second weather update frequency preference is *5-10 minutes* and *10-20 minutes* is the least preferred among the three alternatives. *Thunderstorm* is the most important weather condition that the participant pilots want to be alerted about. It is followed by *icing, low visibility, heavy precipitation, turbulence,* and *high wind alerts*, ranked #2, 3, 4, 5 and 6 respectively.

Although these values show the importance levels of the selected CWIS characteristics in the country, a regional analysis would provide more detailed understanding of customer requirements. Since atmospheric circumstances vary in different geographical areas in the U.S., it is expected to discover differences in customer expectations in certain areas, as well as common needs in the whole country. The results of this analysis are potentially important for CWIS providers who plan to adjust their regional marketing strategies according to customers' requirements.

3.2 Preferred CWIS Characteristics in U.S. Regions

605 pilots from 6 U.S. regions (northwest, north-central, northeast, southwest, south-central, and southeast) were asked about the importance of various CWIS characteristics, and 911 inputs were received since some pilots fly through more than one region. Among these 911 inputs, 24.1% were received from pilots who fly in southeast (SE), 21.7% from northeast (NE), 19.3% from north-central (NC), 14.1% from southwest (SW), 12% from south-central (SC), and 8.5% from northwest (NW), as illustrated in Figure 3. Selected CWIS characteristics and, based on the survey inputs, their relative importance values are included in Table 3, and this data is displayed and analyzed according to three feature categories in the following subsections.

Based on this analysis, two conclusions are made for each category:

- Distinguishing characteristics are identified region by region. A *distinguishing characteristic* is defined as a product feature that is more important in one U.S. region, while it is less preferred in other regions. Product developers may use this information to provide different versions of their CWIS products in different U.S. locations.
- Characteristics that are commonly needed in the whole country are also determined.

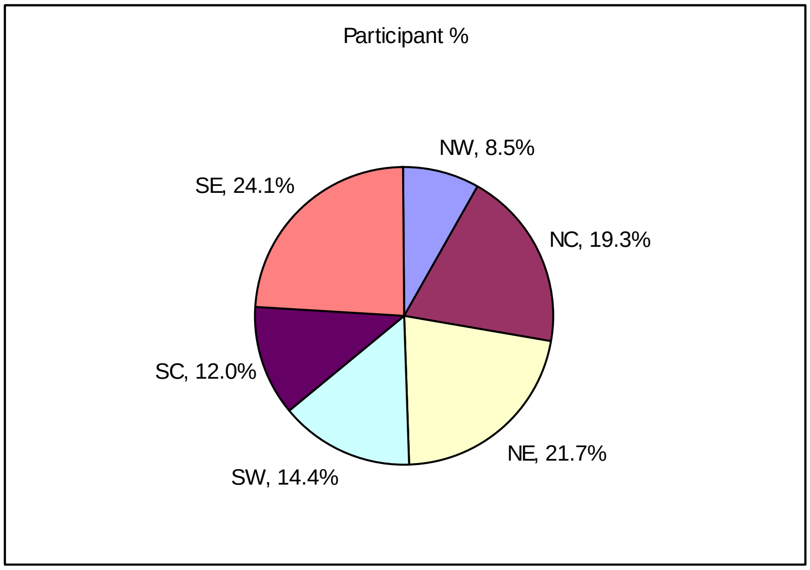

Figure 3. Regional input percentages.

Table 3. Relative importance values of selected CWIS characteristics according to U.S. regions.

			U.S. Regions			
Weather Products	**NW***	**NC***	**NE***	**SW***	**SC***	**SE***
PIREPs	8.8%	10.5%	10.3%	10.2%	10.3%	10.5%
AIRMETs	7.7%	7.6%	7.7%	8.5%	7.6%	8.2%
METARs	14.5%	12.7%	14.0%	13.9%	12.4%	13.2%
TAFs	11.9%	11.1%	12.6%	10.9%	11.0%	12.7%
Winds Aloft	9.7%	8.6%	8.0%	7.5%	7.6%	7.2%
Icing	11.7%	13.4%	12.2%	12.7%	14.2%	11.6%
Convective	11.7%	13.5%	13.2%	13.1%	14.8%	14.0%
Turbulence	9.5%	9.1%	8.4%	9.3%	8.9%	8.6%
Ceiling/Visibility	14.5%	13.5%	13.6%	13.9%	13.2%	13.9%
Weather Update Interval	**NW**	**NC**	**NE**	**SW**	**SC**	**SE**
0-5 minutes	41.7%	37.7%	34.0%	31.5%	35.4%	34.8%
5-10 minutes	32.0%	36.0%	37.3%	38.5%	36.3%	37.0%
10-20 minutes	26.2%	26.3%	28.6%	30.1%	28.3%	28.2%
Weather Alert Condition	**NW**	**NC**	**NE**	**SW**	**SC**	**SE**
Thunderstorm	21.7%	23.8%	23.9%	23.3%	23.7%	23.9%
Icing	16.1%	19.1%	18.5%	18.2%	18.4%	16.0%
Turbulence	16.4%	13.9%	14.6%	14.9%	14.2%	13.9%
Heavy precipitation	13.8%	15.2%	14.7%	15.0%	16.2%	15.8%
High winds	15.3%	13.0%	12.7%	13.2%	12.0%	13.8%
Low visibility	16.7%	14.9%	15.7%	15.3%	15.7%	16.6%

*NW: Northwest, *NC: North-central, *NE: Northeast, *SW: Southwest, *SC: South-central, *SE: Southeast

3.2.1 Weather Products vs. Regions

Figure 4 illustrates the relative importance values of 9 selected weather products according to different regions in the U.S., and based on this chart, Table 4 includes their rankings region by region. The product that has the highest relative importance value is assumed to be ranked #1, and the product with the lowest value is ranked #9.

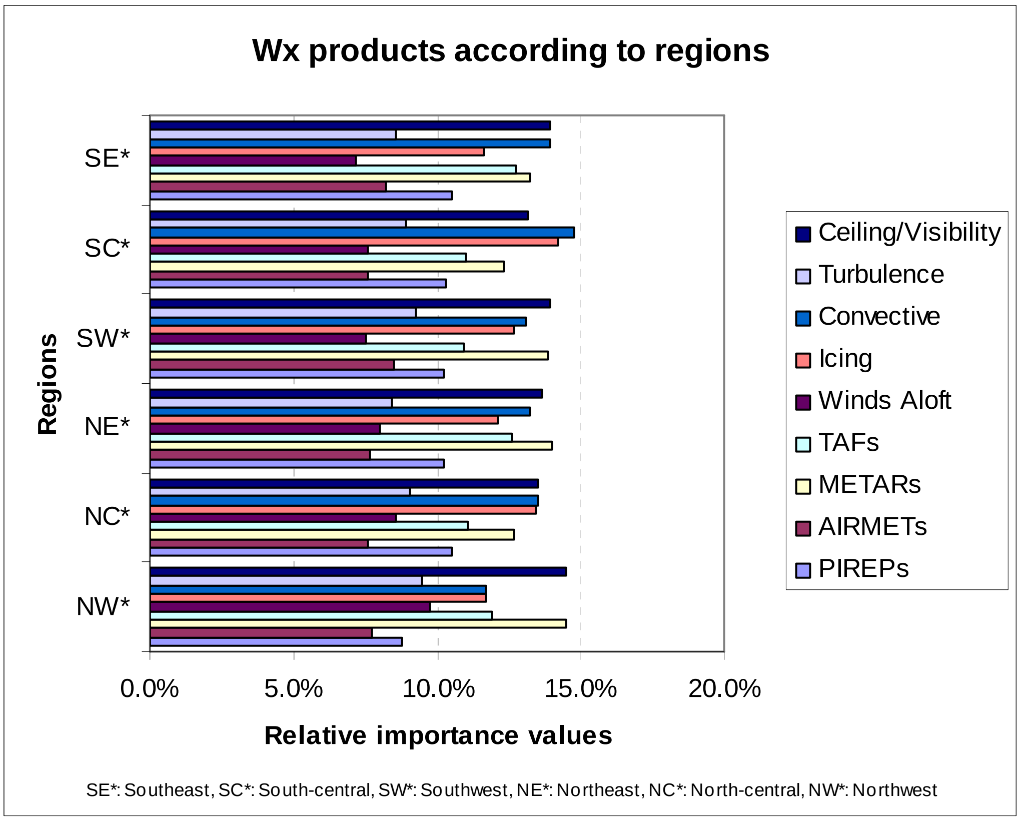

Figure 4. Relative importance values of weather products according to regions.

Table 4. Rankings of weather products region by region.

			U.S. Regions			
Wx Products	NW	NC	NE	SW	SC	SE
Ceiling/Visibility	2	2	2	1	3	2
Convective	5	1	3	3	1	1
METARs	1	4	1	2	4	3
Icing	4	3	5	4	2	5
TAFs	3	5	4	5	5	4
PIREPs	8	6	6	6	6	6
Turbulence	7	7	7	7	7	7
Winds aloft	6	8	8	8	8	8
AIRMETs	9	9	9	9	9	9

According to Table 4, *ceiling/visibility* is very important in all regions, although it is the first preference in SW only. NW, NC, NE and SE rank this product second, while it is the third choice for SC. The rankings for *convective* varies from region to region. Although NC, SC and SE rank it first, NE and SW rank it third and it is #5 in NW. Importance rankings for *METARs* varies quite widely from region to region. NW and NE rank it first; however, it is the second and third choice in SW and SE respectively, while NC and SC rank it fourth. It seems that *icing* is quite important in SC (ranked second) and NC (ranked third). On the other hand, NW and SW rank it fourth, while it is #5 in NE. *TAFs* is ranked at the third place in NW, while other regions rank it either fourth or fifth. *PIREPs*, *turbulence*, *winds aloft* and *AIRMETs* do not appear to be as important as the other weather products. *PIREPs* is the better choice among these since it is mostly ranked the sixth. *Turbulence*, *winds aloft* and *AIRMETs* follow it by scoring mostly seventh, eighth, and ninth place respectively.

Distinguishing weather products region by region: Based on this analysis, it is safe to say that *ceiling/visibility* information is consistently important in all areas as expected (this was the most popular in the U.S. as indicated in Table 2). *Convective* is more important in central U.S. (NC and SC) and SE, compared to other regions. This result is meaningful due to the often unstable atmospheric conditions in these areas. NE and SW rank *METARs* more important than *convective*. *METARs* is also ranked as the most important weather product in NE and NW. However the central regions rank it fourth. *Icing* is the second most important product in SC, and third in NC. It is more important than *ceiling/visibility* information in SC and *METARs* in NC. *TAFs* is in the third place in NW while other regions rank it less important.

Consequently, *ceiling/visibility* is very important in all areas and CWIS should include this weather product to satisfy pilots' expectations around the country. Additionally, this analysis reveals important weather products that have the potential to differentiate CWIS products from region to region as follows:

- NW: *METARs* and *TAFs* are more important compared to other regions.
- NE and SW: *METARs*
- NC and SC: *Convective* and *Icing*

3.2.2 Weather Update Interval vs. Regions

Figure 5 illustrates the relative importance values of 3 selected weather update intervals according to different regions in the U.S., and Table 5 includes their rankings region by region. The interval that has the highest relative importance value is assumed to be ranked #1, and the interval with the lowest value is ranked #3.

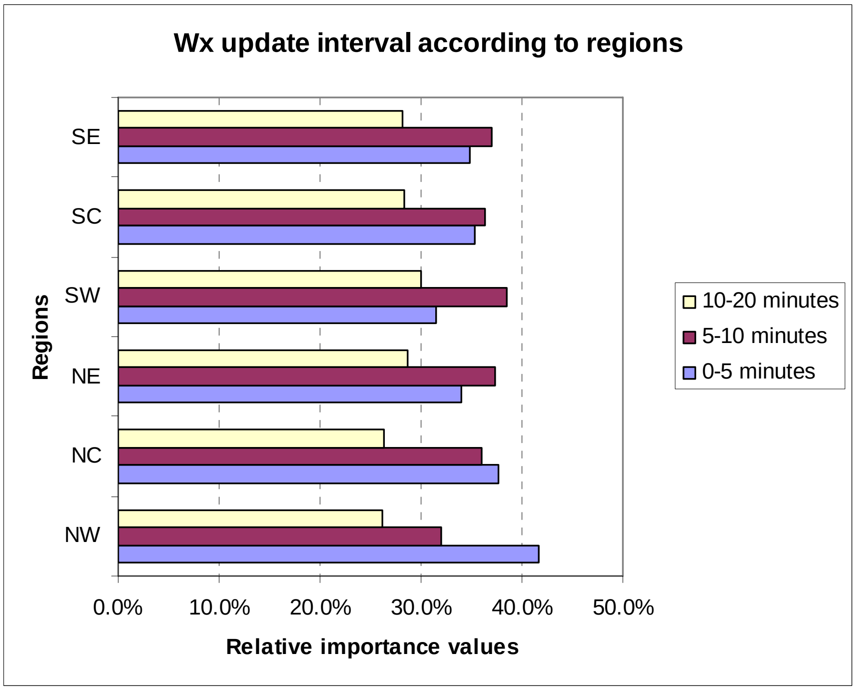

Figure 5. Relative importance values of weather update intervals according to regions.

Table 5. Rankings of weather update intervals region by region.

			U.S. Regions			
	NW	**NC**	**NE**	**SW**	**SC**	**SE**
5-10 min	2	2	1	1	1	1
0-5 min	1	1	2	2	2	2
10-20 min	3	3	3	3	3	3

Table 5 indicates that although weather updates every *5-10 minutes* is the second choice for NW and NC, the rest of the regions put more importance on this update interval, ranking it #1. NW and NC rank weather updates every *0-5 minutes* as #1, while other regions put it in the second place. On the other hand, all regions rank the *10-20 minute-interval* as the least important (or least preferred).

As a result, weather update intervals *0-5 minutes* and *5-10 minutes* seem to be distinguishing factors since the former is the first choice for NW and NC, while the latter is ranked as more important by the other regions, where the participant pilots seem to think that they do not need weather updates as frequent as every *0-5 minutes*. Therefore, the distinguishing weather update intervals are:

- NW and NC: Receiving weather updates every *0-5 minutes* is more important in these regions compared to the rest of the country.
- NE, SW, SC, and SE: *5-10 minutes.*

3.2.3 Weather Alert Conditions vs. Regions

Figure 6 illustrates the relative importance values of 6 selected weather alert conditions according to different regions in the U.S., and Table 6 includes their rankings region by region. The alert condition that has the highest relative importance value is assumed to be ranked #1, and the one with the lowest value is ranked #6.

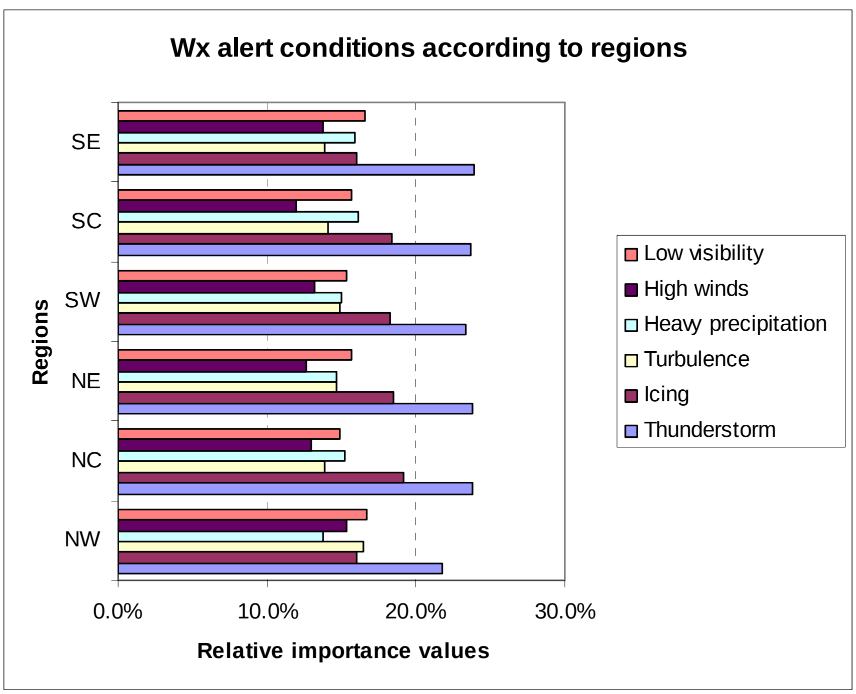

Figure 6. Relative importance values of weather alert conditions according to regions.

Table 6. Rankings of weather alert conditions region by region.

			U.S. Regions			
	NW	NC	NE	SW	SC	SE
Thunderstorm	1	1	1	1	1	1
Icing	4	2	2	2	2	3
Low visibility	2	4	3	3	4	2
Heavy precipitation	6	3	4	4	3	4
Turbulence	3	5	5	5	5	5
High winds	5	6	6	6	6	6

Table 6 indicates that, according to the survey participants in the U.S., *thunderstorm* alerts are the most important among all six alternatives. This was also true for the whole U.S. as indicated in Table 2. NC, NE, SW and SC rank *icing* as the second important weather alert condition, while it is #3 in SE, and #4 in NW. *Low visibility* is the second important alert condition in NW and SE, while it is the third choice in NE and SW, and the fourth in the central regions (NC and SC). Central regions (NC and SC) rank *heavy precipitation* as the third important alert condition among the alternatives. However, eastern regions (NE and SE) and SW put it in the fourth place, and it is the least important alert condition in NW. *Turbulence* is the third important alert condition in NW while it is less important in other regions at fifth place. Survey participants do not seem to concern with *high winds* as an alert condition since most of the regions put it in the last place.

<u>Distinguishing alert conditions region by region:</u> Based on the analysis above, it is clear that *thunderstorm* alerts are very important for the participating pilots all over the U.S. *Icing* alerts are also quite important for most of the regions, even though it is not as important in NW where it is listed #4. *Low visibility* alert is more important in northern regions (NE and SE) and SW that it is in other areas, and *heavy precipitation* is more important in central regions (NC and CS) than it is elsewhere. Although *turbulence* and

high winds are often ranked less important compared to other alert conditions, participant pilots in NW rank it rather important, in the third place. It should also be noted that rankings received from NC and SC pilots are the same, and similar situation occurs for NE and SW.

As a result, *thunderstorm* alert should be provided in all regions, while *low visibility* and *turbulence* seem to be distinguishing characteristics for CWIS that are marketed in NW. *Heavy precipitation* is ranked more important in central regions than it is in other areas. *Icing* is less important in NW that it is elsewhere, and *low visibility* is a distinguishing factor in eastern regions (NE and SE) and SW. Therefore, the distinguishing weather alert conditions region by region are as follows:

- NW: *Low visibility* and *turbulence* are more important compared to the rest of the country.
- NC and SC: *Heavy precipitation* and *icing*
- NE, SE and SW: *Icing* and *low visibility*

3.2.4 Summary of CWIS Characteristics in U.S. Regions

Figure 7 summarizes all distinguishing characteristics region by region on a U.S. map. It should be noted that the pilot survey did not specify the exact borders of these regions, and therefore Figure 7 does not include a clear separation between them.

Based on the survey analysis, all participants expect *ceiling/visibility* information and *thunderstorm* alerts to be provided on their CWIS (stated in Figure 7). However, in addition to these common needs, there are distinguishing characteristics that may affect customer satisfaction in different regions, and this information is potentially important for system providers who market their products in different areas, focusing on changing customer expectations.

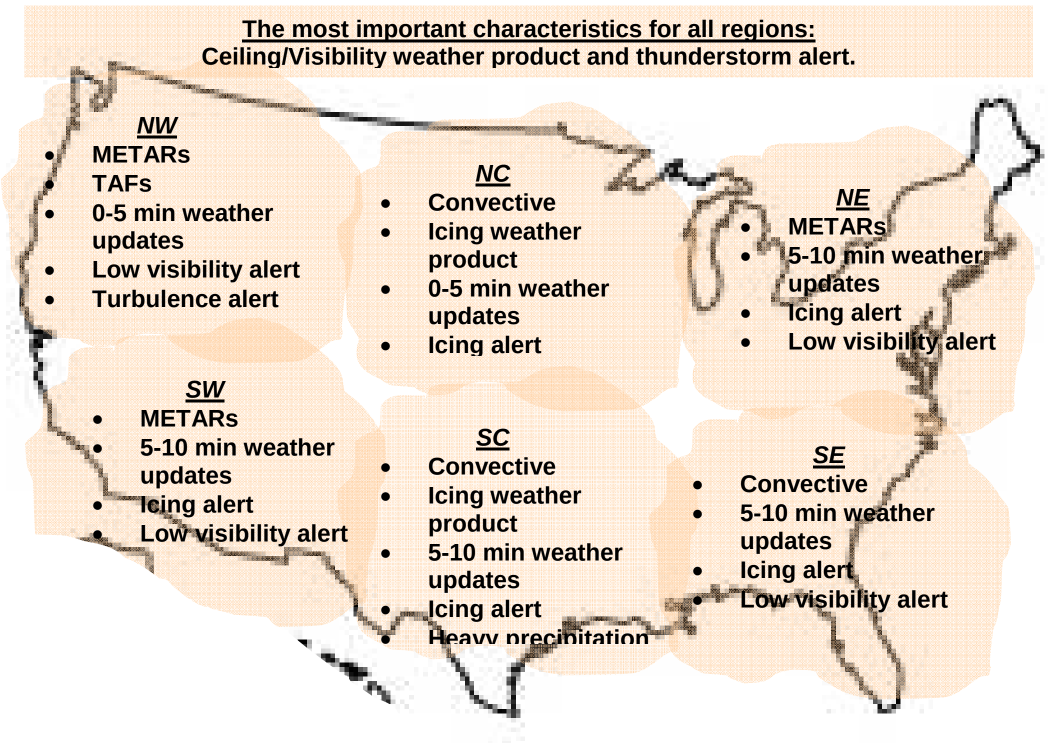

Figure 7. Distinguishing CWIS characteristics according to regions.

According to the summary presented in Figure 7, survey participants from the NE and SW regions show the same expectations, ranking *METARs*, *5-10 minute-weather updates*, *icing* and *low visibility alerts* as important factors, differentiating them from the rest of the country. The SE region indicates similar preferences except that it ranks *convective weather product* more important than *METARs*.

Central regions also indicate similar needs, but differ significantly from the rest. NC and SC participants rank *convective* and *icing weather products*, together with *icing* and *heavy precipitation alerts* as important and distinguishing CWIS characteristics. The only rank difference between NC and SC is the *weather update interval* since NC pilots seem to prefer more frequent weather updates.

The NW region varies from the rest of the U.S. quite significantly, ranking *TAFs* along with *METARs* as an important weather product. Similar to the NC region, NW expects frequent weather *updates (0-5 minutes).* NW and NC are the only regions with this expectation because others seem satisfied with weather updates as frequent as *5-10 minutes*. Participants in NW also expect *turbulence alerts* along with *low visibility alerts*. NW is the only region ranking *TAFs* and *turbulence alert* rather important.

4 Recent Analysis on CWIS Market Penetration

This section includes actual recent market adoption data collected through the following means.

- The project team's contacts with major CWIS hardware and weather providers through phone, email, as well as in person communications at conventions and meetings (e.g., NBAA Meeting & Convention, October 12-14, 2004, Las Vegas, NV; AEA Convention, April 27-30, Dallas, TX),
- AEA (Aircraft Electronics Association) survey data provided to the project team through membership.
- Public information on company web sites and other Internet sources.

Although this research collected company-specific information such as sales volume and number of subscribers, they are left out of this report due to confidentiality. Only average numbers and information made public over the Internet are used for analysis, and compiled with data acquired from AEA.

It should also be noted that, due to competition, business secrecy, inadequate sales in some market segments, and/or simply unknown data, it has not been possible to collect adequate market adoption data for each market segment, to compare with the original study's every prediction.

Additionally, the definition of the GA segment is somewhat different in this study, compared to the original report [1]. The original report excludes business aircraft and rotorcraft from the definition of GA. However, since this study follows GA data (such as number of GA aircraft) obtained from FAA to forecast the future growth of CWIS (See Section 5.3), it uses FAA's definition of GA, which includes business and rotorcraft along with private aircraft. As a result, this study uses the term "GA segment" and "overall GA segment" as described below.

GA Segment: Includes GA aircraft other than business aircraft and rotorcraft.

Overall GA Segment: Contains GA aircraft including private and business aircraft as well as rotorcraft.

4.1 Current State of the CWIS Market

Partnerships between weather providers and hardware manufacturers make it more convenient to provide advanced graphical CWIS to today's pilots. Figure 8 shows selected partnerships between weather data and hardware providers based on conversations with companies in a number of meetings such as NBAA (National Business Aviation Association) Meeting & Convention (October 12-14, 2004, Las Vegas, NV), and AEA (Aircraft Electronics Association) Convention (April 27-30, Dallas, TX) as well as public information provided over the Internet (as of December 2004). Please note that this summary chart may not include all of the weather data providers, hardware providers and partnerships in the market today since the CWIS market has proven to be quite dynamic. Based on Figure 8, CWIS development relies heavily on partnerships between weather data and hardware providers. In particular, WxWorx and XM Satellite Radio is doing quite well supplying weather data to most of the hardware providers included in the chart, and according to expert opinions, the number of WxWorx + XM Radio subscribers is expected to continue to increase dramatically in the future.

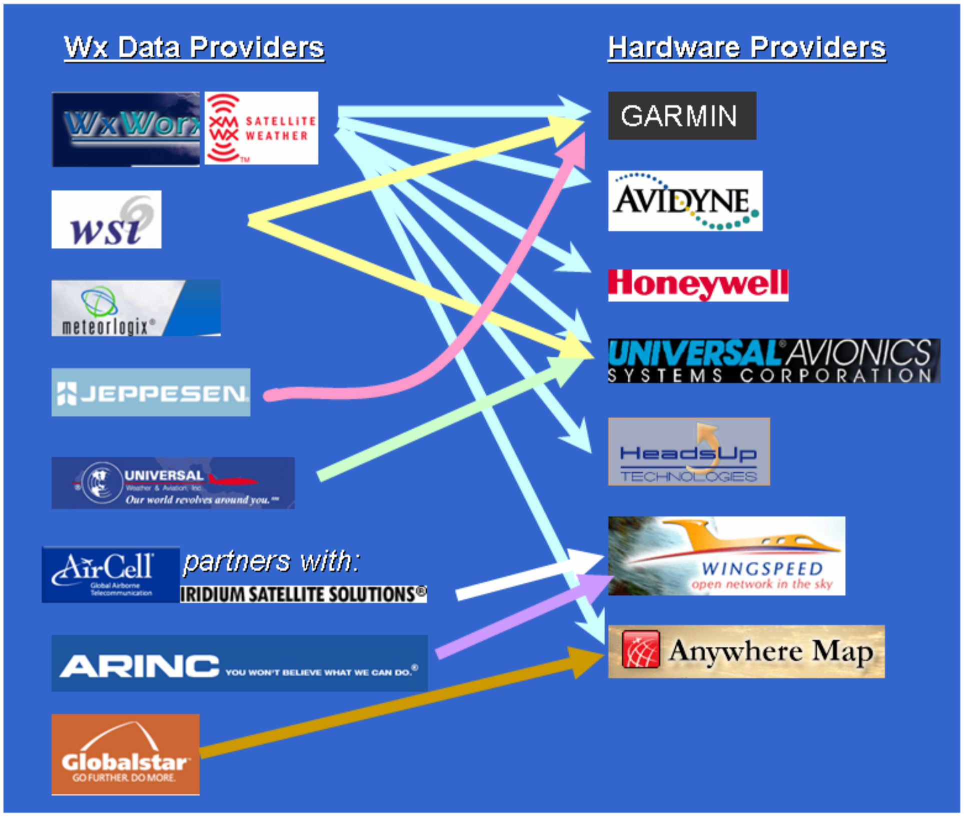

Figure 8. Partnerships between wx and hardware providers.

CWIS that are the products of these partnerships provide graphical weather information to pilots by means of various types of displays such as laptops (e.g., Wingspeed), tablet PCs (e.g., Anywhere Map), PDAs (e.g., Anywhere Map), cellular phones (e.g., Universal), displays integrated into the front panel (e.g., Garmin G1000), flight bags (e.g., Jeppesen), and other portable displays (e.g., Garmin).

According to an AEA survey, market shares of five major CWIS providers in 2004 were as indicated in Table 7 and Figure 9, where Garmin occupied 76.4% of the sales among others. WSI followed Garmin with 9.2%, Honeywell-Bendix King with 7.3% and Avidyne with 5.5%. L3 had the narrowest share with 1% that year. Please note that even though this data contains hardware sales with weather data link capability, most of it covers multi purpose devices.

Table 7. CWIS units sold in 2004.

Manufacturer	Number of Units Sold	Market Share (%)
Garmin	2303	76.4
WSI	276	9.2
Bendix King	219	7.3
Avidyne	167	5.5
L3	29	1.0
Other	22	0.7
Total	3016	100

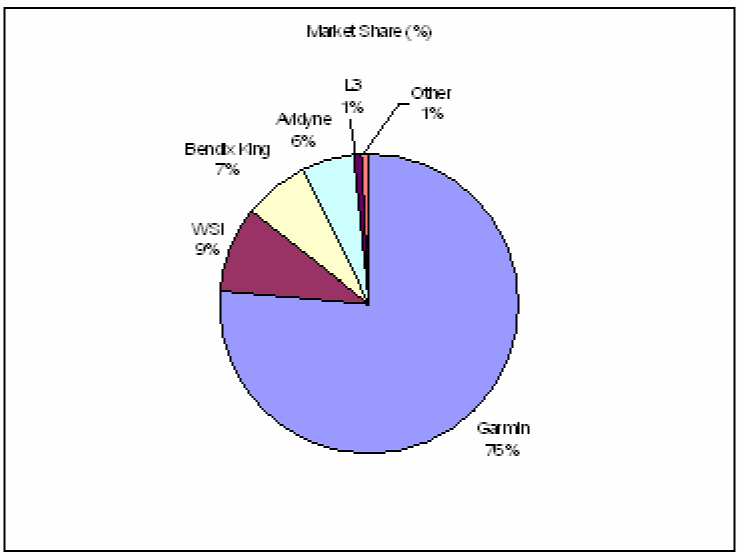

Figure 9. CWIS market share among 5 competitors in 2004 (AEA data).

According to the project team's conclusions based on communications with major system providers, the target market segments for CWIS are as follows in order of significance:

1. Business
2. General Aviation (GA) (business and rotorcraft excluded)

3. Transport
4. Package carriers
5. Corporate rotorcraft

It is common perception among system providers that GA pilots tend to buy the most affordable CWIS products, while business is the #1 segment containing the most dependable buyer group. Although airlines are starting to purchase CWIS products, they have not been willing to invest due to the current economic downturn in this segment. Package carriers and corporate rotorcraft are expected to follow the airline segment. The market adoption rate in the GA segment has been slower than it has in the business segment since GA has been waiting for more low cost CWIS products as concluded in previous studies [3, 4]. Additionally, it is probable that GA will also wait till the utility of these products is proven.

4.2 Actual Market Adoption vs. Predictions of the Original Study

The findings of this study are stated below.

- The estimated average number of CWIS units sold per year from 2000 to 2003 is 2,000.
- Estimated number of weather data link subscribers in the business segment is 3,700.
- Estimated number of cockpits with weather data link in the GA segment (excluding business and rotorcraft) is 16,696.
- Estimated number of cockpits with weather data link in the overall GA segment (including business and rotorcraft) is 20,396.

- Dramatic increase in market penetration is possible due to the introduction of new XM platforms.
- CWIS awareness in GA rose to 90% in 2004.

Table 8 includes the total number of aircraft in the U.S. for each market segment, as well as the estimated number of subscribers for GA and business segments up to year 2004. The actual market adoption (segment by segment) is simply calculated as in Equation (1).

$$\text{Market adoption till 2004} = \frac{\text{Estimated number of subscribers up to 2004}}{\text{Total number of aircarft for each segment in the U.S.}} \qquad (1)$$

Table 8. Actual market adoption in 2004 compared to the predictions of the original report.

Market Segment	**Total number of aircraft in the U.S.**	**Estimated number of subscribers up to 2004**	**Actual market adoption in 2004**	**Market adoption predicted for 2004 (original report)**
GA (private piston & turboprop)	184,415	16,696	9%	6%-10%
Business	24,500	3,700	15.1%	14%-21%
Transport	4,090	N/A	N/A	10%-19%
Commuter	2,672	N/A	N/A	9%-16%
Rotorcraft	8355	N/A	N/A	6%-11%
Overall GA segment (GA+business+rotorcraft)	217,270	20,396	9.4%	N/A

Actual market adoption values are also compared with the predictions of Kauffmann's original report [1] in Table 8. According to these findings, the actual market adoption rates of the GA and business segments are within the original study's prediction interval. That is to say, the original study provided statistically correct predictions for these segments. On the other hand, no adequate data were found for the transport, commuter and rotorcraft segments, and therefore their market adoption could not be calculated in this report.

The next section discusses how to select an adoption model appropriate to the needs of the CWIS market, and creates a new diffusion model to predict the penetration curve of these products from 2005 to 2025. This forecast is also compared with the results of the original study [1].

5 Market Adoption Models

One goal of this study is to search for the most appropriate diffusion model(s) to predict future penetration of CWIS products, and a secondary goal is to extend this model over to a larger product group. As a result, this study considers CWIS as a subgroup of information system (IS) products, briefly defined as systems that store, organize, manipulate, analyze, and distribute data. Some examples of IS products are computers, cellular phones, Personal Digital Assistants (PDA), Geographical Positioning Systems (GPS) and Intelligent Transportation Systems (ITS). Therefore, this study first includes a literature search of existing diffusion models, and examines their suitability for the IS market. Then, it concludes that a new model should be created to predict IS penetration, and develops an adoption model. Finally, it tests the new model on CWIS data and compares the results with the findings of the original study [1].

5.1 Literature Search on Existing Diffusion Models

Before reviewing suitable diffusion models, general characteristics of IS products must be discussed to develop selection criteria, and based on previous studies [5, 6, 7], these characteristics are listed as follows:

1. *Customer behavior towards product attributes:* Customer's purchasing decision is effected by an awareness - uncertainty - expectations process. They first need to be aware of the product, and then go through an uncertainty phase towards the innovation. At this stage, they get familiarized with the product, and finally they develop a set of expectations (attributes) of the product affecting their purchasing decision.

2. *Customer behavior affected by competitors' products:* Once the customer develops expectations of a product, they start evaluating alternatives (competitors' products) based on those expectations before making the purchasing decision.
3. *Customer behavior towards product price:* Price is an important factor in the customer's purchasing decision. IS prices are generally high in the introduction stage of the product life cycle. However, as the technology matures, prices decrease, and this pattern is understood and expected by the consumers.
4. *Time dependent market potential:* Market potential is time dependent in the IS market due to short product life cycles and increased competition. IS products often have short life cycles, i.e., current technology is substituted by newer technology in a relatively short time period. In addition, increasing competition affects the market potential of a particular company's product.

In summary, The IS market is a competitive market with fast developing products. Customer behavior towards product attributes, competition, and price play an important role in purchasing decisions, and hence sales growth. Therefore, the four characteristics above are selected as the criteria employed for searching appropriate marketing models to predict the market adoption of IS products, as well as developing a new model.

5.1.1 Aggregate Diffusion Models: Models of First Purchase

Diffusion models of first purchase are used to predict the life cycle curve of a new product (innovation) based on a number of parameters such as rate of penetration, market potential and industry-specific constants and so on. These parameters are estimated via different approaches including the examination of the penetration of similar products, expert opinions, and early sales data when the product is first introduced to the market. Diffusion models can be identified in three categories as discussed below [8].

Pure Innovative Models: These models assume that only innovative or external influences exist in the diffusion process. It is assumed that the purchase timing of the customers is not influenced by the number of people who have already bought the product. The only influence is assumed to be mass media communication [9]. An example of a pure innovative model is Fourth and Woodlock [10].

Pure Imitative Models: These models assume that only imitation or word of mouth affects the diffusion process. Unlike the innovative models, the timing of the customer purchase is affected by the number of previous buyers. Fisher and Pry's model (1971) [11] is a widely used example of this category.

Integration of Innovative and Imitative Models: A model for this integrative approach was introduced by Bass in 1969 [12]. This model includes both innovative and imitative effects on the diffusion process by assuming that the customers' purchasing time is influenced by both mass media communication (innovative or external effect) and the number of previous buyers (imitative or internal effect).

The integrative approach is appropriate to forecast IS products' life cycle curves since in the introduction phase, customers' purchasing decision is based on media communication such as advertising, but after that it mostly depends on general public opinion or word-of-mouth. For this reason, this study examines only the Bass model and its extensions.

Bass Model. Bass [12] suggested that for the first purchase of a new product, in the introduction phase, the innovators (customers who buy the product due to innovative influences) are affected by promotions, but not affected by the people who have already bought the product (word of mouth) [8]. As the product life cycle progresses, the number of innovators decreases as the number of imitators (customers who buy the product due to imitative influences) increases. The model is shown in Equation (2) [13].

$$S(t) = \underbrace{\alpha[N - Q(t)]}_{\text{Innovation (external) effect}} + \underbrace{\beta\left[\frac{Q(t)}{N}\right][N - Q(t)]}_{\text{Imitation (internal) effect}} \tag{2}$$

where

S(t) :Number of adopters at time t (or sales rate)
N : Ultimate number of adopters (market potential)
Q(t) :Cumulative number of adopters to date
α : Individual conversion ratio when no adopter's influence (coefficient of innovation effect)
β : Effect of each adopter on each non-adopter (coefficient of imitation effect)

In the Bass model, the shape of the product life cycle depends on the relative rates of the innovation and imitation effects. For a successful new product, the imitation effect should exceed the innovation effect in time (β > α), so that the imitators continue to buy the product although the number of innovators declines (Figure 10). When the innovation affect is larger than the imitation effect (α > β), sales would continuously decrease after the first purchases related to the innovative influence (Figure 11).

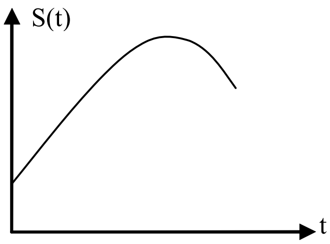

Figure 10. Sales curve (β > α).

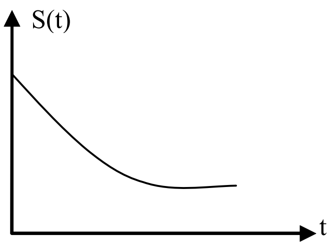

Figure 11. Sales curve (α > β).

The Bass model is simple and elegant, capable of providing effective results, and is one of the most frequently used marketing models. However, it does not meet the criteria developed for IS products in this study since it does not explain customer behavior towards product attributes and price; it assumes that the market potential is constant over time and there are no competition effects on the life cycle of the product of interest. For this reason, this study searches for Bass extensions with a potential to meet some of the criteria as discussed below.

Selected Extensions of the Bass Model. It is important to state that, even though the original Bass model has provided strong empirical support in a variety of product circumstances, revised models have not been widely used [14]. Similarly, this study has not found extensive application of these models to widespread products, or to information system products.

This study investigates up to date extensions of the Bass model starting from 1990 to provide a recent survey. Table 9 shows a comparative table including these four models and discussions of their suitability for IS product development based on the criteria developed in this study.

Table 9. Comparative table of Bass model extensions.

Model	Model Equation	Advantages based on the IS Criteria	Challenges based on the IS Criteria
Horsky, 1990	$S(t) = [N(t) - Q(t)][\alpha + \beta Q(t)]$ $N(t) = \frac{\theta M(t)}{1 + e^{-[K + \bar{\omega}(t) - k\bar{p}(t)]/\delta(t)}}$ where N(t) : Number of people eligible to purchase at time t θM(t) : Number of households that are potential buyers $(0 < \theta \leq 1)$ $\bar{\omega}(t)$: Average wage of population at time t $\bar{p}(t)$: Average price of the product at time t $\delta(t)$: Dispersion of the wage of the population at time t K, k : Coefficients for increased utility and time saving benefits	• *Criterion 1 (Customer behavior towards product attributes):* Horsky includes two product attributes (utility and time savings due to product purchase) in the model. • *Criterion 3 (Customer behavior towards product price)*: Horsky takes customer income into account and this is related to the product price. • *Criterion 4 (Time dependent market potential):* This model considers the changes in market potential over time.	• *Criterion 2 (Customer behavior affected by competitors' products):* This model does not include the effects of competition. • Although it employs the effect of two product attributes on customers' purchasing decision, the model does not include any additional customer expectations of the product. • *Criterion 3 (Customer behavior towards product price)*: The model does not directly include the product price.
Jain and Rao, 1990	$S(t) = [N - Q(t)][\alpha + \beta F(t)]p(t)^{-\eta}$ where p(t) : Product price at time t η : Price elasticity of market potential	• *Criterion 3* (*Customer behavior towards product price)*: Jain & Rao consider the effect of price in their model. They also include the change in price over time since consumers tend to buy more as the price decreases.	• *Criterion 1 (Customer behavior towards product attributes):* This model does not include product attributes. • *Criterion 2 (Customer behavior affected by competitors' products):* It does not take the competition effects into account. • *Criterion 4 (Time dependent market potential):* Market potential is assumed constant over time.
Norton and Bass, 1992	For 3 generations: $S_{1,t} = F(t_1)m_1[1 - F(t_2)]$ $S_{2,t} = F(t_2)[m_2 + F(t_1)m_1][1 - F(t_3)]$ $S_{3,t} = F(t_3)\{m_3 + F(t_2)[m_2 + F(t_1)m_1]\}[1 - F(t_4)]$ where m_i : Incremental market potential for the i^{th} generation t_i : Time past since the introduction of the i^{th} generation	• *Criterion 2 (Customer behavior affected by competitors' products):* Although this model includes the effect of one generation of the same product on another generation rather then competition effects, it is still worthy of consideration for IS products since it has the ability to indicate the effect of one product on another.	• *Criterion 1 (Customer behavior towards product attributes):* This model does not include product attributes. • *Criterion 2 (Customer behavior affected by competitors' products):* It is based on different generations of the same product rather than the effect of one competitor on another. • *Criterion 3 (Customer behavior towards product price)*: It does not include any price effect. • *Criterion 4 (Time dependent market potential):* Market potential is assumed constant over time.
Bass, Krishnan, and Jain, 1994	$\frac{f(t)}{[1 - F(t)]} = [\alpha + \beta F(t)]x(t)$ $x(t) = t + Ln\left[\frac{p(t)}{p(0)}\right]b_1 + Ln\left[\frac{a(t)}{a(0)}\right]b_2$ where $x(t)$: Marketing effort $p(t)$: Price at time t $a(t)$: Advertisin g effect at time t b_1, b_2 : Constants	• *Criterion 3* (*Customer behavior towards product price)*: This model includes the effect of product price including its change over time.	• *Criterion 1 (Customer behavior towards product attributes):* This model does not include product attributes. • *Criterion 2 (Customer behavior affected by competitors' products):* No competition effect included. • *Criterion 4 (Time dependent market potential):* No market potential included.

Summary of the Extensions of the Bass Model. Horsky's model theoretically has the most potential to meet the IS criteria since it meets criterion 4 by incorporating the time-dependency of market potential, and also contributes to criterion 1 by considering two product attributes, and to criterion 3 by relating to product price. However, it does not reflect on the effects of competition, and does not directly include product price. Even though the rest of the models somewhat contribute to criterion 2 (Norton and Bass) and 3 (Jain and Rao; Bass, Krishan and Jain), they do not meet the remaining IS criteria. As a result, this study concludes that, none of the models seem theoretically adequate in meeting the IS criteria, and therefore, this study develops a new market penetration model as a product development decision tool for engineering managers in the IS industry.

5.2 A New Market Adoption Model

CWIS or IS customers' purchase decision is modeled by using a three level decision process as outlined in Figure 12. According to this model, there are three main branching points in the sequence tree diagram of purchase events: awareness, recognition of the need, and purchase decision. Each arrow in this diagram represents a probability (a branch) through the decision process, and the eventual purchase probability is computed as in Equation (3).

$$P(t) = P_1(t) * P_2(t) * P_3(t) \qquad (3)$$

where

P(t): Final purchase probability of the customer at time t
$P_1(t)$: Percentage of potential buyers who are aware of the product at time t
$P_2(t)$: Percentage of potential buyers who recognize the need for it at time t
$P_3(t)$: Percentage of potential buyers who choose to purchase the product.

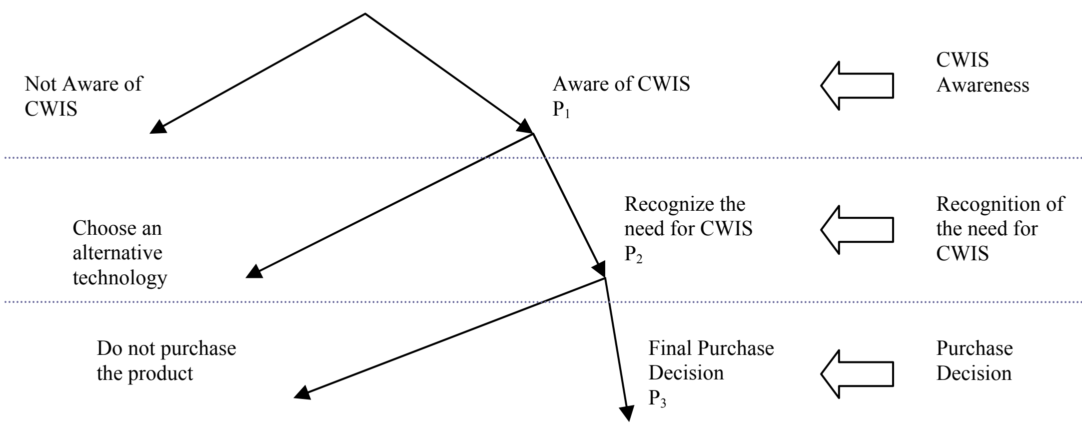

Figure 12. Sequence tree diagram for CWIS or IS purchase in general.

The main challenge is to identify $P_1(t)$, $P_2(t)$, and $P_3(t)$, in the model equation. This study determines $P_1(t)$ and $P_2(t)$ by expert surveys, and uses the notations $P_1(t) = A(t)$ for the percentage of potential buyers who are aware of the product at time t, and $P_2(t) = R(t)$ for the of potential buyers who are aware of the product and recognize the need for it at time t from this point on.

The last level (calculating $P_3(t)$) involves the purchase decision, in which a number of complex issues can play significant roles such as economic issues, product diffusion dynamics in the market, brand images, problems in product supply, unpredictable changes in the business environment, timing issues, warranty and maintenance considerations. This study uses a choice simulator to analyze this final decision, estimating the percentage of customers who will actually buy a particular product over a given time period ($P_3(t)$).

The most common market diffusion models employ the logistic growth model developed by Verhulst in 1843 and applied to various market diffusion problems successfully. Based on this model, Equation (4) can be used to calculate $P_3(t)$.

$$P_3(t) = \frac{1}{1+e^{-(a+bt)}} \tag{4}$$

$P_3(t)$ approaches to 1 as time approaches to infinity (Equation (5)), and parameter b can be calculated by Equation (6).

$$\lim_{t\to\infty} P_3(t) = 1 \tag{5}$$

$$b = \frac{P_3'(t)/P_3(t)}{[1-P_3(t)]} \tag{6}$$

The numerator of Equation (6) represents the growth rate of the diffusion process. Values of a and b are found by analyzing the characteristics of the market adoption rates for CWIS or any other IS product between 2000 and 2004 as explained Appendix C. Final purchase probability can then be expressed as in Equation (7).

$$P(t) = P_1(t) * P_2(t) * P_3(t) = \frac{1}{1+e^{-(a+bt)}} \cdot A(t) \times R(t) \tag{7}$$

Purchase probability of CWIS or another IS product is a function of time (t). This study assumes that existing product owners will not consider replacing their systems. Therefore, the number of product owners is subtracted from the potential buyers' population (M(t) – I(t)). As a result, Equation (8) represents the number of units of CWIS products that will be sold over a period of time (t).

$$S(t) = A(t) \times R(t) \times P_3(t) \times [M(t) - I(t)] \qquad (8)$$

where

M(t): Market potential at time t

I(t): Number of customers who already own the product.

The total cumulative CWIS sales are estimated by using the following formula.

$$S(t) = \left(\frac{A(t) \times R(t) \times (M(t) - I(t))}{1 + e^{-(a+bt)}} \right) \qquad (9)$$

where

A(t): % potential buyers who are aware of the product.

R(t): % potential buyers who are aware of the product and consider purchasing one.

M(t): Market potential.

I(t): Number of customers who already own the product.

a, b: Constants.

5.3 New Model Application on CWIS

This study conducted two expert surveys, one for weather data providers and the other for CWIS hardware manufacturers to collect data on the market penetration of these products (Appendix A ad B respectively). Due to lack of CWIS sales data in other market segments such as transport and package carriers, this section tests the new model only on the "overall GA" data including private and business aircraft as well as rotorcraft.

According to the experts interviewed by this project team, CWIS awareness was about 90% in all segments as of year 2004. Therefore, A(t) (% potential buyers who are aware of the product) is determined as 0.90 for 2004. Based on the views of experts, it is forecasted in this study that the awareness rate will stay at 90% beyond 2004, and therefore A(t) is assumed to be 0.90 between 2004 and 2025 as well. This study assumes a 5% increase per year in awareness from 2000 to 2003, and therefore the value of A(t) is selected as 0.75 for 2000.

In order to determine the function R(t) (% potential buyers who are aware of the product and consider purchasing one), CWIS sales data between 2000 and 2004 were analyzed based mostly on the numbers obtain from AEA. This data is then compared with the sales of alternative technologies to identify the market share of CWIS among competitors (R(t)). Weather radars and stormscopes are two major products considered as alternative technologies to the CWIS, and for this reason, their sales data have also been compiled.

As shown in Figure 13, which is based on the data in Table 10, weather radar sales have been relatively stable for the past five years. The cumulative sales graph in Figure

14 shows a steady increase in weather radar sales indicating that these products are still in their growth phase.

Table 10. Number of weather radar units sold between 2000 and 2004.

	2000	2001	2002	2003	2004
Number of weather radar units sold	102	115	125	92	115

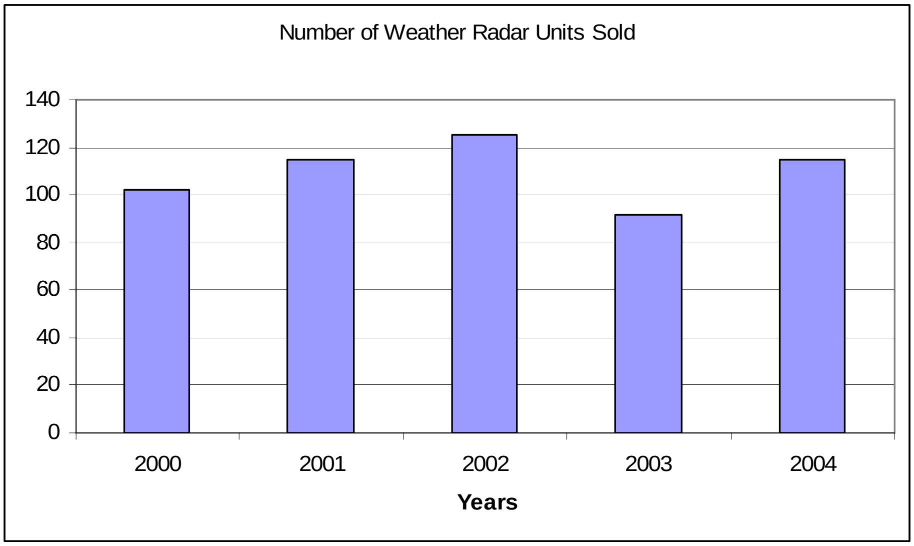

Figure 13. Annual sales numbers for weather radar.

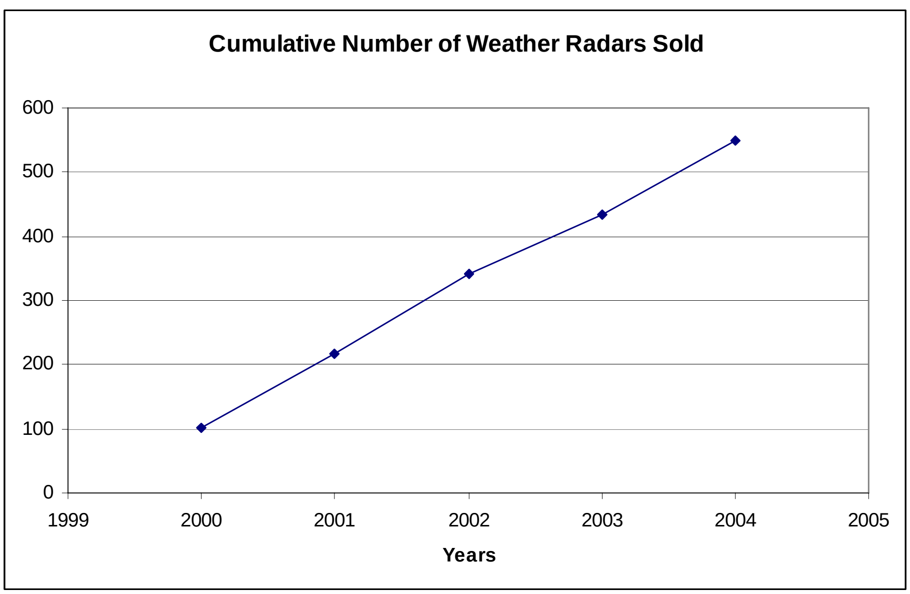

Figure 14. Cumulative number of weather radars sold between 2000 and 2004.

Stormscope constitutes the other major technology that competes with CWIS. As shown in Figure 15 (based on the sales data in Table 11), a dramatic decrease in sales is visible from 2001 to 2004. The cumulative sales graph in Figure 16 shows this slowing growth, and one explanation for it is that stormscope sales are entering the maturity stage of their life cycle since it has been some time since their first release to the market.

Table 11. Number of stormscope units sold between 2000 and 2004.

	2000	2001	2002	2003	2004
Number of stormscope units sold	799	662	345	255	232

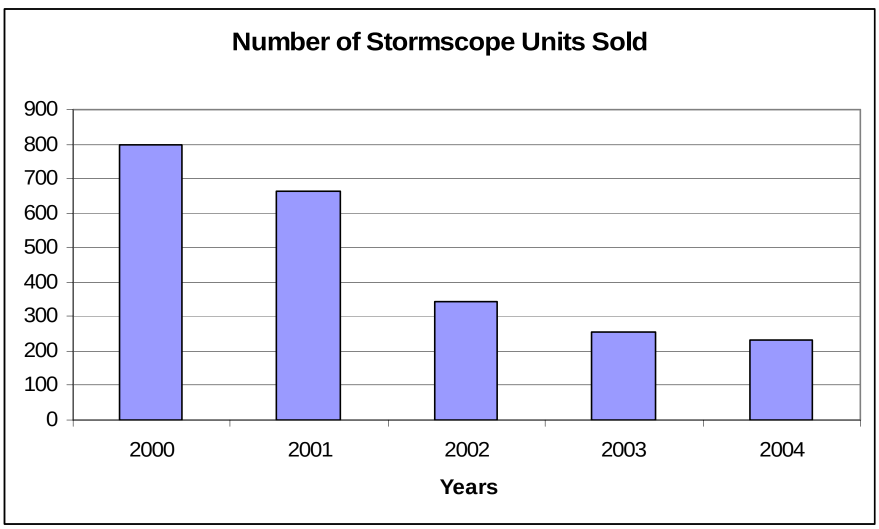

Figure 15. Annual sales numbers for Stormscopes.

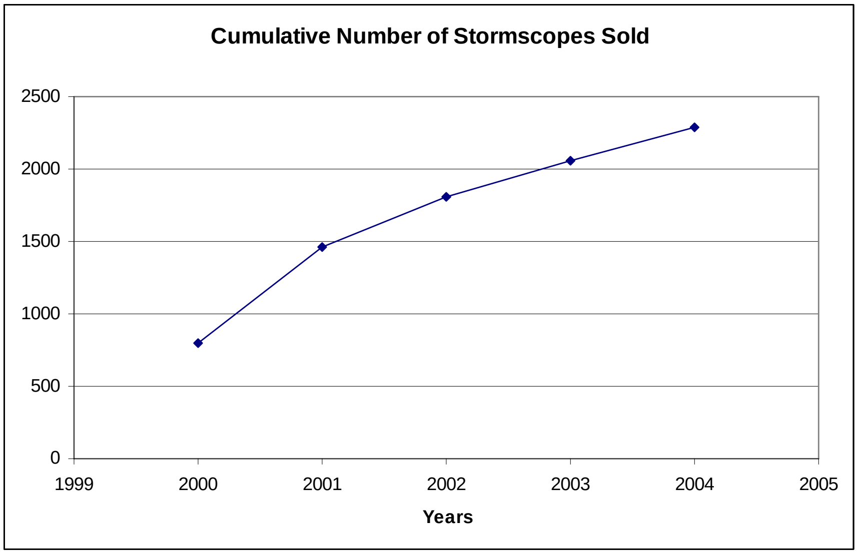

Figure 16. Cumulative number of stormscopes sold between 2000 and 2004.

The annual sales numbers of CWIS units from year 2000 to 2004 are listed in Table 12 and illustrated in Figure 17, where a dramatic increase is visible from 2001 on. Please note that these numbers are the sum of installed and portable unit sales. The data about installed CWIS were acquired from AEA, and the sales numbers for portable products were gathered from the estimates of the experts surveyed since there was no official statistics available for the sales of portable CWIS platforms at the time of this study. Figure 18 shows cumulative CWIS sales and the sharp rise in sales can be seen from 2001 to 2004, indicating the beginning of the growth phase of the CWIS life cycle.

Table 12. Number of CWIS units sold between 2000 and 2004.

	2000	2001	2002	2003	2004
Number of CWIS units sold annually (installed + portable)	2,290	2,218	3,821	5,051	7,016

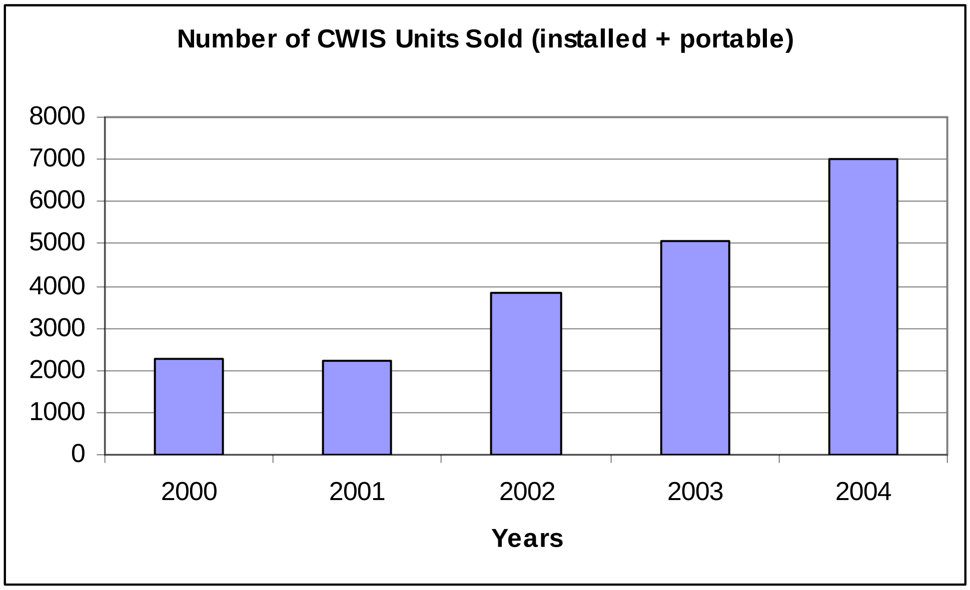

Figure 17. Annual sales numbers for CWIS (installed + portable).

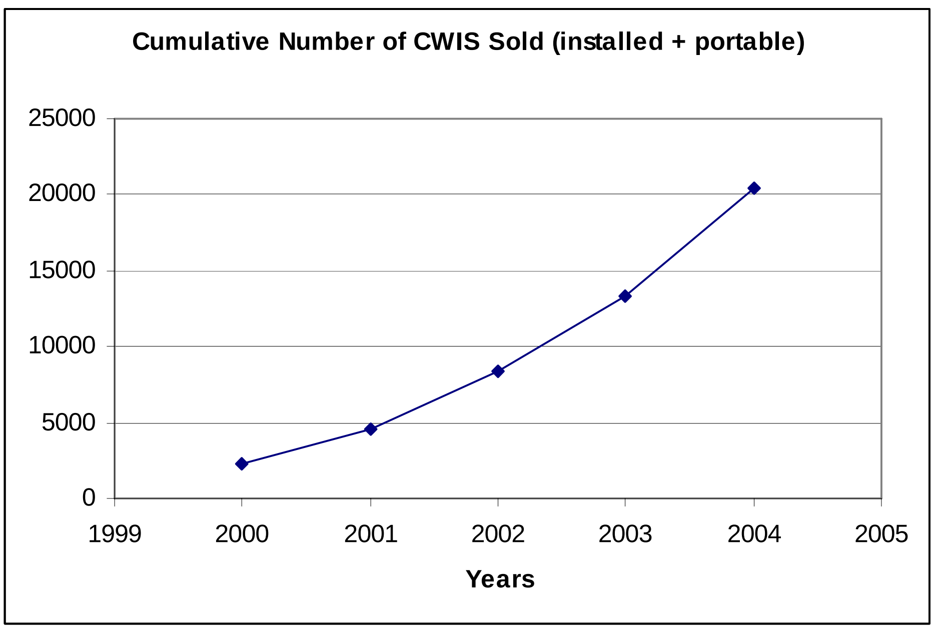

Figure 18. Cumulative number of CWIS units sold from 2000 to 2004.

The annual market share of CWIS compared to weather radar and stormscope sales is calculated in Table 13. The 2004 data suggest that 95% of those who invest in a weather instrument have chosen to buy CWIS this year, which is a significant increase from 72% in 2000. This study assumes that this upward trend indicates a steady market share (95%) for CWIS from 2005 and beyond. As a result, R(t) (% potential buyers who are aware of the product and consider purchasing one) is identified as 72%, 74%, 89%, 93% and 95% from 2000 to 2004 and assumed to stay at 95% from 2005 to 2025.

Table 13. Market share of CWIS compared to two competitor technologies.

Years	2000	2001	2002	2003	2004
Weather radar sales	102	115	125	92	115
Stormscope sales	799	662	345	255	232
Number of CWIS units sold annually (installed + portable)	2,290	2,218	3,821	5,051	7,016
Share of CWIS in weather instrument sales	72%	74%	89%	93%	95%

M(t) (market potential at time t) is assumed to be the number of GA aircraft in the U.S., and the data used to identify M(t) per year are based on the FAA's forecasts and statistics [15], where the GA segment includes private and business aircraft as well as rotorcraft (a.k.a., the overall GA segment in this study). FAA assumes that the number of GA aircraft will increase at a rate of 0.85 annually between 2000 and 2011. This study takes this rate as it is and also assumes that it will be the same from 2011 to 2025. Another assumption is the consideration of only one CWIS unit per aircraft, even though it may be possible that multiple units are used especially in aircraft shared by multiple pilots due to the increasing use of portable systems.

Table 14 includes all the terms of Equation (9) as identified so far, and calculates the predicted annual and cumulative sales as well as the market adoption rates of CWIS in the overall GA segment from 2000 to 2025. The computation of the constants (a and b) in Equation (9) can be found in Appendix C at the end of this report.

In Table 14, shaded areas represent the years that this study acquired sales and market data, while the data for 2005 – 2025 are the predicted values via the new model by using Equation (9). In addition, the I(t) (number of customers who already own the product) values are taken from the cumulative sales column.

Table 14. Sales and market adoption rate predictions of CWIS for the overall GA segment.

t	Year	A(t)	R(t)	M(t)	I(t)	M(t)-I(t)	A(t).R(t).[M(t)-I(t)]	Annual Sales S(t)	Cumulative Sales	Adoption Rate (%)
1	2000	0.7	0.72	204300	0	204300	102967	2290	2290	1.1
2	2001	0.75	0.74	210,825	2290	208535	115737	2218	4508	2.1
3	2002	0.8	0.89	212,970	4508	208462	148425	3821	8329	3.9
4	2003	0.85	0.93	215,125	8329	206796	163472	5051	13380	6.2
5	2004	0.9	0.95	217,270	13380	203890	174326	7016	20396	9.4
6	2005	0.9	0.95	219,415	20396	199,019	170161	7715	28111	12.8
7	2006	0.9	0.95	221,345	28111	193234	165215	10426	38538	17.4
8	2007	0.9	0.95	223,280	38538	184742	157955	11794	50332	22.5
9	2008	0.9	0.95	225,215	50332	174883	149525	12206	62538	27.8
10	2009	0.9	0.95	227,145	62538	164607	140739	11348	73885	32.5
11	2010	0.9	0.95	229,070	73885	155185	132683	9636	83522	36.5
12	2011	0.9	0.95	230,995	83522	147473	126090	7657	91178	39.5
13	2012	0.9	0.95	232958	91178	141780	121222	5871	97049	41.7
14	2013	0.9	0.95	234939	97049	137889	117895	4407	101457	43.2
15	2014	0.9	0.95	236936	101457	135479	115835	3333	104790	44.2
16	2015	0.9	0.95	238950	104790	134160	114707	2557	107347	44.9
17	2016	0.9	0.95	240981	107347	133634	114257	2032	109379	45.4
18	2017	0.9	0.95	243029	109379	133650	114271	1670	111049	45.7
19	2018	0.9	0.95	245095	111049	134046	114609	1437	112486	45.9
20	2019	0.9	0.95	247178	112486	134692	115162	1279	113765	46.0
21	2020	0.9	0.95	249279	113765	135514	115865	1182	114947	46.1
22	2021	0.9	0.95	251398	114947	136451	116666	1116	116063	46.2
23	2022	0.9	0.95	253535	116063	137472	117538	1080	117143	46.2
24	2023	0.9	0.95	255690	117143	138547	118458	1056	118198	46.2
25	2024	0.9	0.95	257863	118198	139665	119414	1045	119243	46.2
26	2025	0.9	0.95	260055	119243	140812	120394	1039	120282	46.3

Figure 19 compares the forecasts of CWIS sales from 2000 to 2004 with the actual sales data to examine the validity of the model. As observed in this figure, the distance between the two curves is quite narrow, one indicator of a valid model. Forecasting error should also be calculated to support this argument, and therefore MAPE (Mean Absolute Percentage Error) and MPE (Mean Percentage Error) values are found as 5.9% and 5.4% respectively. The MAPE value shows how large the forecast errors are in comparison to the actual values, and 5.9% is a small percentage. MPE determines if the forecasting method is biased, and even though 5.4% indicates that the model slightly under-estimates (as observed in Figure 19), this is a negligible value. As a result, it is concluded that the forecasts of the new market adoption model between 2000 and 2004 are very close to accurate, which is a promising result for the predictions from 2005 to 2025.

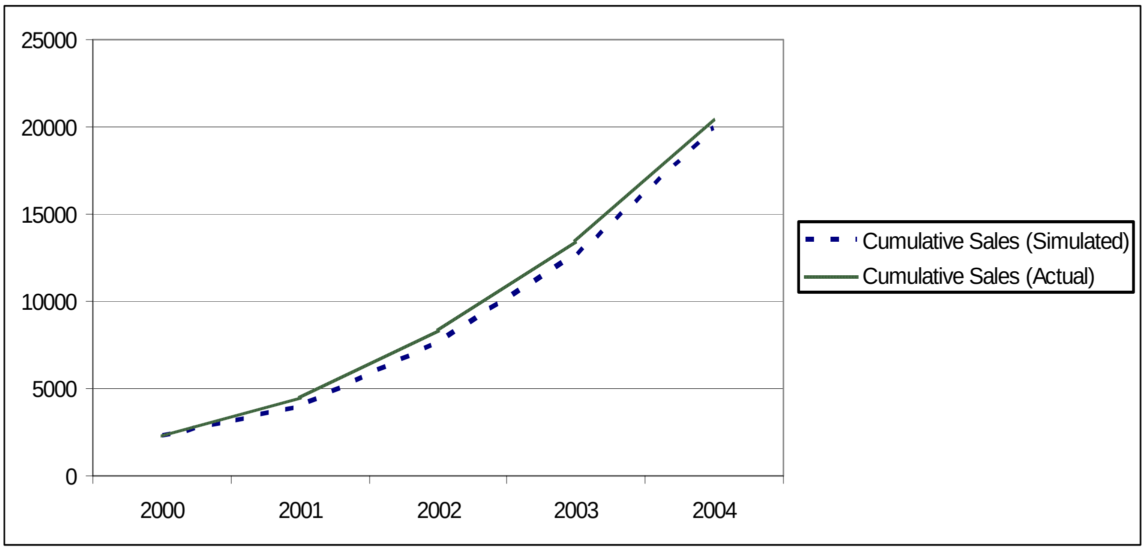

Figure 19. Simulated (predicted) versus actual sales data between 2000 and 2004.

Figure 20 illustrates the model's predictions from 2000 to 2025 for CWIS annual sales in the whole GA segment, according to which, sales will peak around 2008 and will start dropping afterwards. Figure 21 includes the cumulative graph of the annual sales, showing a typical product life cycle curve for CWIS, indicating that cumulative sales will continue to grow from 2005 to 2025, and the maturity phase seems to start around 2014.

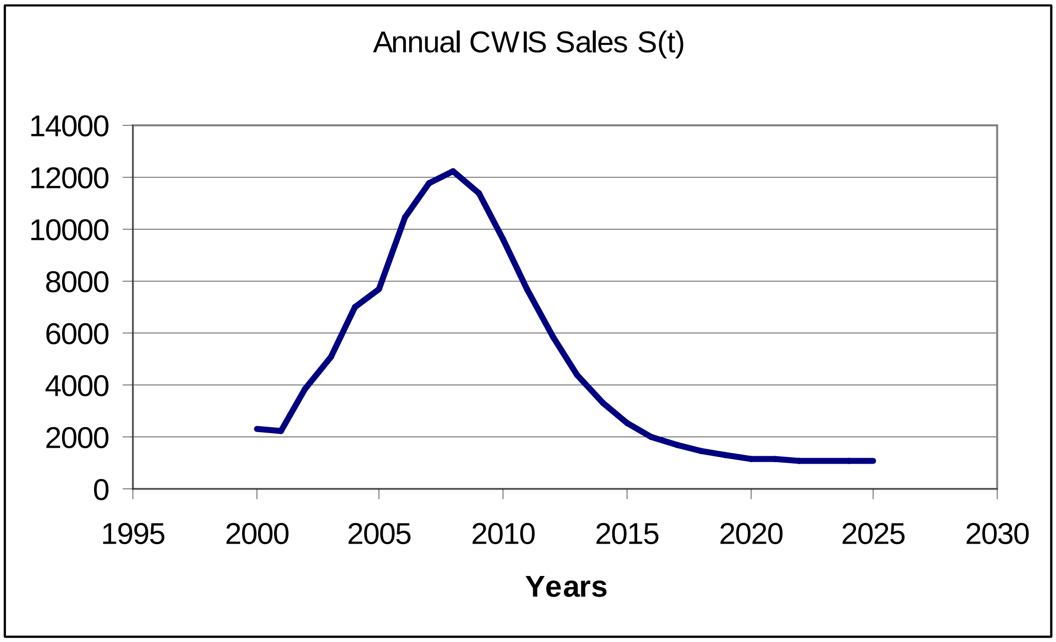

Figure 20. Annual sales forecast for CWIS for the overall GA segment.

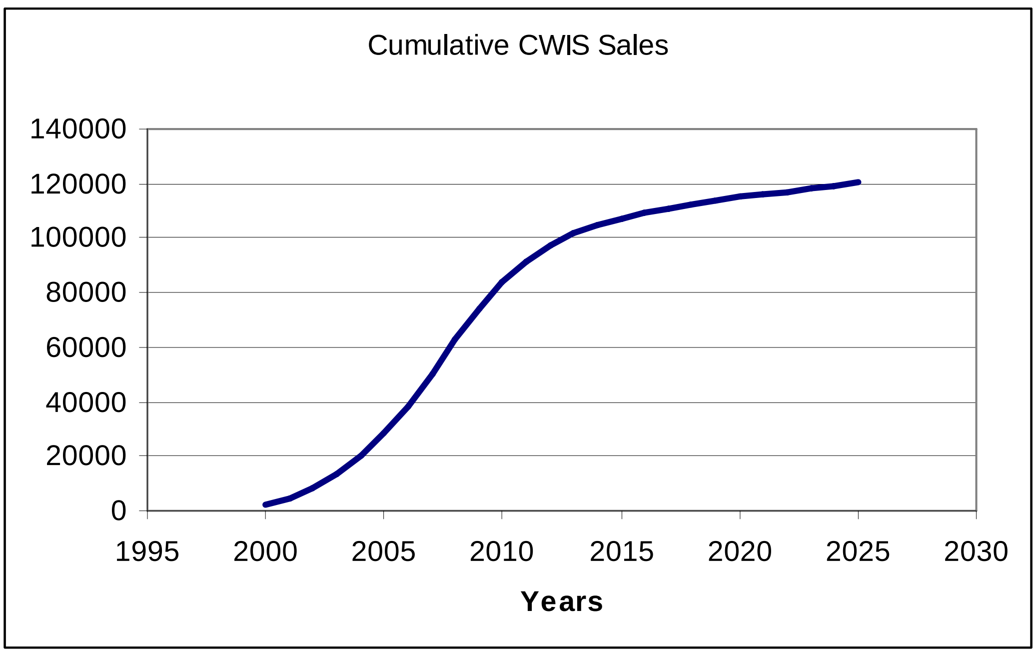

Figure 21. Cumulative sales forecast for CWIS.

Figure 22 presents market adoption rate values estimated by the new model. According to these predictions, market adoption rate is expected to approach 44% in year

2014 as entering the maturity phase and 52% in year 2025 reaching the maximum adoption rate in the overall GA segment.

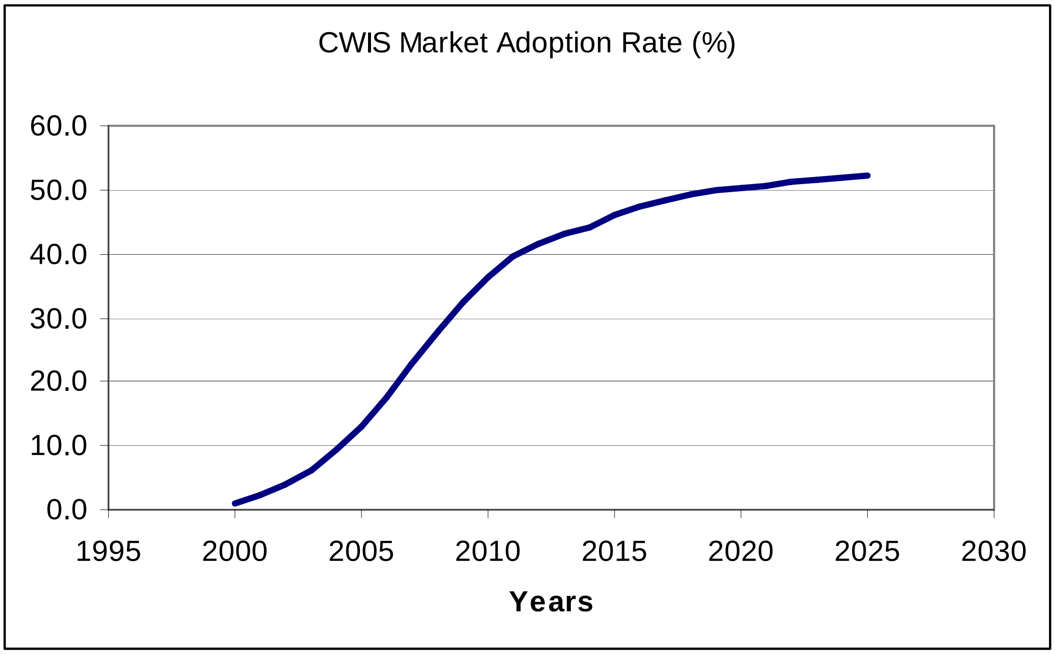

Figure 22. Market adoption rate forecast for CWIS in the overall GA segment.

5.4 Comparison with the Original Study

The original study [1] made the following predictions:

- The GA segment achieves a little above 50% market penetration in 2025 as it enters the maturity phase. In year 2014, this rate is around 39%.
- Market adoption in the business segment increases faster than the other segments, and reaches 80% adoption rate in 2025. In 2014, the adoption rate is almost 69%.
- Rotorcraft is the slowest segment and only achieves 40% adoption rate in 2025 in its maturity phase. In 2014, this rate is about 29%.

Before beginning to compare the findings achieved here with the original report, the assumptions made in this study (which somewhat differ it from the original study) are stated as follows:

- This study uses data for the “overall GA segment,” which consists of private aircraft, business aircraft and rotorcraft. Therefore, the definition of GA is different from the one used in the original study, which excluded business and rotorcraft.
- To compare this study’s predictions with the original study, it is assumed that the total maximum market penetration of GA, business and rotorcraft in the original study is the weighted average of these segments’ individual maximum adoption rates for year 2025. That is to say, the average maximum market penetration predicted in the original report is considered to be the weighted average of 50% (for GA), 80% (for business), and 40% (for rotorcraft). Consequently, this study assumes that the maximum adoption prediction for the sum of all three segments is 53%, which is now comparable with the “overall GA segment” forecasts computed in this report (see Section 5.3).
- Similarly, for year 2014, the average market adoption of these three segments as defined in the original study is calculated as 42% (the weighted average of 39% for GA, 69% for business, and 29% for rotorcraft).

Figure 23 visualizes the difference between the findings of this study and the original report [1], where the solid curve is the forecast found by means of the new model here, and the dashed curve belongs to the original study. The predictions of this study for the overall GA segment (private + business + rotorcraft) and their comparison with the original study are as follows:

- The market adoption rate in 2014 for the overall GA segment is 44%. This is assumed to be 42% in the original study as discussed above, which indicates that the predictions of both studies for 2014 are very close.
- This study finds that the maximum market penetration rate in 2025 is 52%. This is assumed to be 53% in the original study, leaving only 1% difference between the two maximum penetration forecasts. According to the predicted penetration curve in this study, CWIS in the overall GA segment starts entering maturity around 2014. On the other hand, from the shape of the original study's curve the maturity stage seems to start a few years later, probably around 2018. As a result, this study predicts a somewhat faster developing market penetration curve compared to the original, and it also forecasts a slightly lower market adoption in 2025.

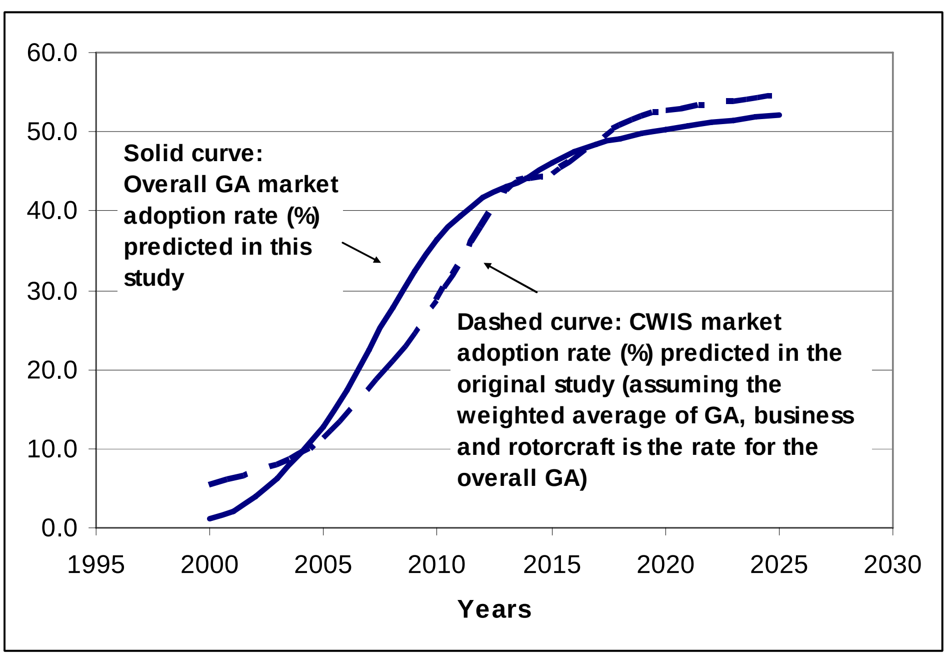

Figure 23. The forecast difference between this study and the original study.

6 Conclusions

The longitudinal research consists of two consecutive studies and produced two reports. The first report was submitted in August 2003 and included general market analysis about the CWIS products in the market at the time, identified their characteristics and examined developing market dynamics. This report is the second and final report, completing the longitudinal research by relying on CWIS market data acquired by the following means:

- The project team's contacts with major CWIS hardware and weather providers through phone, email, as well as in person communications at conventions and meetings (e.g., NBAA Meeting & Convention, October 12-14, 2004, Las Vegas, NV; AEA Convention, April 27-30, Dallas, TX),
- AEA (Aircraft Electronics Association) survey data provided to the project team through membership.
- Public information on company web sites and other Internet sources.

Although this research collected company-specific information such as sales volume and number of subscribers, they are left out of this report due to confidentiality. Only average numbers and information made public over the Internet are used for analysis, and compiled with data acquired from AEA.

This study first provides a bird's eye view of the current CWIS market including the partnerships between hardware and weather data providers, and concludes that the target market segments for CWIS are as follows in order of significance are:

1. Business
2. General Aviation (GA) (business and rotorcraft excluded)

3. Transport
4. Package carriers
5. Corporate rotorcraft

It, then, updates important product characteristics by focusing on possible region-specific marketing concerns by means of a customer (pilot) survey. It identifies distinguishing CWIS characteristics region by region (northwest, north-central, northeast, southwest, south-central, southeast) as well as in the U.S. in general. Regional information is potentially important for system provides who market their products in different areas, focusing on changing customer expectations. As a result, this study finds that survey participants from the northeast and southwest regions show the same expectations, ranking *METARs*, *5-10 minute-weather updates*, *icing* and *low visibility alerts* as important factors, differentiating them from the rest of the country. The southeast region indicates similar preferences except that it ranks *convective weather product* more important than *METARs*. Central regions also indicate similar needs, but differ significantly from the rest, ranking *convective* and *icing weather products*, together with *icing* and *heavy precipitation alerts* as important and distinguishing CWIS characteristics. The only rank difference between north-central and south-central is the *weather update interval* since NC pilots seem to prefer more frequent weather updates. The northwest region varies from the rest of the U.S. quite significantly, ranking *TAFs* along with *METARs* as an important weather product. Survey participants from this region expect frequent weather *updates (0-5 minutes)* as well. They also require *turbulence alerts* along with *low visibility alerts*. Finally, northwest is the only region ranking *TAFs* and *turbulence alert* rather important.

This study develops surveys to collect data from CWIS hardware manufacturers and weather data providers to examine the level of CWIS market adoption in 2004, and to predict future growth. It also gathers historical data on CWIS sales over the past years to predict future adoption rates. Based on this information, it updates Kauffmann's original study [1] and verifies the original study's predictions from year 2000 to 2004 based on actual data. As a result, this study concludes that the actual market adoption rates of GA and business segments from year 2000 to 2004 are within the original study's prediction interval. That is to say, the original study provided statistically correct predictions for these segments in this time frame.

Another goal of this research is to predict market penetration from 2005 to 2025 and compare these predictions with the forecasts provided in the original report [1]. To accomplish this, it creates a new market penetration model suitable for the information systems (IS) including the CWIS market. The major assumptions made in this study are:

- The definition of the GA segment is different in this study, compared to the original report [1]. The original report excludes business aircraft and rotorcraft from the definition of GA. However, since this study follows GA data (such as number of GA aircraft) obtained from FAA to forecast the future growth of CWIS, it uses FAA's definition of GA, which includes business and rotorcraft along with private aircraft. As a result, this study uses the term "GA segment" as the GA segment excluding business and rotorcraft, and "overall GA segment" as the GA segment including business aircraft and rotorcraft.
- To compare this study's predictions with the original study, it is assumed that the total maximum market penetration of GA, business and rotorcraft in the original

study is the weighted average of these segments' individual maximum adoption rates for year 2025. That is to say, the average maximum market penetration predicted in the original report is considered to be the weighted average of 50% (for GA), 80% (for business), and 40% (for rotorcraft). Consequently, this study assumes that the maximum adoption prediction for the sum of all three segments is 53%, which is now comparable with the "overall GA segment" forecasts computed in this report.

- Similarly, for year 2014, the average market adoption of these three segments as defined in the original study is calculated as 42% (the weighted average of 39% fro GA, 69% for business, and 29% for rotorcraft).
- This study assumes only one CWIS unit per aircraft, even though it may be possible that multiple units are used especially in aircraft shared by multiple pilots due to the increasing use of portable systems.

The validity of the new market adoption mode is examined by means of the forecasting errors calculated based on the actual data from 2000 to 2004 and the forecast values provided by the model in this time frame. The error values are found to be negligible resulting in a capable forecasting model.

By using the new model based on the assumptions above, this report finds that the predicted market adoption rate for year 2014 for the overall GA segment is almost 44%. This rate is assumed to be 42% in the original study, which indicates that the predictions of both studies for 2014 are very close.

This study also finds that the maximum market penetration rate in 2025 is 52%. This is assumed to be 53% in the original study, leaving only 1% difference between the two maximum penetration forecasts. According to the predicted penetration curve in this study, CWIS in the overall GA segment starts entering maturity around 2014. On the other hand, from the shape of the original study's curve the maturity stage starts a few years later, probably around 2018. As a result, this study predicts a faster developing market penetration curve compared to the original, and it also forecasts a slightly lower market adoption in 2025.

It should be noted that, due to competition, business secrecy, inadequate sales in some market segments, and/or simply unknown data, it has not been possible to collect adequate market adoption data for the other market segments (such as transport and package carriers) to compare with the original study's predictions. Future work includes collecting data related to the market segments left out in this study and more model testing on other IS products to support the new model's capability.

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Appendix A – Survey for weather data providers

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The University of North Carolina at Charlotte
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Conducted for

Aviation Weather Information Element
Aviation Safety Program
Projects and Advanced Concepts
Branch, MS 152, Bldg 1168, Rm 129
NASA Langley Research Center
Hampton, VA 23681-2199

Thank you for your willingness to participate in our project to estimate the market acceptance rate for advanced cockpit weather information systems (CWIS). This research is being conducted by East Carolina University and The University of North Carolina at Charlotte under the direction of the Aviation Weather Information (AWIN) project at the NASA Langley Research Center in Hampton, Virginia.

CWIS can be defined as systems that provide graphical and/or textual weather information to the flight deck of an aircraft via a data link and a display. Several years ago we conducted a study for NASA that predicted the adoption rate of these systems. As the various aviation market segments continue to adopt these products over the next several years, we hope to compare the original study and its predictions with the actual market influences, technologies, business cases, and adoption rates to validate the accuracy and usefulness of the methods used in that previous study. Using this information, it is also possible to refine the original model and identify suggestions for improvement. The resulting new technology adoption model will provide a unique and comprehensive case study that describes developing, tracking, and assessing a feasibility evaluation approach for advanced technologies in aviation weather information systems.

We hope you are willing to complete the survey within the next week and return it to me. Thank you again for your cooperation in this project. If you have any questions, I can be reached at East Carolina University (252-328 9645) or by email at kauffmannp@mail.ecu.edu. For more information on our research, please visit our project web site at http://core.ecu.edu/itec/ozang/cockpitwx.html. Questions for the NASA – AWIN project should be directed to Paul Stough at 757 864 3860 or h.p.stough@nasa.gov. I look forward to a successful project with your help.

Sincerely,

Paul Kauffmann, Ph.D., P.E.

Cockpit Weather Information Systems Survey
Introduction and Overview

This document provides introductory information for participants in a survey to estimate the market adoption (penetration) timing for cockpit weather information systems.

Who is conducting this survey?
This survey is conducted by East Carolina University and the University of North Carolina at Charlotte under the direction of the Aviation Weather Information (AWIN) project at the NASA Langley Research Center in Hampton, VA.

What is the objective of the survey?

The objective of this survey is to estimate the technology adoption timing (market penetration curve) for advanced cockpit weather information systems. These survey results will be used to estimate the future impact of cockpit weather systems in reducing weather - related accidents.

What market segments will the survey examine?

The study will develop estimated adoption rate data for five aviation market segments: transport, commuter, business, general aviation, and rotorcraft.

What assumption has been made regarding the hardware and components that advanced cockpit weather information will require?

The survey assumes that, in general, the weather information system may have three components: (1) a weather data service / provide; (2) a data / communication link element to receive the transmitted weather data from the weather data provider / service; (3) a display / interface device to convert the weather data to visual information.

Will specific estimates and responses from participants be identified?
No. For confidentiality purposes, individual participant responses will not be identified. The report will represent the general results and responses. However, we would like to list the names of the organizations that participated in the survey in the report. If you have special confidentiality needs, please contact us or indicate your wishes on the survey.

Should I involve others in my organization in completing the surveys?
The first question in each survey asks you to evaluate your expertise for each market segment. You should answer market segment questions only if you feel you have an understanding of that market. If another person in your organization has more experience with a particular market segment or topic, please involve that individual in those survey questions. Some organizations plan to use a team to complete the surveys.

Who is participating in this survey?
A broad representation of the aviation weather information community is participating in this survey. One of the main goals of this survey is to find out the number of cockpits equipped with a weather information data link. Since weather information providers disseminate the aviation weather products to the end users, the most accurate and complete market data can only be obtained form that specific sector.

How quickly should I complete my survey and when will the report be completed?
Please plan on completing your survey and sending it back to us within a week. The survey data should be compiled and the report completed by October 15, 2004.

Will each participant receive a copy of the report?
Yes. The completed report will be sent to each participant.

For other questions, contact Paul Kauffmann, Professor and Chair, East Carolina University, Department of Industrial Technology, Science and Technology Building, Greenville, NC 27858 (kauffmannp@mail.ecu.edu).

Cockpit Weather Information System Survey

Primary Survey Contact: ____

Telephone ________________________________ **Email** ________________________________

Job Title: ____

Please let us know any other participants who helped completing this:

Other Participant ____________________________ **Other Participant** __________________________

Job Title: ______________________________ **Job Title:** _______________________________

Please email the completed forms to kauffmannp@mail.ecu.edu or mail it to the address below:
Dr. Paul Kauffmann, Professor and Chair, East Carolina University, Dept. of Industrial Technology, Science & Technology Building, Greenville, NC 27858.

Market Segment Expertise
You and your organization may be particularly focused on one or several of the target market segments. This question asks you to rate your market segment expertise. *(Note: If you or your organization does not have knowledge of a specific market, please skip the questions on that market segment or include input from others to augment the survey information).*

I rate my knowledge (or my organization's knowledge) of cockpit weather information issues for the target market segments as:				
	Expert	**Very Good**	**Good**	**No knowledge of this market**
Transport Segment	☐	☐	☐	☐
Commuter Segment	☐	☐	☐	☐
General Aviation Segment	☐	☐	☐	☐
Business Segment	☐	☐	☐	☐
Rotorcraft Segment	☐	☐	☐	☐

Comments:

1. Market segment size, potential customers, and product awareness: This question asks you for four data points for each market segment:

1) How large is the total market segment in your view?
2) Of that total market, not all aircraft in a market segment are potential purchasers of CWIS systems. What number do you see as potential purchasers / adopters of cockpit weather systems defined as aircraft that will have both a display and access to graphical weather data?
3) Since product awareness limits the decisions of the potential customers, we ask you to estimate the number of those potential purchasers who are aware of CWIS products.
4) Estimate the total number of aircraft in the U.S. that have an active Cockpit Weather Information System onboard for this market segment.)

For example, you may believe that there were 5500 aircraft in the transport segment in 2002 and only 4000 of these were potential CWIS customers. Of that 4000 potential customer group, only 1500 were aware of CWIS at that time. Finally, you may estimate that 500 transport aircraft have an active advanced weather information system installed in the cockpit and are capable of receiving graphical weather information via a data link.

Since these numbers will change over time, we ask you to provide estimates over the next 15 years. Please enter your best estimates. If you have no knowledge of a segment, enter NA.

		2002	**2004**	**2006**	**2008**	**2010**	**2015**	**2020**
Transport Market Segment	Total Market							
	Number of potential customers							
	Number of potential customers that are aware of CWIS							
	Number of CWIS adopters / users							

Comments:

		2002	**2004**	**2006**	**2008**	**2010**	**2015**	**2020**
Commuter Market Segment	Total Market							
	Number of potential customers							
	Number of potential customers that are aware of CWIS							
	Number of CWIS adopters / users							

Comments:

		2002	2004	2006	2008	2010	2015	2020
General Aviation Market Segment	Total Market							
	Number of potential customers							
	Number of potential customers that are aware of CWIS							
	Number of CWIS adopters / users							

Comments:

		2002	2004	2006	2008	2010	2015	2020
Business Market Segment	Total Market							
	Number of potential customers							
	Number of potential customers that are aware of CWIS							
	Number of CWIS adopters / users							

Comments:

		2002	2004	2006	2008	2010	2015	2020
Rotorcraft Market Segment	Total Market							
	Number of potential customers							
	Number of potential customers that are aware of CWIS							
	Number of CWIS adopters / users							

Comments:

2. Your current subscribers
Would you mind sharing the information on the current number of subscribers that use your organization's aviation weather data service? (Please check the box that applies)

	I prefer not to disclose that information at this time.
	I would like to share that information, I understand that the information I provide is confidential and organization-specific responses will not be identified.

If you agree to share the subscriber information please answer questions 2.a and2b.

2a. Your customer base
Please enter below your estimates for the current number of aircraft in the U.S. that are the subscribers of your organization's weather data service for each segment. (Example: If you enter 500 in the first column, that means 500 transport aircraft are receiving weather data from your organization)

Transport Aircraft How many transport aircraft in the U.S. are receiving weather data from your organization? (Please enter below)	**Commuter Aircraft** How many commuter aircraft in the U.S. are receiving weather data from your organization? (Please enter below)	**General Aviation (GA) Aircraft** How many GA aircraft in the U.S. are receiving weather data from your organization? (Please enter below)	**Business Aircraft** How many business aircraft in the U.S. are receiving weather data from your organization? (Please enter below)	**Rotorcraft Aircraft** How many rotorcraft aircraft in the U.S. are receiving weather data from your organization? (Please enter below)

2b. Forecast of your market penetration growth.
Please enter below your estimates for the number of aircraft that will use your organization's weather services by the time periods below.

Years ↓	Transport Aircraft	Commuter Aircraft	General Aviation Aircraft	Business Aircraft	Rotorcraft Aircraft
2006					
2008					
2010					
2015					
2020					

Comments:

3. Impact of Major Developments

Evaluate the possible impacts of the major technology or market developments that may affect the adoption of Cockpit Weather Information Systems (Please check the boxes that apply)

	Will cause dramatic decreases in the rate of adoption	Will cause minor decrease in the rate of adoption	Will not affect the adoption rate	Will moderately increase the rate of adoption	Will cause dramatic increase in the rate of adoption
New frequency allocations	☐	☐	☐	☐	☐
Introduction of low cost PDA or PC notebook based CWIS	☐	☐	☐	☐	☐
New satellite based technologies	☐	☐	☐	☐	☐
New user interface/display technologies	☐	☐	☐	☐	☐
Government actions/regulations	☐	☐	☐	☐	☐
Other: ……………… ………………	☐	☐	☐	☐	☐
Other: ……………… ………………	☐	☐	☐	☐	☐
Other: ……………… ………………	☐	☐	☐	☐	☐

Comments:

Please email the completed forms to kauffmannp@mail.ecu.edu or mail it to the address below:

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Department of Industrial Technology
Science & Technology Building
Greenville, NC 27858.

-----------------------Thank you. Your response to this survey is confidential------------

Appendix B – Survey for hardware manufacturers

Department of Industrial Technology
East Carolina University
College of Technology and Computer Science
205 Science and Technology Building,
Greenville, NC 27858

Aviation Weather Information Element
Aviation Safety Program
Projects and Advanced Concepts
Branch, MS 152, Bldg 1168, Rm 129
NASA Langley Research Center
Hampton, VA 23681-2199

Conducted for

Engineering Management Program
The William States Lee College of Engineering
The University of North Carolina at Charlotte
9201 University City Boulevard, Charlotte, NC
28223

Thank you for your willingness to participate in our project to estimate the market acceptance rate for advanced cockpit weather information systems (CWIS). This research is being conducted by East Carolina University and The University of North Carolina at Charlotte under the direction of the Aviation Weather Information (AWIN) project at the NASA Langley Research Center in Hampton, Virginia.

CWIS can be defined as systems that provide graphical and/or textual weather information to the flight deck of an aircraft via a data link and a display. Several years ago we conducted a study for NASA that predicted the adoption rate of these systems. As the various aviation market segments continue to adopt these products over the next several years, we hope to compare the original study and its predictions with the actual market influences, technologies, business cases, and adoption rates to validate the accuracy and usefulness of the methods used in that previous study. Using this information, it is also possible to refine the original model and identify suggestions for improvement. The resulting new technology adoption model will provide a unique and comprehensive case study that describes developing, tracking, and assessing a feasibility evaluation approach for advanced technologies in aviation weather information systems.

We hope you are willing to complete the survey within the next week and return it to me. Thank you again for your cooperation in this project. If you have any questions, I can be reached at East Carolina University (252-328 9645) or by email at kauffmannp@mail.ecu.edu. For more information on our research, please visit our project web site at http://core.ecu.edu/itec/ozang/cockpitwx.html. Questions for the NASA – AWIN project should be directed to Paul Stough at 757 864 3860 or h.p.stough@nasa.gov . I look forward to a successful project with your help.

Sincerely,

Paul Kauffmann, Ph.D., P.E.

Cockpit Weather Information Systems Survey
Introduction and Overview

This document provides introductory information for participants in a survey to estimate the market adoption (penetration) timing for cockpit weather information systems.

Who is conducting this survey?
This survey is conducted by East Carolina University and the University of North Carolina at Charlotte under the direction of the Aviation Weather Information (AWIN) project at the NASA Langley Research Center in Hampton, VA.

What is the objective of the survey?

The objective of this survey is to estimate the technology adoption timing (market penetration curve) for advanced cockpit weather information systems. These survey results will be used to estimate the future impact of cockpit weather systems in reducing weather - related accidents.

What market segments will the survey examine?

The study will develop estimated adoption rate data for five aviation market segments: transport, commuter, business, general aviation, and rotorcraft.

What assumption has been made regarding the hardware and components that advanced cockpit weather information will require?

The survey assumes that, in general, the weather information system may have three components: (1) a weather data service / provide; (2) a data / communication link element to receive the transmitted weather data from the weather data provider / service; (3) a display / interface device to convert the weather data to visual information.

Will specific estimates and responses from participants be identified?
No. For confidentiality purposes, individual participant responses will not be identified. The report will represent the general results and responses. However, we would like to list the names of the organizations that participated in the survey in the report. If you have special confidentiality needs, please contact us or indicate your wishes on the survey.

Should I involve others in my organization in completing the surveys?
The first question in each survey asks you to evaluate your expertise for each market segment. You should answer market segment questions only if you feel you have an understanding of that market. If another person in your organization has more experience with a particular market segment or topic, please involve that individual in those survey questions. Some organizations plan to use a team to complete the surveys.

Who is participating in this survey?
A broad representation of the aviation weather information community is participating in this survey. One of the main goals of this survey is to find out the number of cockpits equipped with a weather information data link.

How quickly should I complete my survey and when will the report be completed?
Please plan on completing your survey and sending it back to us within a week. The survey data should be compiled and the report completed by October 15, 2004.

Will each participant receive a copy of the report?
Yes. The completed report will be sent to each participant.

For other questions, contact Paul Kauffmann, Professor and Chair, East Carolina University, Department of Industrial Technology, Science and Technology Building, Greenville, NC 27858 (kauffmannp@mail.ecu.edu).

Cockpit Weather Information System Survey

Primary Survey Contact: ____

Telephone ______________________________ **Email** ______________________________

Job Title: ____

Please let us know any other participants who helped completing this:

Other Participant __________________________ **Other Participant** __________________________

Job Title: __________________________ **Job Title:** __________________________

Please email the completed forms to kauffmannp@mail.ecu.edu or mail it to the address below:
Dr. Paul Kauffmann, Professor and Chair, East Carolina University, Dept. of Industrial Technology, Science & Technology Building, Greenville, NC 27858.

Market Segment Expertise
You and your organization may be particularly focused on one or several of the target market segments. This question asks you to rate your market segment expertise. *(Note: If you or your organization do not have knowledge of a specific market, please skip the questions on that market segment or include input from others to augment the survey information).*

I rate my knowledge (or my organization's knowledge) of cockpit weather information issues for the target market segments as:				
	Expert	**Very Good**	**Good**	**No knowledge of this market**
Transport Segment	☐	☐	☐	☐
Commuter Segment	☐	☐	☐	☐
General Aviation Segment	☐	☐	☐	☐
Business Segment	☐	☐	☐	☐
Rotorcraft Segment	☐	☐	☐	☐

Comments:

1. Market segment size, potential customers, and product awareness: This question asks you for four data points for each market segment:

5) How large is the total market segment in your view?
6) Of that total market, not all aircraft in a market segment are potential purchasers of Cockpit Weather Information Systems (CWIS). What number do you see as potential purchasers / adopters of cockpit weather systems defined as aircraft that will have both a display and access to graphical weather data?
7) Since product awareness limits the decisions of the potential customers, we ask you to estimate the number of those potential purchasers who are aware of CWIS products.
8) Estimate the total number of aircraft in the U.S. that have an active Cockpit Weather Information System onboard for this market segment.

For example, you may believe that there were 5500 aircraft in the transport segment in 2002 and only 4000 of these were potential CWIS customers. Of that 4000 potential customer group, only 1500 were aware of CWIS at that time. Finally, you may estimate that 500 transport aircraft have an active advanced weather information system installed in the cockpit and are capable of receiving graphical weather information via a data link.

Since these numbers will change over time, we ask you to provide estimates over the next 15 years. Please enter your best estimates. If you have no knowledge of a segment, enter NA.

		2002	2004	2006	2008	2010	2015	2020
Transport Market Segment	Total Market							
	Number of potential customers							
	Number of potential customers that are aware of CWIS							
	Number of CWIS adopters / users							

Comments:

		2002	2004	2006	2008	2010	2015	2020
Commuter Market Segment	Total Market							
	Number of potential customers							
	Number of potential customers that are aware of CWIS							
	Number of CWIS adopters / users							

Comments:

		2002	2004	2006	2008	2010	2015	2020
General Aviation Market Segment	Total Market							
	Number of potential customers							
	Number of potential customers that are aware of CWIS							
	Number of CWIS adopters / users							

Comments:

		2002	2004	2006	2008	2010	2015	2020
Business Market Segment	Total Market							
	Number of potential customers							
	Number of potential customers that are aware of CWIS							
	Number of CWIS adopters / users							

Comments:

		2002	2004	2006	2008	2010	2015	2020
Rotorcraft Market Segment	Total Market							
	Number of potential customers							
	Number of potential customers that are aware of CWIS							
	Number of CWIS adopters / users							

Comments:

2. Customer data

Would you mind sharing the information on the current number of customers that use a cockpit weather information system manufactured by your company? (Please check the box that applies)

	I prefer not to disclose that information at this time.
	I would like to share that information, I understand that the information I provide is confidential and organization-specific responses will not be identified.

If you agree to share the user information please answer questions 2.a and2b.

2a. Your customer base

Please enter below your estimates for the current number of aircraft in the U.S. that use a cockpit weather information system manufactured by your company for each segment. (Example: If you enter 500 in the first column that means 500 transport aircraft is equipped with a cockpit weather information system manufactured by your company)

Transport Aircraft How many transport aircraft in the U.S. are equipped with a cockpit weather information system manufactured by your company? (Please enter below)	**Commuter Aircraft** How many commuter aircraft in the U.S. are equipped with a cockpit weather information system manufactured by your company? (Please enter below)	**General Aviation (GA) Aircraft** How many GA aircraft in the U.S. are equipped with a cockpit weather information system manufactured by your company? (Please enter below)	**Business Aircraft** How many business aircraft in the U.S. are equipped with a cockpit weather information system manufactured by your company? (Please enter below)	**Rotorcraft Aircraft** How many rotorcraft aircraft in the U.S. are equipped with a cockpit weather information system manufactured by your company? (Please enter below)
……..	……..	……..	……..	……..

2.b. Forecast of your market penetration growth.

Please enter below your estimates for the number of aircraft that will have a cockpit weather information system manufactured by your company by the time periods below.

Years ↓	**Transport Aircraft**	**Commuter Aircraft**	**General Aviation Aircraft**	**Business Aircraft**	**Rotorcraft Aircraft**
2006					
2008					
2010					
2015					
2020					

Comments:

3. Impact of Major Developments

Evaluate the possible impacts of the major technology or market developments that may affect the adoption of Cockpit Weather Information Systems (Please check the boxes that apply)

	Will cause dramatic decreases in the rate of adoption	Will cause minor decrease in the rate of adoption	Will not affect the adoption rate	Will moderately increase the rate of adoption	Will cause dramatic increase in the rate of adoption
New frequency allocations	☐	☐	☐	☐	☐
Introduction of low cost PDA or PC notebook based cockpit weather information system	☐	☐	☐	☐	☐
New satellite based technologies	☐	☐	☐	☐	☐
New user interface/display technologies	☐	☐	☐	☐	☐
Government actions/regulations	☐	☐	☐	☐	☐
Other: ……………… ………………	☐	☐	☐	☐	☐
Other: ……………… ………………	☐	☐	☐	☐	☐
Other: ……………… ………………	☐	☐	☐	☐	☐

Comments:

Please email the completed forms to kauffmannp@mail.ecu.edu or mail it to the address below:

Dr. Paul Kauffmann,
Professor and Chair
East Carolina University
Department of Industrial Technology
Science & Technology Building
Greenville, NC 27858.

-----------------------Your response to this survey is confidential-------------------------

Appendix C – Calculation of a and b in Equation (9)

In order to calculate a and b in Equation (9), the data from 2000 to 2004 is used, starting by rearranging the equation as follows:

$$e^{-(a+bt)} = \left(\frac{A(t) \times R(t) \times (M(t) - I(t))}{S(t)}\right) - 1$$

$$C = \left(\frac{A(t) \times R(t) \times (M(t) - I(t))}{S(t)}\right)$$

$$e^{-a} = C - 1$$

$$a = -\ln(C - 1)$$

For t = 0 we expect C to have a high value since the adoption rate at t=0 must be very low. We assume that the market adoption rate was less than 1% in 1999. Since I(0)=0, S(t)/M(t) ratio corresponds to the market adoption rate for year 1999. Therefore, for an adoption rate of 1%, the value of M(t)/S(t) should be equal to 100.

$$C > A(0) \times R(0) \times 100$$

For t=0, we assume that A(0) and R(0) will be the same as A(1) and R(1). Therefore, A(0) and R(0) are 0.7 and 0.72 respectively. That leads to:

$C > 49.4$

Hence;

$a < -3.89$

To find b, we use the 2004 data given in Table 14. For t=4, C is found as 24.8469

$$e^{-(a+4b)} = C - 1$$

$$e^{-(a+4b)} = 23.8469$$

$$-a - 4 \cdot b = \ln(23.8469) = 3.1716$$

$$a = -3.1716 - 4 \cdot b$$

We know that a < -3.89 which indicates

$$-(3.1716 + 4 \cdot b) < -3.89$$

$$b > 0.18$$

Therefore, we determine the range of acceptable values for a and b. By trial and error, the values of a and b are refined to fit the data given for the years between 2000 and 2004. The values of a and b are identified as -4.2 and 0.43 respectively. For the years 2005 to 2014, we use Equation (9) and a, b values above to generate the forecasts.