NAV CANADA

Assessment of Aerodrome Forecast (TAF) Accuracy Improvement

Final Report

May, 2002

Table of Contents

Acknowledgement

The TAF study team wishes to acknowledge the participation of the following airlines in the conduct of this assessment:

Air Canada
Air Canada Regional (JAZZ)
Westjet
Canada 3000

Their cooperation and contribution to the study was invaluable, without which a credible assessment of the impacts of improving the accuracy of aerodrome forecasts (TAFs) in Canada would not have been possible.

Executive Summary

This Assessment of Aerodrome Forecast Accuracy study was undertaken to:

a) Support NAV CANADA contract negotiations with the Meteorological Service of Canada for the provision of aviation weather services. Specifically, consideration was given to building pay-for-performance incentives for improving aerodrome-forecast accuracy into the new contract. Before this could be done, a better understanding was required as to whether improving aerodrome forecast accuracy in Instrument Flight Rule (IFR) weather conditions would be of sufficient economic benefit to offset the costs of their achievement.

b) Obtain a better sense of the weather information desired by NAV CANADA's major customers, and gauge their response to several proposed new weather products being considered for development.

This report presents the quantification of the benefit to IFR carrier flights landing at Canadian airports providing an Aerodrome Forecast (TAF) resulting from an improvement in the accuracy of aerodrome forecasts in Canada. The methodology for the quantification and the corresponding economic model were developed by NAV CANADA. Assistance from several airlines, the Meteorological Service of Canada (MSC), and a private contractor were essential in conducting this study.

The scope of the analysis, including the key assumptions made in order to frame the boundaries of the study are as follows:

- The use of 'No Alternate IFR' flight rules was considered for those airlines using this procedure;
- Extended Range Twin-Engine Operations (ETOPS) regulations were deemed not significantly impacted by en route alternate selections resulting from an inaccurate forecast;
- Charter and business IFR operations using small aircraft were not considered in this analysis but are impacted by inaccurate forecasts;
- Traffic growth statistics used do not reflect the dramatic impact of September 11th since its effects are expected to be diminished by the time any improvements to TAF accuracy are realized;
- Achievement of a specific forecast-accuracy improvement level was not assumed, but a benefit corresponding to a specific improvement can be asserted from the 100 percent accurate forecast computed in this study, assuming benefits are linear;
- It was recognized that the effects of improving forecast accuracy would take time to realize, and that the quantified impacts could be much larger than estimated as the "comfort level" of their use improves;
- The impact of improved forecast accuracy on safety was not estimated; and
- Downstream or rippling effects were not considered. Some studies suggest that consideration of these impacts could double the direct effects of inaccurate forecasts.

In determining the avoidable cost to the airlines of imperfect forecasts, it was first necessary to estimate the operational impact of the current forecast accuracy, in terms of the number of cancellations, delays, diversions and amount of added fuel carried. This is referred to as the *Base Case*. An analysis of a 'perfect forecast' scenario, representing the *Option Case*, provides the basis for estimating an upper bound of the potential magnitude of impacts that would be avoided. The airline operating costs associated with avoiding these impacts represents the potential value of perfect forecast accuracy.

An economic model was developed to quantify the potential impacts of improving TAF accuracy. The spreadsheet-based model considers many elements of information, including:

- **Meteorology Data**: provides an indication of the current forecast accuracy in terms of the relative frequency of occurrence of various weather scenarios for destination and alternate

aerodrome-forecasts. The meteorology data was obtained from the Meteorological Service of Canada archives for a period of five years.

- **Traffic Data:** provides the number of IFR arrivals by airport, airline and aircraft type for the top 10 airports (by traffic volume) in Canada, and the frequency of alternates filed for each of these airports. This data was obtained from the Aircraft Movement Statistics (AMS) database for the period September 2000 to September 2001, and from the Flight Data Acquisition and Analysis System (FDAA).

- **Fleet Data:** provides information on the aircraft types for the airlines assessed. Airline-based information was used whenever it was available.

- **Decision Tree Probabilities:** the probabilities of encountering the various pre- and post-flight departure choices. This data was obtained directly from each airline through a one-day workshop. The airlines included Air Canada, Air Canada Regional, West Jet and Canada 3000. These probabilities, when combined with the meteorology, traffic and fleet data, yield an estimate of the number of IFR flights cancelled, delayed and diverted in a year, and avoided in the perfect forecast case (Option Case).

- **Operational Impacts and Other Cost Data:** provides probabilities of cost impacts for the major operational choices, such as canceling or delaying a flight. This data originated with the airlines.

The *Base Case* segment of the model provides an estimate of the number of cancellations, delays, diversions and additional fuel loaded, by airline and airport with the current level of forecast accuracy. The *Option Case* module generates an outcome with a format identical to that of the Base Case, but with different values reflecting the probabilities of the weather scenarios that would be expected under a ‘perfect forecast’ scenario. The *TAF value* module combines all of the operational impact and cost data and translates the estimated avoided cancellations, delays, diversions, added fuel and payload substitution into dollar terms.

The study results are summarized as follows:

1) Value of TAF Accuracy Improvement
- The quantified benefit of perfectly accurate forecasts is estimated at $12 million for the one million IFR flights expected to land in Canada every year at airports with TAFs. This benefit, assuming that it is proportional to the level of improvement, will be smaller for accuracy improvements that result in less than perfect forecasts.

2) Secondary Benefits
- The TAF performance measurement system must contain the right information and be communicated in an intuitive format. The current system does not focus on the metrics which are critical to the airlines’ operation, and is difficult to read and interpret. A revised performance measurement system that aligns with the meteorological analysis completed in this study and presented in an intuitive fashion would better serve the customer and greatly enhance its value.

3) Carrier Response to Current and Proposed NAV CANADA Weather Products
- Canadian air carriers desire consistency in aviation weather products available between Canada and the United States, and would like a one-stop-shopping service provider for this information.
- If the airline thought a proposed weather product would assist in making better and more timely decisions then the response was positive. However, without an indication of the cost of developing these, a proper assessment is not possible.

This report concludes that:

- TAFs, and weather information in general, are a key input to the flight planning and decision making process of airlines, and therefore, there is considerable potential economic benefit to them of improving aerodrome forecast accuracy. However, the net benefit can be ascertained only when all costs have been determined and the performance improvement realized.

- There are specific, key areas of flight operations and key aerodromes, which will yield the greatest share of the benefit, and which will serve to better target any investment in TAF accuracy improvement.

- The value of the current TAF performance measurement system can be improved by:

  a) carefully selecting the measures that are of interest to the airlines. These generally focus on weather conditions near operating limits that affect flight planning decisions -- alternate selection, cancellations, delays, diversions.
  b) presenting this information in an easy to understand and interpret format

- Proposed weather products are of potential interest to the carriers.

- Dialogue with the airlines, like that undertaken in the conduct of this study, is critical in ensuring that limited resources are most effectively targeted.

1.0 INTRODUCTION

Since November 1, 1996, the Meteorological Service of Canada (MSC) of Environment Canada (EC) has provided aviation weather services to NAV CANADA under the auspices of the Aviation Weather Services Agreement. The Agreement established a business arrangement between the two organizations ensuring the effective delivery of a wide range of aviation weather services, including the production of aviation weather forecasts. Additionally, service delivery guarantees and standards were introduced in the Agreement along with a number of quality assurance and performance measurement initiatives.

One of the products generated by the MSC is Aerodrome Forecasts (TAF). Through the life of the Agreement, much focus has been placed on the verification of TAFs for IFR weather conditions[1]. Current verification scores show that TAFs in IFR weather conditions are accurate approximately 50 percent of the time.[2] This is comparable to scores in the United States. The desire to improve this score has prompted NAV CANADA to consider building "pay-for-performance" incentives into the new Aviation Weather Service Agreement.

Before a decision to incorporate pay-for-performance incentives into the new Agreement can be reached, a better understanding is required as to whether improving TAF accuracy in IFR weather conditions will be of sufficient economic benefit to offset the costs of their achievement. As part of this analysis, NAV CANADA consulted with the main airlines operating in Canada in order to obtain a better understanding of the value to them of improving TAF accuracy. NAV CANADA also took this opportunity to introduce a number of new aviation weather products currently in the development phase in order to gauge user interest and allow them to provide feedback. The objectives of the study are summarized as follows:

- To assess the value to NAV CANADA's customers of improving the accuracy of aerodrome weather forecasts (TAF) currently provided by the MSC for some 175 airports in Canada.

- To introduce a number of new aviation weather products currently in the development phase in order to gauge user interest. Products include the Convective Forecast Product (CFP), 48-hour Aviation Weather Prognostic Chart, and the Aviation Surface Analysis Chart, Automated Supplementary Enroute weather Predictions, and Lightning Data. It will also be used as an opportunity to inquire about other weather products that would be considered useful.

A study of this nature requires the knowledge of individuals with expertise in meteorology, economics and airline operations. Accordingly, a team was assembled having considerable expertise in each of these areas – Joanne Lancaster, Peter Friedrichs and Russ Trenholm, an independent consultant.

The team couldn't have completed the study without the cooperation of Air Canada, Air Canada Regional, West Jet and Canada 3000. Their input was essential in gaining a good appreciation of the flight planning process, and the data they provided was invaluable in the quantification of TAF accuracy.

The MSC was key to providing the study with the necessary meteorological data. They were also extremely helpful in ensuring the specification of the request was analytically and conceptually correct and consistent with the objectives of the study.

[1] The phrase, "TAFs in IFR weather conditions" shall mean TAFs, which correctly and incorrectly forecast the occurrence of IFR weather.

[2] TAF accuracy is defined in this context as: IFR Reliability – a measure of the number of minutes forecast and observed to be IMC relative to the number of minutes forecast to be IMC; and IFR Probability of Detection – a measure of the number of minutes forecast and observed to be IMC relative to the number of minutes observed to be IMC.

2.0 BACKGROUND

Knowledge of the future weather conditions at an IFR flight's destination and alternates directly affect the decisions made about the conduct of the flight. Weather forecasts represent one of many pieces of information that assist dispatchers and pilots in determining the amount of fuel to load, the best alternate to use (if one is required at all), and deciding whether or not to cancel or delay the flight. These decisions are particularly critical when the weather conditions at the flight's destination or planned alternate(s) are at or near the operational limits (limits of the pilot, the aircraft and the air navigation system).

While TAFs cannot eliminate bad weather, they can help to mitigate the effects if they are able to accurately predict the condition with sufficient advance notice to be incorporated in the aircraft operator's planning of a flight, where the bad weather impacts can be minimized. However, inaccuracies in the forecasts that lead to missed events (where a bad weather condition is not predicted) or false alarms (where a bad weather condition is incorrectly predicted) may result in decisions and corresponding costs that could have been avoided had the forecast correctly predicted the condition. In some situations, it may also lead to a safety risk.

For example, when the condition at the destination airport at the scheduled time of arrival is incorrectly predicted to be below limits (false alarm) then the flight may be unnecessarily cancelled or delayed. This will adversely impact the air carrier as well as disrupt their passengers. When additional fuel is required to allow for a more distant alternate because a closer one was falsely predicted to be below alternate limits, then the airline's costs will increase or revenue will be sacrificed through reduced payload. The magnitude of this latter impact increases with the length of the flight.

A missed event at a filed alternate could force an aircraft to make an unscheduled stop or to return to the origin if there are no other suitable alternates within its fuel reserves. This assumes, of course, that the missed event is detected early enough in the flight to allow such choices. In the worst case, an unreliable forecast may not be corrected in sufficient time for the pilot-in-command to do anything other than to attempt to land in the bad weather condition. If the missed event is at the destination and the aircraft is unable to land, then additional inconveniences are created at the selected alternate. If the missed event occurs at the alternate too, then the available options are further reduced.

This study provides a solid basis for the valuation of an improvement in TAF accuracy. All aspects of flight operations that are impacted by the TAF are scrutinized, but only those that materially affect its value are included in the generalized approach.

3.0 Scope of the Analysis

3.1 Sites and Operations

It is generally accepted that accurate weather information has considerable value to the aviation industry. However, quantifying this value for a system of airports, airlines, and routes is difficult. The literature has revealed a handful of attempts at evaluating TAFs, but for a limited traffic component - one airport, one carrier, one impact area.[3] The results from these studies do not provide enough information on the value of investments in improving TAF accuracy.

This study is an attempt to provide an assessment of TAF accuracy in Canada. In doing so, the analysis considers:

a) Traffic at all sites where TAFs are currently provided (assessed separately for the top 10 airports);
b) A good understanding of the flight planning processes by the major domestic airlines (mainline and regional), representing almost 50 percent of the IFR traffic in Canada;
c) Three different route categories, plus regional operations;
d) All key operational impacts and associated costs;
e) Various TAF accuracy scenarios including "no alternate IFR" (see below)

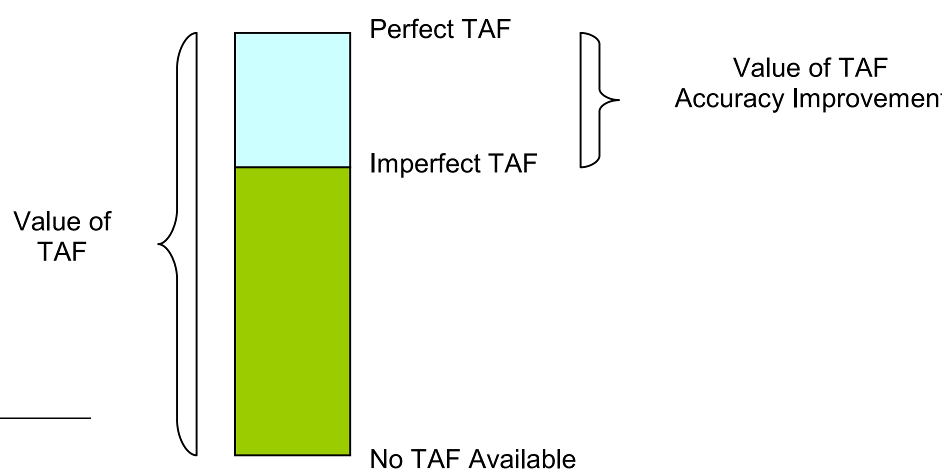
The ability to conduct such a broad analysis would not have been possible without the cooperation from the participating airlines, as well as the study's access to a significant amount of information, including aircraft traffic, flight plans, aircraft operating costs, and meteorological data from MSC.

3.2 Value of TAF versus Value of TAF Accuracy

The value of an aerodrome forecast and the value of its accuracy are, as one would expect, closely linked. Assessing the value of improving TAF accuracy is meaningless unless a TAF actually exists, but the value of a TAF is largely affected by its accuracy. A TAF that is correct only 50 percent of the time would be considered less valuable than one with a 90 percent accuracy.

The valuation of a TAF is based on the economic costs to the airlines of not providing the service, whereas the valuation of an improvement in TAF accuracy is based on the economic costs to the airlines of an imperfect forecast given the existence of an aerodrome forecast.

The concept of TAF valuation is depicted in the following figure. The value of a TAF must be associated, either implicitly or explicitly, with some level of accuracy. This is depicted in the green shaded portion of the bar. With an imperfect forecast, an additional value accrues as its accuracy improves, as shown in the blue shaded segment. This study focuses on the blue shaded area.



3 See References

3.3Downstream Effects

It is well appreciated that the impacts of flight cancellations, delays and diversions often span well beyond the initially affected flights. This is especially true for “hub and spoke” type operations typical in North America. Moreover, the impact can be significant for flights that are disrupted at the beginning of the day since there is little slack in the system. That is why many airlines “protect” their early flights as much as possible.

Although these downstream or “rippling” effects can be significant, they are difficult to quantify accurately[4]. As a result, only direct customer impacts are assessed in this study.

3.4 Long-Term Effects

It is human nature to minimize risk, especially from those events that are unknown or uncertain, which is why we have insurance. Weather forecasts are no different, and to mitigate potential inaccuracies in TAFs flight dispatchers and pilots will file one or more alternate airports, or take on additional fuel. While the insurance is worthwhile when the destination is in bad weather, it becomes a cost in good weather. The trick, then, is “buy” the insurance only when you need it, as would be the case with accurate TAFs.

As TAFs become more reliable, it is expected that the confidence in using them will increase and dispatchers/pilots will be less inclined to add the same degree of “insurance” when good weather conditions are being forecast. The end result is a more efficient operation. It should be noted, however, that this effect would require a period of demonstrated improvement before being realized. These long-term impacts are not quantified.

3.5 No Alternate IFR

Some airline operations are approved to operate, under certain circumstances and to certain airports, without the requirement for an alternate airport. This condition is referred to as “no alternate IFR”, and it provides a savings to the airline by reducing the amount of fuel load necessary to get to the alternate (if one were filed). This results in less fuel burn to carry the additional fuel load, less payload substitution if the flight is at its weight limit for the desired range, or a combination of both.

If a forecast incorrectly predicts below “no alternate IFR” limits, then an airline approved to operate without an alternate for a given destination would carry additional fuel unnecessarily. Conversely, if the forecast indicates above “no alternate IFR” limits for the destination, and, while en route the actual weather is observed to be below these limits, then there may be a requirement for a fuel stop. In both instances costs are incurred by the airline that could have been avoided had the TAF at the destination been accurate.

Appendix Five provides a more detailed description of the “no alternate IFR” analysis contained in this study.

3.6 ETOPS Considerations

ETOPS (Extended Range Twin-Engine Operations) regulations require twin-engine aircraft to fly within a specified time limit of the available alternates on its flight path (currently 120 minutes on one engine for most operators). The eligible alternates are based on their TAF predicted limits. If a preferred alternate is not available, then the route must be modified so that the aircraft maintains its required proximity to the remaining available alternates. If an alternate becomes unavailable en route, then a revised routing may be necessary, possibly necessitating a fuel stop.

After discussions with Gander Oceanic and several airlines operating twin-engine aircraft over the Atlantic Ocean, it appears that the current ETOPS limits of 120 minutes are sufficiently long so as

[4] Some studies suggest that a doubling of the direct costs would more appropriately reflect the true impact.

not to cause operational constraints by the unavailability of any particular Canadian airport. In other words, the ETOPS limits are not significantly impacted by en route alternate selections that may result from an inaccurate TAF. As a result, ETOPS is not considered in this analysis.

3.7 Other IFR Operations

While this study focuses on the airlines consulted, representing almost 50 percent of the domestic IFR movements, many other types of IFR operations are affected by the accuracy of TAFs. They include:

a) Courier/cargo – highly sensitive to on time performance, with TAFs likely playing a very critical role in their flight planning process.
b) Charter operations – less sensitive than airlines since passengers are mostly non-business and non-connecting.
c) Business/corporate – somewhat sensitive, but fewer people affected, and use smaller aircraft.
d) Other General Aviation – least sensitive since they are typically most flexible in time; they also use smaller aircraft. However, they may be adversely affected if conditions change to IFR and they are not qualified or their aircraft are not adequately equipped.

A portion of the remaining IFR activity (not belonging to any of the airlines consulted) was assessed in two distinct groups – a) medium to large remaining jet flights; and b) turbo props and regional jets (e.g. CRJ) representing a regional type of operation. Aircraft with piston-powered engines, small non-piston aircraft and those that comprised a small proportion of the total activity (generally less than 1 percent) were excluded from the analysis. These IFR aircraft types are typically associated with non-commercial operations.

3.8 Traffic Growth

This analysis provides an estimate of the value of improved TAF accuracy for IFR traffic experienced for the 12 month period ending September 1st, 2001. This, therefore, accommodates some of the impact of the recent downturn in the economy, but does not reflect the dramatic impact of the events of September 11th. It can be considered, however, reflective of the traffic volume expected in the short term, as current traffic levels recover to pre-Sept 11th levels. Any change in traffic volume will affect the magnitude of the benefits proportionally.

3.9 Achievement of Specific TAF Accuracy Improvement Levels

This study makes no assumption about the viability of achieving specific improvements in TAF accuracy. It computes the costs to the TAF users that would be avoidable under a “perfect forecast” scenario – referred to as the Option Case. If it can be assumed that the impacts avoided are linear with respect to the improvement in accuracy, then any accuracy enhancement can be estimated based on the “perfect forecast” estimate.

MSC, in conjunction with NAV CANADA, has formed a working group with the objective of establishing a plan and process that would result in an improvement in accuracy. Should this initiative proceed, it is fully expected that improvements will be incremental and take time to be realized.

3.10 Safety

There is no doubt that flying in weather conditions beyond the capabilities of the aircraft, pilot and the air navigation system is unsafe. It is also well understood by the aviation industry that weather forecasts can go wrong, especially in regions and times of year where conditions are known to change rapidly. But even with the best of intentions, there are occasions where the pilot may find himself in a difficult situation. In most such instances, he will be appropriately covered by the “insurance” of having added fuel, or a safe alternate. In some cases, however, when things go really bad, and few choices are left, the situation could become a safety risk, rather than a cost/efficiency concern.

It is reasonable to expect that an improvement in the accuracy of TAFs will not only save the airlines money, but it will improve flight safety. However, it is difficult to quantify this impact.

4.0 APPROACH

The fundamental premise of the approach is that improvements in TAF accuracy lower the airline's cost of operations [5]. Estimating the value of this requires an understanding of the impacts and resulting costs to the airlines that would be avoided with perfect TAFs.

In determining these avoidable costs it is necessary to first estimate the impact the current level of TAF accuracy has on IFR carrier operations. This scenario is referred to as the Base Case. An analysis of a "perfect forecast" scenario, representing the Option Case, provides an indication of the potential magnitude of impacts such as cancellations, delays and diversions that would be avoided. The corresponding reduction in operating costs represent the potential value of perfect TAF accuracy. It should be noted, however, that even perfect TAFs will not entirely eliminate the impacts due to weather, since bad weather will continue to occur. However, it is the accurate knowledge of the occurrence of poor weather that allows flight operations to plan for these conditions and thereby mitigate some of their negative effects.

A review of the literature (see Appendix Seven -- References) identified several common concerns in the estimation of weather forecasts. The approach employed in this assessment attempts to alleviate some of these by:

a) Focusing on the aviation sector and on the elements of the forecasts that are critical to the airline decision-making process.
b) Considering the measures relevant to the airline flight planning process and employing a wide range of scenarios rather than a single, all encompassing measure.
c) Utilizing an analytic decision-making framework, that is systematic and complete in that it accommodates all key areas of impact.
d) Incorporating a multi-disciplinary team comprised of economists, meteorologists, and flight operations specialists.
e) Consulting with the major airlines, validating the approach and results, and obtaining insights to their decision-making process.
f) Involving the MSC for advice on the meteorological aspects of the analysis, and for the determination of the frequency for the various forecast weather scenarios.

4.1 Definition of TAF Accuracy

The quantification of the value of an improvement in TAF accuracy is not possible without a clear, meaningful and measurable definition of accuracy. Past studies have often been critical of the accuracy metric(s) used in the evaluation. As noted by Murphy and Ehrendorfer (Ref [8]), no single accuracy measure can describe all aspects of accuracy, and no accuracy measure can be appropriate for all users.

To address these concerns, the approach employed in this study focuses on the forecast elements and outcomes that are most critical to (i.e. have an impact on) commercial airline IFR operations. At the same time, the approach is practical so that the relevant measures of TAF accuracy can be easily assessed, and repeated over time.

TAFs contain many elements of information, including wind direction and speed, ceiling, visibility, and precipitation. While all of these are considered in the planning and dispatching of an IFR flight, ceiling and visibility were considered to be key. This is due to the fact that they are

[5] This approach is consistent with the "cost-loss" framework (ref [2], [3]).

identified in the Canadian Aviation Regulations (CAR) in specifying alternate minima. Moreover, ceiling and visibility form the core metrics of the NAV CANADA TAF performance measurement system[6].

If accuracy is represented by the difference in the observed and forecast conditions which are characterized by a continuum of possible outcomes, then it too would be a continuum. However, such an approach, although precise, would make accuracy measurement impractical. As a result, and consistent with the current performance measurement system, it was decided to define thresholds, or limits, within which the TAF and observed conditions could be compared. The outcome, therefore, becomes "0-1" – the forecast is either accurate or it is not – and the degree of accuracy is not considered. For example, if the ceiling (or visibility) was forecast to be above a specified limit, and this was in agreement with the observation for the same time period and place, then the TAF would be deemed accurate for that limit. While this simplifies the analysis, it makes the specification of the limit a critical element[7].

Only the initially issued forecasts covering the validity period were considered in the determination of accuracy; amendments were not considered. However, the TAF qualifiers TEMPO (temporarily) and BCMG (becoming) were assessed for both the destination and alternates, and the qualifier PROB (probability) was considered for the alternate only (see Section 4.4).

The resulting "above/below" condition allows the accuracy to be described at any airport in terms of a simple two by two matrix as shown below. **False alarms** represent a predicted "below limit" event that did not occur at the specified time and place, and **missed events** are "below limit" outcomes that were not predicted to occur.

Observation (METAR)	**Forecast (TAF)**	
	Above Limits	**Below Limits**
Above Limits	**Accurate**	**False Alarm**
Below Limits	**Missed Event**	**Accurate**

The same matrix is applicable to both the destination and the alternate (although the limits will vary). When the two are coupled, the number of possible outcomes increases to 16 (4 times 4). The likelihood of these outcomes at any airport provides a measure of TAF accuracy for that location.

Four of the 16 outcomes (or scenarios) are considered accurate in that the forecast (at the expected time of arrival) aligns for both the destination and the alternate. That is, an observation of above (below) limits is confirmed by the forecast of above (below) limits. Similarly, four scenarios are considered totally inaccurate since the forecast is incorrect for both. The remaining eight are considered "partially" accurate in that the forecast is accurate for either the destination or alternate, but not both.

For airlines authorized to use "no alternate IFR" at selected airports, the following six possible outcomes at destinations eligible for this type of operation are added to the 16 scenarios described above.

[6] The airlines indicated that wind and freezing precipitation were also important factors.
[7] One of the differences between the definition employed in this study and that used in the NAV CANADA performance measurement system is the specification of the limits.

An advantage of this approach is that the specification allows the use of different operating limits at the same airport, to reflect varying capabilities of aircraft using the airport. As the operating limits near "0-0" (zero feet ceiling and statute-mile visibility), the accuracy of the TAF improves (less opportunity for the forecast to be wrong).

<table>
<tr><th rowspan="3" colspan="2">Observation (METAR)</th><th colspan="3">Forecast (TAF)</th></tr>
<tr><th rowspan="2">Above Contact Limits</th><th colspan="2">Below Contact Limits</th></tr>
<tr><th>Above Landing Limits</th><th>Above Landing Limits</th></tr>
<tr><td colspan="2">Above No Alternate IFR Limits</td><td>Accurate Above Limits</td><td colspan="2">False Alarm</td></tr>
<tr><td rowspan="2">Below No Alternate IFR Limits</td><td>Above Landing Limits</td><td>Missed</td><td colspan="2">Accurate</td></tr>
<tr><td>Below Landing Limits</td><td>Event</td><td colspan="2">Below Limits</td></tr>
</table>

The next sections briefly describe the five main components of the study. Further detail is provided in subsequent chapters and appendices. The main components include:

a)Flight Planning Decision Process
b)Traffic
c)Meteorology
d)Operational Impacts
e)Costing

4.2 Flight Planning Decision Process

Since the flight planning process is comprised of a series of decisions (how much fuel do I need, which alternate do I file, do I delay or cancel the flight, do I divert to the alternate?) it can be depicted in the form of a decision tree. Decision trees provide an intuitive means of describing the ways in which airlines behave under various forecast weather situations. They can also be used, as they are in this study, to quantify the impacts of an improvement in forecast accuracy.

Consultation with the major airlines was critical in this element to:

a)Verify that the TAFs represent an important component of the flight planning and decision-making process;
b)Verify the decision tree for each of the forecast weather scenarios;
c)Provide an estimate of the likelihood of the various “branches” or choices in each of the decision trees; and
d)Verify that the resulting impacts are representative of what is experienced by the airline.

Generally, the following hierarchy of considerations governs the flight planning decisions for airlines:

a)Canadian Aviation Regulations.
b)Safety.
c)Airline policy.
d)Commercial, including customer needs.

The flight planning process can be conveniently divided into pre- and post-departure decisions. For obvious reasons, the choices available and corresponding costs will vary for each. For pre-departure, the main choices are:

a)Cancel the flight (which may occur after a period of delay);
b)Delay the flight;
c)Add more fuel and depart; or
d)Select another or multiple alternate(s), if necessary.

Post-departure choices are limited to three related actions and outcomes:

a)Divert to the filed alternate (or return to the origin) or fuel stop enroute;
b)Land at the destination; or
c)Attempt a landing at the destination, miss the approach and continue to the filed alternate.

Each of the weather scenarios triggers various combinations of the identified choices, depending on the forecast and actual conditions at the destination and alternate.

4.3 Traffic

The value of TAF accuracy is affected by the amount of IFR traffic and aircraft types operating from an airport with aerodrome forecasts. The type of aircraft will influence the capability to function in various whether conditions and the costs if the flight is cancelled, delayed or diverted, while the amount of traffic affects the number of potentially avoidable cancellations, delayed flights and diversions.

There are currently 174 airports where TAFs are produced by MSC for NAV CANADA. Since each airport encounters different weather conditions, traffic volumes, frequency of alternate selection and aircraft mix, each will yield a distinct value for a particular improvement in TAF accuracy. Focussing on the busiest ten airports (representing over 60 percent of IFR traffic), and generalizing the remaining sites was thought to adequately represent the potential impact of TAF accuracy improvement without the significant effort that would be required to assess all sites individually. Due to data availability at some of the smaller sites, the analysis includes only those airports with a control tower or flight service station.

The necessary traffic information was extracted from the Aircraft Movement Statistics (AMS) and the Flight Data Acquisition and Analysis System (FDAAS), as follows:

a)Aircraft arrivals by airport, airline and aircraft type (from AMS); and
b)Frequency of filed alternate aerodrome by air carrier and destination (from FDAAS).

4.4 Meteorology

To estimate the economic benefits of improving the TAF accuracy in weather conditions which are critical to the end-user, NAV CANADA required the MSC to conduct an analysis of their archive for each of the 10 specified aerodromes and corresponding filed alternates. The analysis determined the amount of time, in terms of minutes, that each of the sixteen scenarios occurred for the following aviation weather limits (of ceiling and visibility):

1)Normal limits for landing and alternate – as defined in MANAIR (typically 200 feet ceiling and ½ mile visibility for the destination; varies for the alternate)
2)Lowest published limits for Category II or III airports, where applicable. The limits are normally specified in terms of RVR (Runway Visual Range), which had to be translated into a visibility limit so that the meteorology analysis could be performed. For sites with an RVR of 1,200 feet, a visibility limit of ¼ statute miles was applied. This was divided by two for an RVR of 600 feet.
3)No alternate IFR limits – where applicable. A limit of 1,500 feet ceiling and 6 statute miles visibility was used (2,500 feet and 3 statute miles may also be used).

Other considerations in the meteorology assessment include accommodating TAF qualifiers:

For destination (normal and CAT II/III) and alternate limits:
- PROB (probability) not considered for the Destination TAF; PROB is considered for the Alternate TAF;
- TEMPO (temporarily) and BECMG (becoming) considered for both Destination and Alternate TAFs; and
- Amended TAFs not considered.

For no alternate IFR limits:
- PROB, TEMPO and BECMG considered for Destination TAFs; and
- Amended TAFs not considered.

Realizing that TAF accuracy can be affected by the validity period, the meteorology analysis was completed for periods of 1 to 3 hours, 4 to 6 hours, 6 to 12 hours and more than 12 hours. Two of these periods correspond to the four route categories that were established to capture airline specific information (see below).

4.5 Operational Impacts

Unless the TAF predicts a prolonged period of weather below operating limits, most airline flights are expected to depart on schedule. Otherwise, flights may be cancelled, delayed, or diverted, and many that depart are likely to be loaded with some additional fuel[8]. In the "perfect forecast" case (which alters only the frequency of the 22 weather scenarios), the difference in the number of cancellations, delays, diversions, etc represent avoidable impacts. Each of these impacts correspond to a series of remedial actions, and each of these will affect the cost of operating aircraft, managing crew and accommodating passenger needs.

For example, a cancelled flight could result in the aircraft remaining idle until the next scheduled departure for the same destination, or it could be re-deployed to another airport. Similarly the crew (flight deck and cabin) may re-deployed on the next departure to the same destination or to another airport, or be sent home if their duty time will be exceeded. Options for inconvenienced passengers may include ticket refunds (lost net revenue), meals, alternate transportation, compensation (for missed connections) or overnight accommodation. Refer to Appendix Six for a more complete listing of the various choices considered.

4.6 Costing Analysis

The final step in the assessment converts the remedial actions or choices into costs. Since these actions are considered "avoidable" under an improved TAF situation, the corresponding costs represent a potential saving to the airlines.

Fuel burn and other aircraft operating costs (maintenance, ground handling, airport and air navigation fees) are applied, as appropriate, to the actions taken by the airline in an attempt to remedy the situation. Similarly, unit costs are applied to the crew and passenger impacts. Since these costs vary by aircraft type, the fleet mix needs to be considered.

---

[8] Additional fuel is defined as the amount of fuel that would be carried over and above the normal contingency fuel to account for forecast adverse weather conditions at the destination and/or the need to file a more distant alternate (or the need to file an alternate).

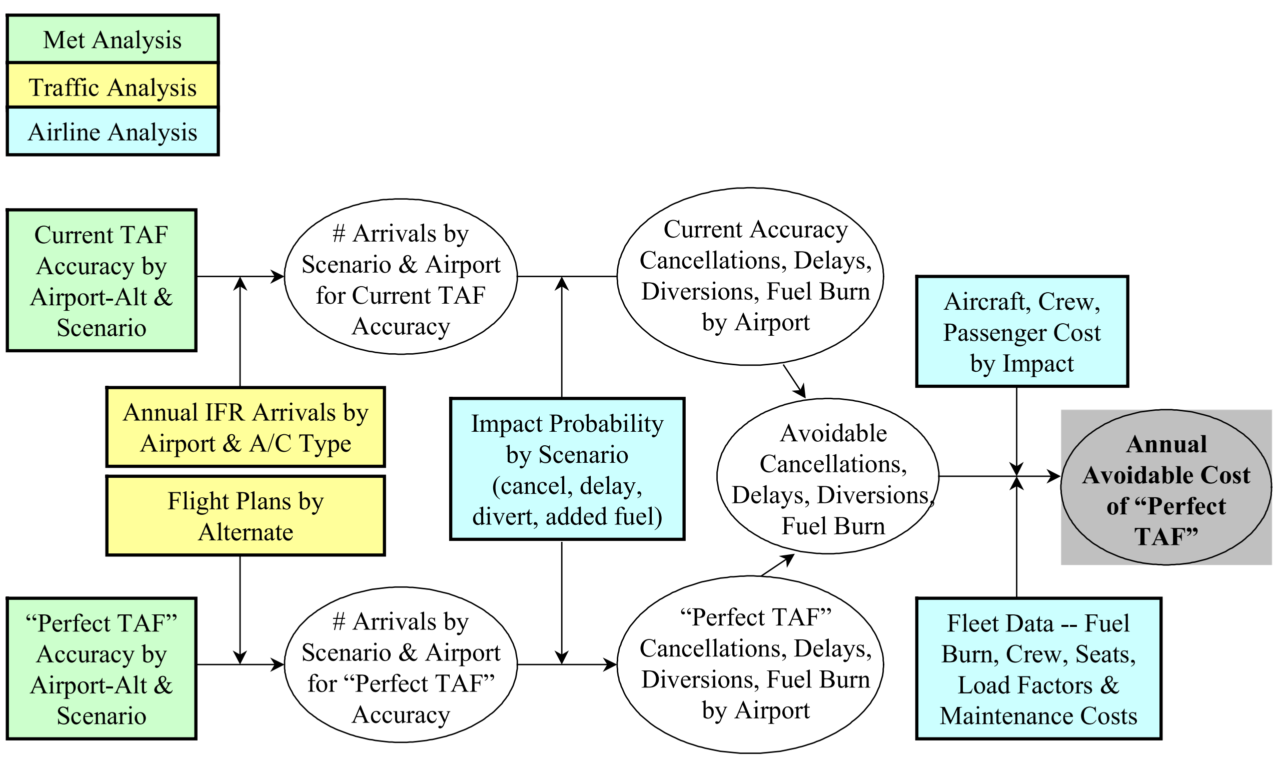
4.7 Route Categories

There are a wide range of factors affecting the choices faced by the airlines. Although flight planning decisions could be affected by many site-specific conditions, a major consideration is the route and aircraft type. However, the number of route/airline/aircraft combinations is substantial and well beyond the ability of this analysis to accommodate. As a result, a categorization of routes was thought, and confirmed by the airlines, to adequately capture the major flight planning decision elements. Such a grouping also aligns well with specific aircraft types and performance considerations. The following four route categories were identified:

a)Oceanic (any trans-Pacific or trans-Altantic flight terminating in Canada)
b)Long Continental (flights originating in North America and terminating in Canada of more than 3 hours duration)
c)Short Continental (flights originating in North America and terminating in Canada of less than 3 hours duration)
d)Regional (flights operated by a regional airline terminating in Canada). This category was further segmented into turbo-prop and turbo-jet, and hub and non-hub operations.

Figure 1 presents an overview of the approach. The coloured boxes -- green for meteorology data originating from MSC; yellow for traffic - data from AMS and FDAAS, and blue for the airline inputs – represent the analysis elements. Intermediate results are shown in the ovals, with the final outcome in the shaded oval. The analysis is repeated for each airline.

Figure 1: Overview of Approach



5.0 The Economic Model

The purpose of the economic "TAF" model is to facilitate the quantification of the impacts and corresponding value of improving TAF accuracy. The benefit of a model (using a standard spreadsheet application) is that it can easily accommodate complex relationships, and quickly assess the impact of changes to any of the input assumptions.

The structure of the TAF model closely follows the approach. The model is divided into five components, each of which is briefly described in following sections:

a)Data Inputs and Assumptions, including:
- Meteorology;
- Traffic;
- Fleet;
- Decision Tree Probabilities; and
- Operational Impacts and Costs

b)Base Case Traffic Affected (current forecast accuracy)
For each consulted airline, residual mainline and regional, and airport

c)Option Case Traffic Affected (perfect forecast accuracy)
For each consulted airline, residual mainline and regional, and airport

d)TAF Value
For each consulted airline, residual mainline and regional, and airport

e)Summary of Results

5.1 Data Inputs and Assumptions

Meteorology Data
This data provides an indication of the current TAF accuracy in terms of the relative frequency of occurrence of the 16 scenarios defined in Section 3.0. The data represents the amount of time, in minutes, that each of these was encountered over the past 5 years for each destination-alternate pair. The data is also provided for four time horizons – less than 3 hours, and 4 to 6 hours, 7 to 12 hours and more than 12 hours. The 4 to 6 hour data set is applied to the Regional and Short Continental route categories, representing their flight planning horizon and travel time to the destination. The 7 to 12 hour validity period is used for the Oceanic and Long Continental route segments.

The meteorology data was obtained from MSC archives for a period of five years.

Traffic Data
The traffic data includes the number of IFR arrivals by airport, airline and aircraft type. The top ten airports (by traffic volume) are considered individually, while the remaining TAF sites are assessed as one single residual "airport". This information was obtained from the Aircraft Movement Statistics (AMS) database for the period Sept 2000 to Sept 2001.

Data was also required on the frequency of alternates filed for about 30 Canadian destinations in order to complete the meteorology analysis. The source of this data was the Flight Data Acquisition and Analysis System (FDAAS). Four one-week periods were analyzed representing each of the four seasons.

Fleet Data
The fleet data contains information on the aircraft types for the airlines assessed. Specifically, it indicates for each type:

Data Element for Each Type	Source
1) Number in the fleet	Airline
2) Capacity (seats)	Airline
3) Typical number of flight deck and cabin crew	Airline
4) Hourly fuel burn (lbs per hour)	Airline, Form 41, C&D
5) Hourly maintenance cost	Airline, Form 41, C&D
6) Hourly depreciation cost	Form 41, C&D
7) Percent of the type used by route category	Airline
8) Average Load Factor	Airline

Notes:

Form 41 – U.S. Department of Transportation
C&D – Conklin and DeDekar

The airline information was always used whenever it was available.

The fleet data, when combined with the traffic data provides weighted averages by route category and airport. These values were used in the valuation elements of the economic analysis.

Decision Tree Probabilities
The probabilities of encountering the various pre- and post-flight departure choices were obtained directly from each airline through a one-day workshop. These probabilities, when combined with the meteorology, traffic and fleet data, yield an estimate of the number of IFR flights cancelled, delayed and diverted in a year, and avoided in the perfect TAF case. The amount of additional fuel carried, in terms of flight minutes, was also obtained from the airlines for the relevant scenarios. This allowed the estimation of the amount of extra fuel burned or the amount of payload displaced.

Operational Impacts and Other Cost Data
A cancelled, delayed or diverted flight represents a situation for the airline that requires a series of possible remedial actions. The data for this element comprises probabilities for the major choices available (See Appendix Six), and corresponding time and cost impacts (e.g amount of additional flight time, waiting time, or ground handling cost, etc.).

As with the decision tree probabilities, this data originated from the airlines.

All airline-related data was validated with each of the airlines by presenting the base case results computed by the TAF model. The model was available at these subsequent one-day sessions to allow the testing and modification of any assumption, if necessary.

5.2 Base Case Traffic Affected

The outcome of this segment of the model is an estimate, for the current level of TAF accuracy, of the number of cancellations, delays, diversions and additional fuel loaded, by airline and airport.

The formulation is as follows:

 # Cancels = ∑ *# arrivals* X *Prob Cancel for scenario* X *Prob Scenario*

 # Delays = ∑ *# arrivals* X *Prob Delay for scenario* X *Prob Scenario*

 # Departures = # *arrivals* - # Delays - # Cancels

by route category and summed over the 16 (or 22) scenarios

Where:

Prob Cancel and *Prob Delay* originate from the airlines and vary by scenario
Prob Scenario originates from the meteorology analysis

For flights that are not cancelled or delayed, the following formulations apply:

 # lbs Add Fuel = ∑ **# Departures** X *Prob Added Fuel for Scenario* X *Minutes Added Fuel* X *Fuel Burn Rate* X *Prob Scenario* *X (1- Prob Payload Subst due to Added Fuel)*

 # Fuel Stops = ∑ **# Departures** X *Prob FS for Scenario* X *Prob Scenario*

 # Diversions = ∑(**# Departures - # Fuel Stops**) X *Prob Diversion for Scenario* X *Prob Scenario*

 # Missed Appr = ∑(**# Departures - # Fuel Stops - # Diversions**) X *Prob MA for Scenario* X *Prob Scenario*

In some instances, adding fuel will limit the amount of payload. The analysis assumes that whenever this occurs, all the added fuel is substituted. The formulation thus becomes:

 # lbs Payload Subst = **# lbs Add Fuel** X *Prob Payload Subst due to Added Fuel*

by route category and summed over the 16 (or 22) scenarios

Where:

Prob FS, Prob Diversion, Prob MA, *Prob Added Fuel, Minutes Added Fuel* and *Fuel Burn Rate* originate from the airlines and vary by scenario
Prob Scenario originates from the meteorology analysis

Assumes:

a)Flights making fuel stops are not subsequently diverted, or do not result in a missed approach at the destination.
b)Diverted flights do not result in a missed approach at the destination.
c)Missed approaches become diversions.

5.3 Option Case Traffic Affected

This component of the TAF model generates an outcome that is identical to that of the Base Case. The values, however, are different since they reflect the probabilities of the weather scenarios that would be expected under a “perfect forecast” scenario. All other data inputs and assumptions remain the same.

An additional output in this segment computes the difference in number of cancellations, delays, diversions, fuel stops, added fuel and payload substitution between the Base Case (current forecast accuracy) and Option Case (perfect forecast accuracy). Negative differences (i.e. a reduction in the number) represent a reduction and, therefore, yield a potential saving to the airline. There are occasions that a perfect forecast will produce an increase in the number of cancellations or delays in cases of missed events, but the reduction in the number of diversions, fuel stops and amount of added fuel carried more than offsets this. (see Section 6.0 – Summary of the Results).

5.4 TAF Value

This section of the TAF model combines the meteorology, traffic, fleet and operational analyses and translates the estimated avoided cancellations, delays, diversions, added fuel and payload substitution into economic terms.

Each operational impact such as cancellation or diversion results in a series of corrective actions, and each action, in turn, has an associated cost and probability. The number of avoided impacts and the corresponding actions and costs all combine to produce an estimate of the potential economic benefit expected to result if the TAFs were always correct.

The airline's response to unforeseen operational impacts generally affect three entities – aircraft, crew and passengers/cargo. The cost of dealing with each of these is assessed for each operational impact.

The generalized formulation is as follows:

Total Avoided Cost = **# Cancels Avoided** X Cost per Cancel + **# Delays Avoided** X Cost per Delay + **# Diverts Avoided** X Cost per Divert + **# Fuel Stops Avoided** X Cost per Fuel Stop + # **lbs Add Fuel Avoided** X %Fuel Burn Rate/hr X Flight Duration + # **lbs Payload Subst Avoided** X Cost per Pound

Where:

Cost per Cancel, *Cost per Delay* and *Cost per Divert* are computed for Aircraft, Crew and Passengers components based on information originating from the airlines (see Appendix Six). *Cost per Pound* of payload substituted is a direct input from the airlines.

%Fuel Burn Rate/hr represents the amount of fuel needed to carry the fuel, and is estimated to be 4% per hour, compounded. So, if 1,000 pounds of additional fuel is required at the end of a 5 hour flight, then 21.67% * 1,000 = 217 pounds of fuel will be burned to carry it (this means that 1,217 pounds of additional fuel is required at the beginning of the flight). Short and Regional flights are assumed to average 2 hours, Long Continental is estimated to average 4 hours, and Oceanic assumes 7 hours.

Note that for payload substitution, no additional fuel is burned since all the added fuel is assumed to be substituted.

The last worksheet in the model presents a summary of the estimated benefits, by carrier, route category and airport. As noted earlier, this is an estimate based on the traffic volume for the 12 months ending Sept 1 2001, and for a perfect TAF. This will vary from site-to-site and aircraft operator, on the actual TAF accuracy level achieved and the volume and mix of traffic.

6.0 SUMMARY TAF ACCURACY IMPROVEMENT BENEFITS

The findings of this undertaking can be divided into two components – the quantified value of improving TAF accuracy; and the "spin-off" benefits of this study.

6.1 Value of TAF Accuracy Improvement

Three key areas of airline operating savings are evident from the analysis. These are:

a)Reduced fuel burn or payload substitution, representing about 60 percent of the total potential saving;
b)Fewer diversions, which yield about 30 percent of the total benefit; and
c)Fewer fuel stops (a variation of a diversion) comprising the remaining 10 percent of potential saving.

Avoided cancellations and delays represent about one percent of the total benefit. In some instances, the number of cancellations and delays may in fact increase as a result of a more accurate aerodrome forecast at the destination or alternate airport, but with a corresponding reduction in the number of diversions or missed approaches.

Reduced Fuel Burn/Payload Substitution
Unless no suitable alternates are available or the forecast calls for a prolonged period of below limit conditions at the destination, the airlines will generally choose to depart as scheduled and risk the possibility of a diversion (or fuel stop). It is highly likely that additional fuel will be loaded on these occasions in anticipation of adverse weather conditions at the destination or alternate.

The potential saving in fuel burn/payload substitution originates from a reduction in the number of "false alarms" in the perfect forecast case (see Section 4.1 for definition), and a corresponding decrease in the amount of fuel carried and, thus, consumed. The impact is particularly acute when operating under "no alternate IFR" conditions, since a false alarm results in the unnecessary addition of fuel for the alternate airport.

The annual fuel burn and payload substitution cost that would be avoided with perfect TAFs is estimated to be about $5.4 million per year for the airlines consulted, and $7.0 million in total for all airline IFR operations landing in Canada. This benefit originates from 30,000 fewer flights requiring added fuel, translating into 10 million fewer pounds of fuel burned and 2.5 million fewer pounds of payload substituted.

Fewer Diversions
Diversions occur whenever the destination is observed to be below landing limits while the aircraft is en route and either a landing cannot be attempted (RVR is below the specified operating limits), or a landing was attempted and unsuccessful, resulting in a missed approach. The probability of diversions due to weather is low (about 0.1 percent over all sites and operators), but the consequence, when it does happen, is high.

The analysis indicates that almost 700 fewer flights would be diverted with perfect TAFs, translating into about $3.7 million in avoidable costs in total.

Fewer Fuel Stops
Fuel stops are necessary when the ceiling or visibility for the filed alternate fall below alternate limits (i.e. missed event) while the flight is en route to its destination and no other alternates are available within the fuel reserve. A fuel stop may also be required when the destination limits fall below "no alternate IFR" limits while en route and an alternate cannot be found, again within the remaining fuel reserve. As TAF accuracy improves, the need for fuel stops should diminish, approaching zero with a perfect TAF.

The annual savings with perfect TAFs is estimated to be about $800,000 per year for the airlines consulted, and $1.1 million in total for all IFR landings at Canadian TAF airports. This benefit is the result of approximately 370 avoidable fuel stops.

Avoided cancellations and delays comprise about 1 percent of the potential airline benefit of perfect forecasts. Correcting “missed events”, where the TAF does not predict a below limits condition, will often result in an increase in the number of cancellations or delayed flights, but with a corresponding reduction in diversions, fuel stops and added fuel carried.

Total Quantified Impact
The value of improving the current accuracy of aerodrome forecasts to 100 percent is estimated at $12 million annually. This is considered a conservative estimate for the reasons provided in Section 3 of the report.

Achieving perfect TAFs, however, may not be easily realized, or cost-effective. Rather than striving for improvements “across the board”, it would be more efficient to focus on those areas where improvements generate the greatest potential value to the air carriers. The analysis reveals three such areas:

a)Reducing the number of false alarms in predicting “No alternate IFR” conditions for those carriers with this capability. This area alone represents about 20 percent of the annual potential benefit ($2.4 million), and about a third of the benefits for the “No alternate IFR” capable carriers. The magnitude of impact is due to the combination of the high cost of carrying fuel for an unnecessary alternate and the frequent occurrence of false alarms in this area (i.e. forecast is below “No alternate IFR” limits and actual is above).

b)For those carriers without “No alternate IFR capability”, the greatest benefits are derived from fewer diversions resulting from a decrease in the number of missed events at the destination when the weather is at or near the landing limits. In total, this area represents a third of the annual potential benefit ($3.7 million), and about half of the benefits for those carriers without “No alternate IFR capability”.

c)Almost 40 percent of the total potential impact ($4.5 million) would be avoided from improving the forecasts at the preferred alternate by reducing the frequency of false alarms, which force air carriers to select a less efficient alternate (i.e. more distant, requiring more added fuel).

Toronto Lester B. Pearson International airport offers the largest potential benefit, with half of this attributable to the elimination of false alarms for the “No alternate IFR” condition. Montreal Dorval is second, with two thirds of its potential derived in this scenario.

For operations in Eastern Canada, Halifax and St John’s are key, and for airlines operating in the west, Calgary International offers the greatest potential. Ottawa, Winnipeg and Vancouver rank next in line as critical airports with regard to TAF accuracy.

6.2 Spin-off Benefits

One of the most rewarding aspects of a study of this scope is that, more often than not, unanticipated, but constructive, themes become apparent along the way. Such was the case with this study.

The NAV CANADA TAF Performance Measurement System
Although the NAV CANADA TAF performance measurement system itself was not the primary focus of discussion with the carriers, it was, by virtue of its relationship with TAF performance, discussed at great length. Specifically, there was considerable, fruitful discussion with the carriers regarding the usefulness of specific performance measurement metrics in relation to the flight dispatch process, and how performance information could be made more useful to the air carriers to facilitate flight dispatch.

There was considerable interest by the carriers in focusing additional attention to refining the current performance measurement system. Two main themes were discussed:

a) Refine or change the metrics used to illustrate performance; focus on metrics that will facilitate the flight dispatch process.
b) Present the metrics in a manner, which is useful to flight dispatch operations and can easily be incorporated into the flight dispatch, decision-making process.

To emphasize their support of any performance-related initiative, which may result from this study, two of the airlines indicated their willingness to participate in future efforts, along the lines noted above.

Building Stronger Links with Clients and Partners
Strong lines of communication are an integral part of providing good client service, nd in ensuring that resources are expended wisely. This study allowed NAV CANADA, at the working level, to not only gain a better understanding of how what we do impacts our clients' operations, but also to establish lines of communication, so that we can continue to liaison with our clients in the future.

Since meeting with the airlines to discuss TAF performance, we've received feedback, on more than one occasion, regarding how TAFs are performing. This is useful information. As the service provider to the airlines, we have been able to relay this information to the Meteorological Service of Canada, which in turn allows them to focus on what is important to our clients.

Nurturing and strengthening the relationships that were established during this study, with the airlines and between the airlines and the MSC, is important. NAV CANADA is in a unique position to continue to promote communication between all parties.

7.0 Aviation Weather Products and Services

Current and forecast weather conditions are essential inputs to the pre-flight and post-launch decision making processes. During sessions with the airlines, including a one-day visit to a System Operation Centre (SOC), it quickly became apparent how dependent their operations are on reliable and accurate weather information and the impact inaccurate weather forecasts and products can have on them. Having accurate, reliable, and easy to access aviation weather products is key to a smooth and efficient flight-planning operation.

Just how important is the weather to the air carriers? All aspects of flight planning hinge upon the current and forecast weather, for example, flight planning systems/software are configured to automatically alert the dispatcher whenever the observed weather deviates from the forecast, and whenever a forecast is amended. The same software ingests current aerodrome forecasts (TAFs) to determine the most appropriate alternate(s) to file and the recommended amount of fuel to load. It is no exaggeration to say that dispatchers and pilots are constantly monitoring the weather and reacting to it. In fact, of the three computer display terminals in front of each flight dispatcher, one terminal is dedicated solely to weather and one other is partially dedicated to it – flight dispatchers maintain a continuos weather watch.

As weather is such an integral part of flight planning, the carriers' requirement for weather information goes well beyond the aerodrome forecast (TAF). The consultation sessions with the carriers afforded an opportunity to discuss other aviation products and services and allowed us to gain a better understanding and appreciation of their weather requirements.

7.1 Sources of Aviation Weather

Although the larger operations contract with private companies to provide them with aviation weather information and services, there does not appear to be one service-provider, which provides everything. Hence, to fulfill this requirement, each air carrier has a number of sources for weather information, such as:

a) Private service-providers, e.g. Weather Services International (WSI) - a private firm in the US that specializes in the provision of customer specific aviation weather information/products, and Honeywell;
b) NAV CANADA Aviation Weather Web Site (AWWS);
c) Environment Canada Web Site;
d) Other Internet sources.

From the carriers' perspective, this is less than ideal. Independent service providers package weather information differently, each with their own gaps. As packaging, cost and accessibility are key, the carrier must either choose more than one service provider or select the one that best meets their needs.

7.2 Aviation Weather Products

Since multiple sources are used to acquire weather information, the carriers are very aware of products, which 'stop' at the 49th parallel, i.e. products which are available in the US, but not in Canada (or vise versa). This goes beyond the products developed for individual carriers by private service-providers like WSI and includes products developed by the FAA/National Weather Service (NWS), such as the Collaborate Convective Forecast Product (CCFP), which the carriers are aware of and would like to see extended into Canadian airspace. Additional information on the CCFP, or rather a potential equivalent product for Canada, is provided in section 6.4. Other identified requirements for weather information over Canada include, improved weather radar images and access to such, better turbulence forecasting, improved surface analysis chart, and aerodrome specific temperature forecasts.

Weather Radar - In all cases, the carriers' cited the US weather radar (NEXRAD) data as being better than that, which is available over Canada. This relates to geographical coverage, filtering of images (better filtering out of geography is required so precipitation is discernable, e.g. near Calgary), and timeliness (current update rate of images is not adequate for approaching severe weather situations, e.g. a line of thunderstorms).

Turbulence Forecasting – Carriers want to avoid turbulence. In addition to areas of moderate-severe turbulence posing a threat to passenger and aircraft safety, areas of light-moderate turbulence contribute to passenger discomfort. Examples of turbulence forecasting tools, such as those utilized by Northwest Airline, were cited as tools, which could benefit Canadian carriers.

Surface Analysis Chart – Currently, some carriers receive information (graphically) on surface weather conditions from WSI, e.g. the position of synoptic features, cloud cover, and areas of precipitation. The information, however, is not contained on one product but rather found on several products. This leaves the carrier having to consult multiple products to gain an understanding of current synoptic conditions. Having all aviation relevant variables on one chart would benefit flight-planning operations.

Aerodrome Specific Temperature Forecasts - At high altitude aerodromes, such as Calgary, daytime maximum temperatures are important considerations for fuel load and aircraft weight in the summer months. Flight dispatchers currently utilize public weather forecasts to estimate the daily maximum and minimum temperatures for specific aerodromes. As public forecasts cover large areas, they do not always capture the mesoscale temperature differences that may be displayed at individual aerodromes. It was mentioned that having an aerodrome specific temperature forecast would assist flight planning.

Additional detail on the carriers' interest in new aviation weather products and services can be found in section 6.4, which details the carriers' reaction to potential new products currently under development in NAV CANADA.

7.3 The Aerodrome Forecast (TAF)

This study considers only two elements of the TAF, ceiling and visibility, and illustrates how improving the accuracy of such will translate into financial savings for the airlines. These two metrics where chosen for study for a number of reasons, not the least of which is because they are the metrics currently tracked by the NAV CANADA TAF performance measurement system and hence can be monitored for improvement. They are also two of the metrics which are key to flight planning operations – however, they are not the only metrics of importance to airlines.

Through the course of discussion, the variables described below were discussed in the context of performance measurement. The carriers expressed their desire to see the NAV CANADA TAF performance measurement system expanded to include verification and performance statistics on the accuracy of predicting the above mentioned variables, as they relate to flight operations/efficiency.

Wind - At certain key aerodromes in Canada, Toronto Pearson for example, wind is an important consideration for flight planning operations, as wind conditions may dictate which runways are operational. If air traffic control is forced to switch to a less than optimal runway configuration due to wind, it severely reduces the number of aircraft per hour, which can be landed. If this can be planned for, from a flight dispatch perspective, additional fuel may be loaded onto the aircraft pre-departure, to allow for flow control delays or holding delays over the terminal.

Precipitation vs. Freezing Precipitation – Precipitation does not necessarily impact flight operations. For example, rain and snow may have no impact, particularly if they do not contribute to a significant reduction to visibility or to runway contamination. Freezing precipitation or the onset of such, on the other hand, can severely impact flight operations if it is not properly planned for. Airlines may elect to delay flights, or take other action, in order to avoid freezing precipitation at an aerodrome, if they are confident of the forecast.

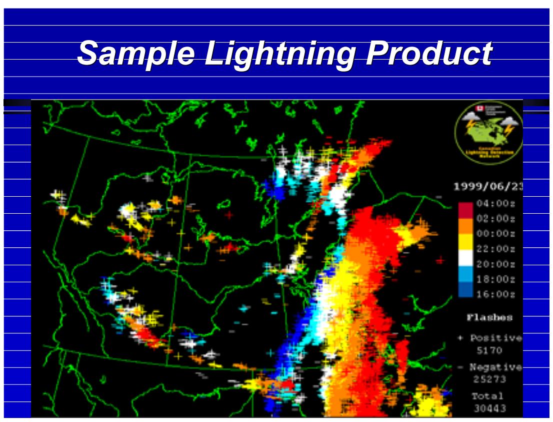
Severe Weather – Pilots want to avoid severe weather, i.e. thunderstorms. A forecast of severe weather, whether in the main body of the TAF or in the conditional group, severely limits the usefulness of the TAF, from a flight planning perspective. Currently, the TAF performance measurement system does not verify the occurrence of severe weather. Hence, dispatchers and pilots have no real information with which to gauge the accuracy of this variable.

7.4 New Aviation Weather Products and Services

As technology and user needs continue to evolve, so must the suite of aviation weather related forecasts and products, which are at the pilots' disposal. Five potential new products and services were introduced to the carriers during our meetings with them; these include:

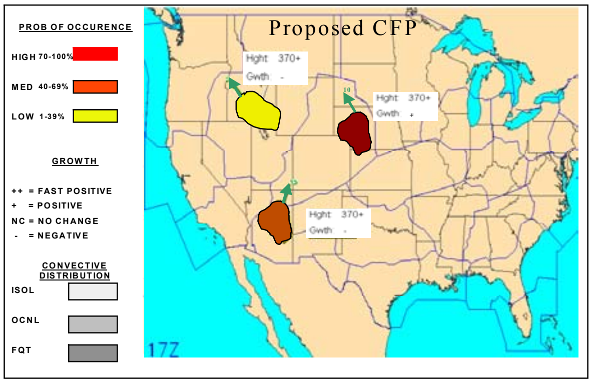
- The Canadian Lightning Detection Network (CLDN),
- Convective Forecast Product (CFP),
- Aviation Surface Analysis Chart (ASAC),
- 48-hour Aviation Weather Prognosis Chart (AWPC), and
- Aviation Weather Web Site (AWWS) and Automated Supplementary Enroute weather Predictions (ASEP).

The **Canadian Lightning Detection Network** was discussed in the context of increased flight efficiency and flight safety. The presentation focussed on the provision of accurate and timely severe weather information to traffic flow management personnel and flight service specialists, which could translate to fewer ground and air delays by offering more efficient circumnavigation of thunderstorms. This could translate into potential savings to operators.



Airlines expressed that CLDN data would be useful operationally as a supplement to existing weather radar data, especially if the current quality of weather radar data is not improved, and as an information source to assist with refueling operations.

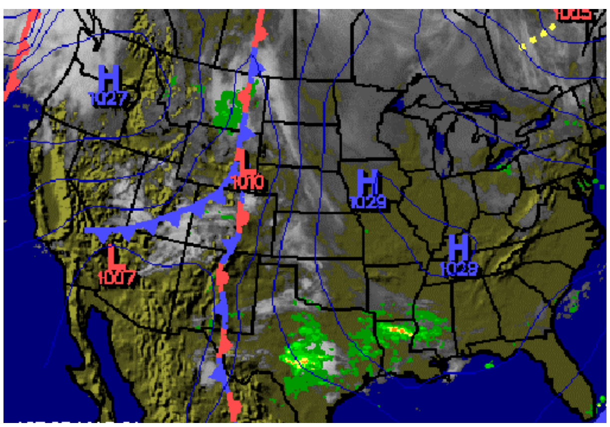
The **Convective Forecast Product** depicts the location, intensity, and probability of convective activity. It is similar to an operational product produced by the US National Weather Service for US airspace (the Collaborative Convective Forecast Product). The product can be utilized as a strategic planning tool for air traffic management, which could minimize the disruptive affect that thunderstorms have on air traffic flow management, and consequently increase the efficiency of operations leading to potential saving to operators.



Note the above graphic is an example only.

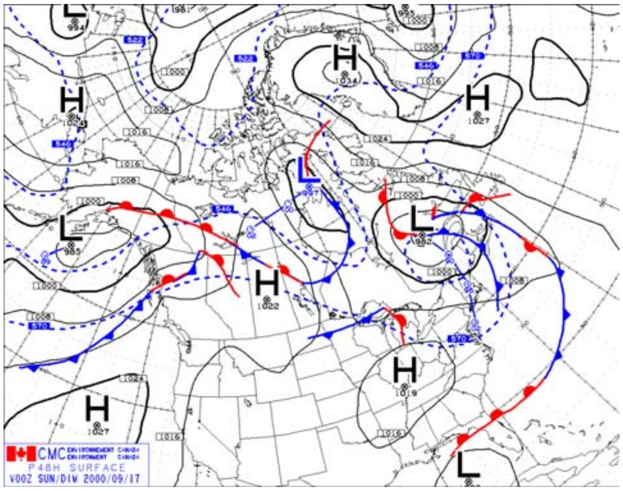
Operators are aware of this product for US airspace and are interested in a similar product for Canada. One airline expressed discontent that all US products end at the 49th parallel and stated the requirement for a 'seamless' suite of products.

The **Aviation Surface Analysis Chart**, is a product that will optimize and improve aviation weather information by providing a comprehensive, national weather analysis to support aviation activities in Canada. The product will focus on variables of significance to aviation.



The airlines noted that Weather Services International (WSI) makes all of this information available but not by way of a single product. The current surface analysis chart available on the NAV CANADA site does not meet the needs of the user - it is worth noting that this product is a public weather product provided without charge to NAV CANADA by the Meteorological Service of Canada.

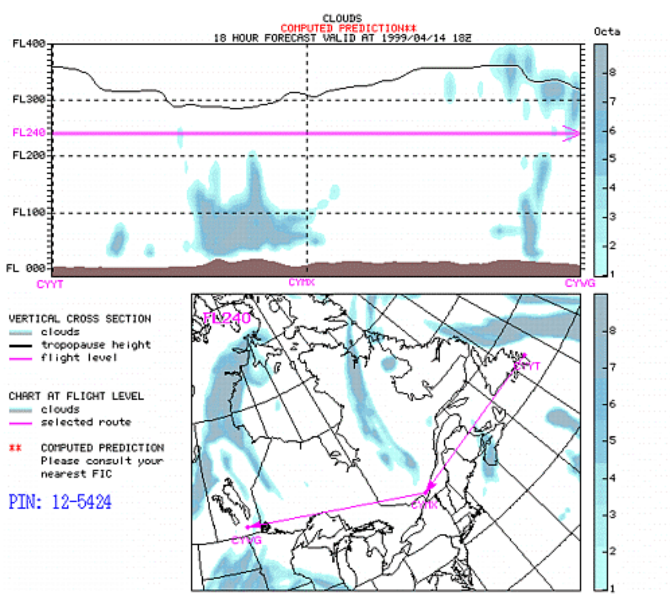
The **48-hour Aviation Weather Prognosis Chart** will provide pilots, FSS weather briefers, air traffic controllers and airline dispatchers with a comprehensive, national aviation weather prognosis chart, which extends beyond the current 24-hour time frame.



The product will focus on variables of significance to aviation in order to optimize and improve aviation weather information available in Canada.

The airlines expressed that this product would be useful for long-range, contingency planning purposes and could be used to provide advisories to passengers.

The airlines were briefed on the re-launch of NAV CANADA's **Aviation Weather Web Site (AWWS)** and the development of a new suite of weather-graphic products - **Automated Supplementary Enroute weather Predictions (ASEP)** products.



The increased functionality of the AWWS will allow users the unique ability to create and save their own, use-defined routes for subsequent recall.

ASEP products are state-of-the-art, graphical weather products which are easier to interpret than traditional, text-based weather products. ASEP products can be produced 'on-the-fly' using user-input parameters such as flight planned altitude, time of departure, expected time en-route and departure/destination/way-points.

The airlines expressed interest in the ASEP suite of products, particularly wind and turbulence fields.

7.5 Summary of Weather Services and Products

Weather, current and forecast, is a key consideration in the flight planning process. Access to accurate and timely weather information is crucial. There are a number of gaps in the current way carriers acquire weather information and in the type of services, forecasts and information, they have available to them. Some gaps, which were identified by the carriers', include:

a)The lack of a 'one-stop shopping' type of service for the provision of Canadian aviation weather information to Canadian air carriers.

b)The inconsistency of weather information and products available in the US versus Canada.

c)The lack of performance information available on aviation impact variables other than ceiling and visibility. Note that additional requirements for performance information were identified and are outlined in section 6.2.

d)The lack of aviation specific products, which forecast variables that are important to flight dispatch operations.

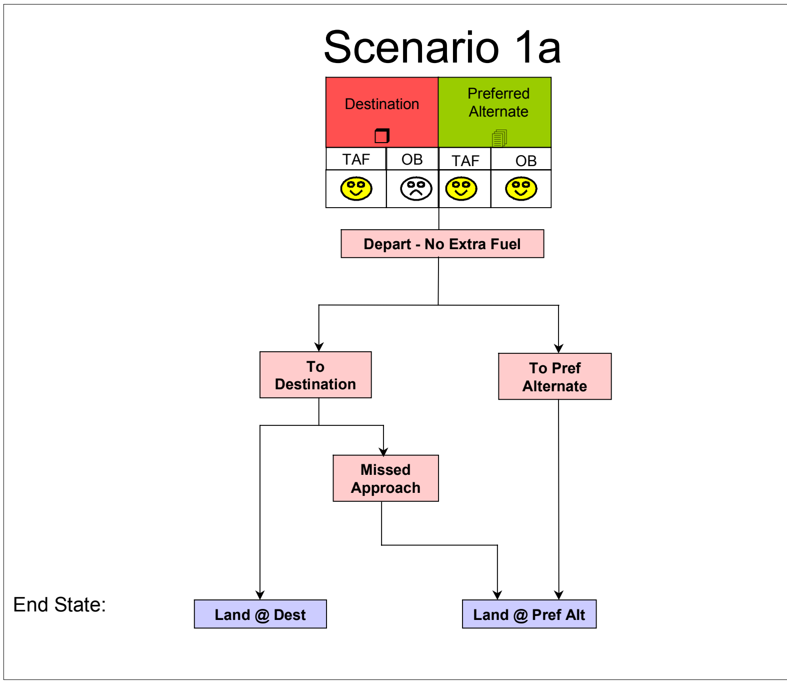
APPENDIX ONE: "With alternate" Scenarios

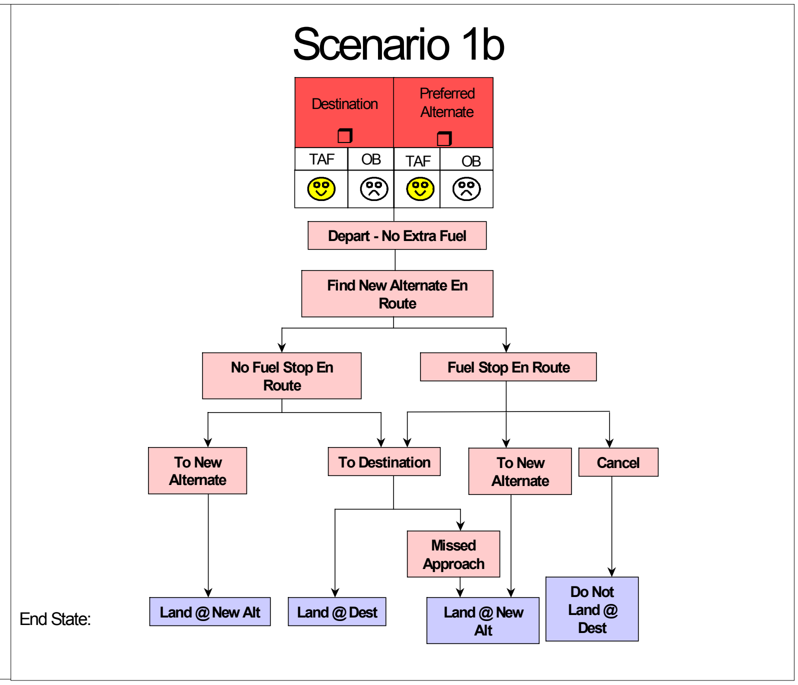
When the Aerodrome Forecast for the destination and alternate are considered, sixteen potential "scenarios" are possible when a missed-event and false-alarm are taken into account.

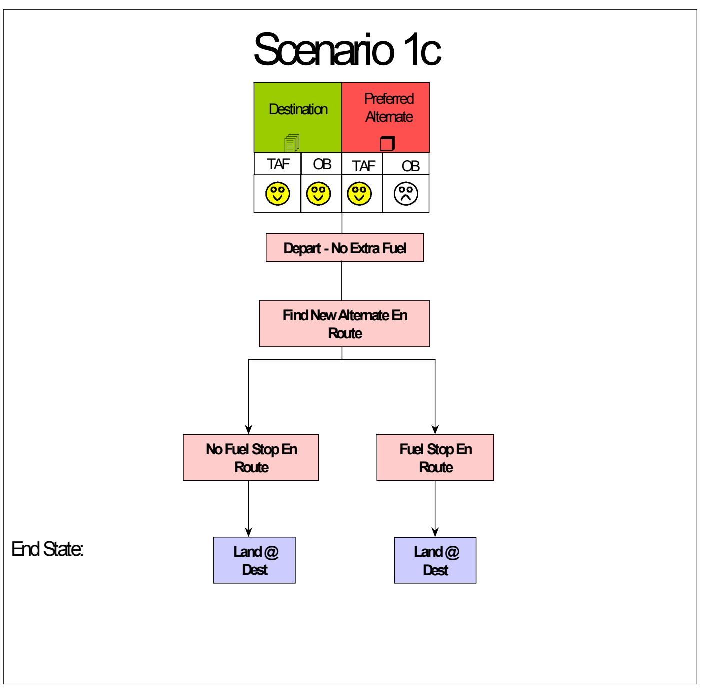
Scenario	Destination			Preferred Alternate		
	Forecast	Observation	Result	Forecast	Observation	Result
1a	Above	Below	Missed Event	Above	Above	Accurate AL
1b	Above	Below	Missed Event	Above	Below	Missed Event
1c	Above	Above	Accurate AL	Above	Below	Missed Event
1d	Above	Above	Accurate AL	Above	Above	Accurate AL
2a	Below	Above	False Alarm	Above	Above	Accurate AL
2b	Below	Above	False Alarm	Above	Below	Missed Event
2c	Below	Below	Accurate BL	Above	Below	Missed Event
2d	Below	Below	Accurate BL	Above	Above	Accurate AL
3a	Above	Below	Missed Event	Below	Below	Accurate AL
3b	Above	Below	Missed Event	Below	Above	False Alarm
3c	Above	Above	Accurate AL	Below	Above	False Alarm
3d	Above	Above	Accurate AL	Below	Below	Accurate BL
4a	Below	Above	False Alarm	Below	Below	Accurate BL
4b	Below	Above	False Alarm	Below	Above	False Alarm
4c	Below	Below	Accurate BL	Below	Above	False Alarm
4d	Below	Below	Accurate BL	Below	Below	Accurate BL

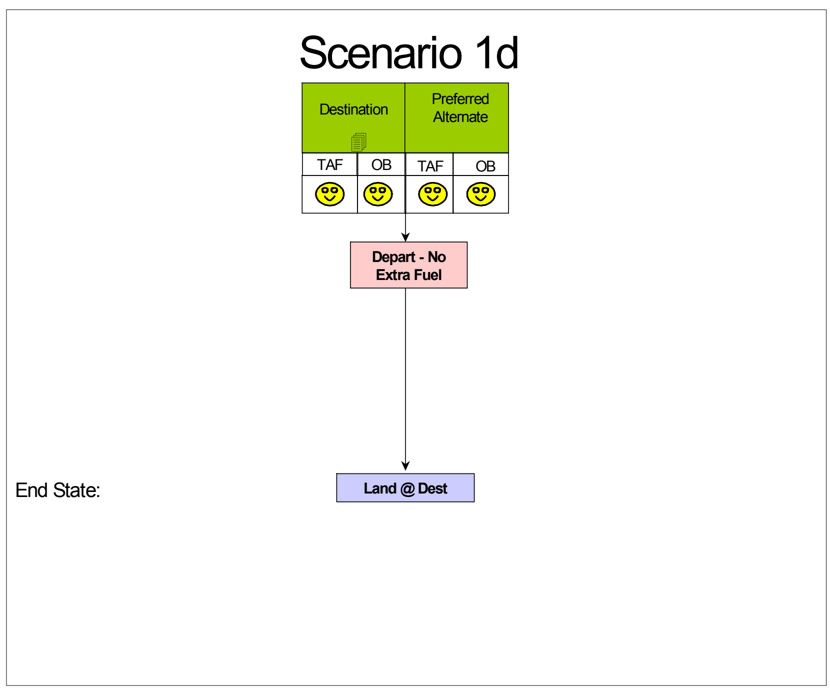
APPENDIX TWO: Decision Trees

Scenario 1: The Aerodrome Forecast is for above limit conditions at the destination and preferred alternate.

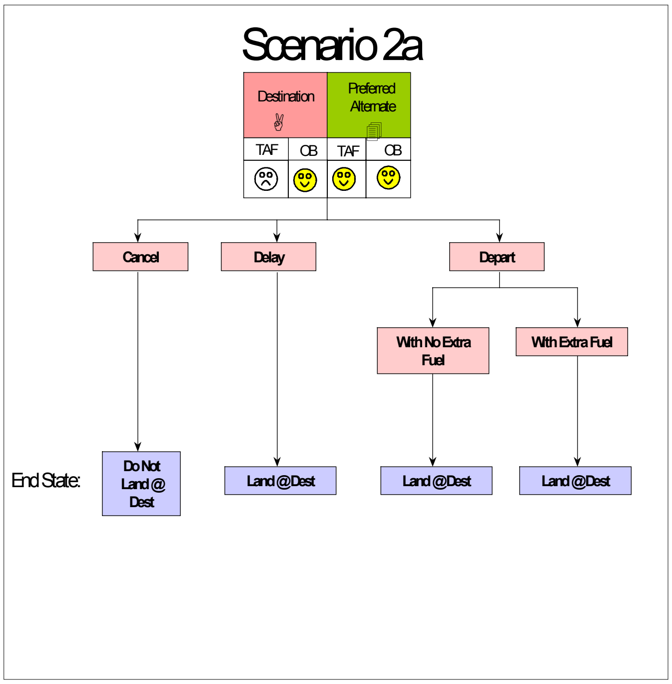


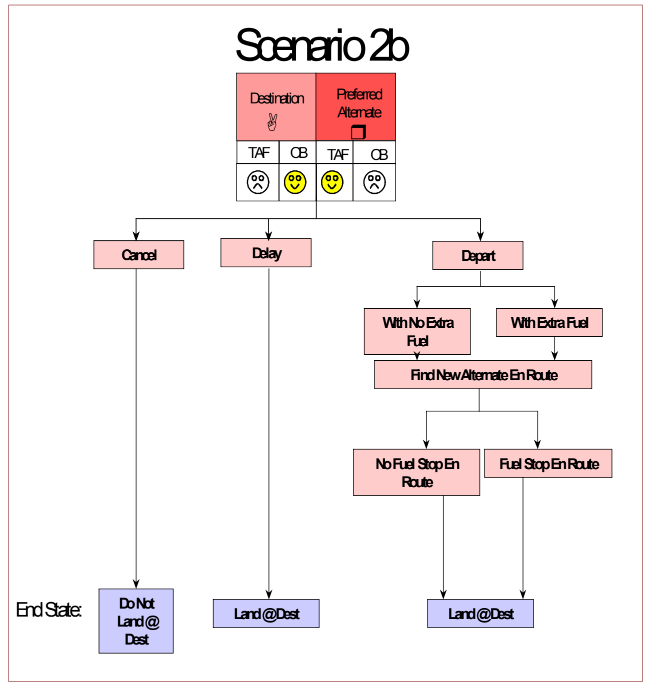


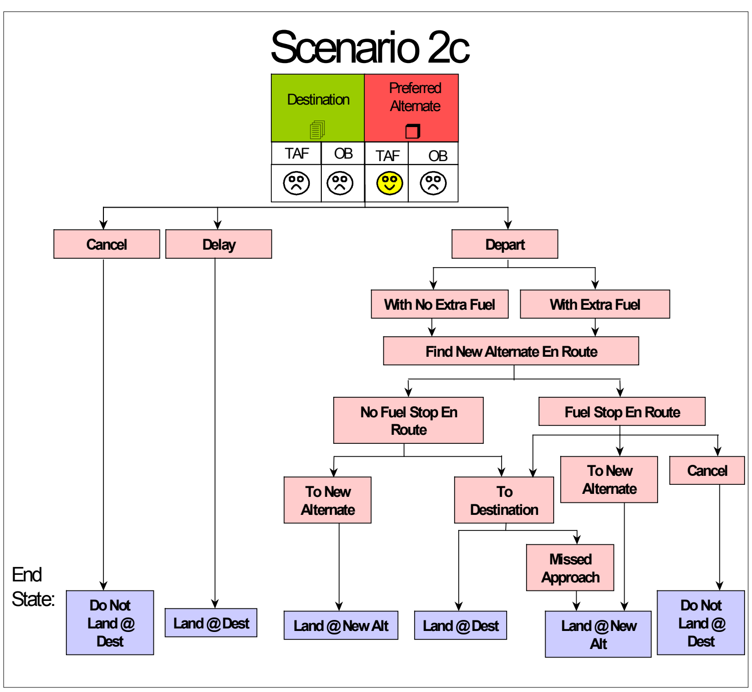


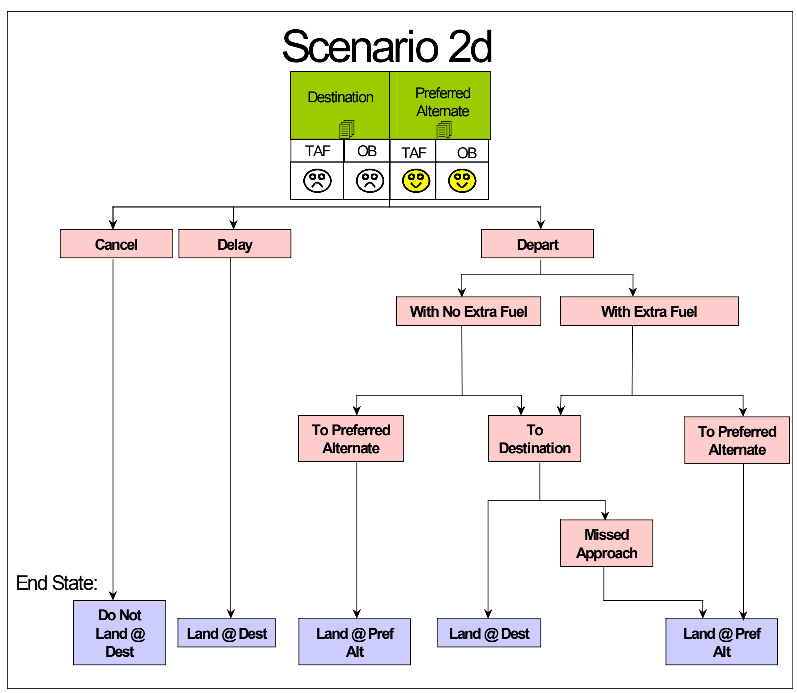


Scenario Two: The Aerodrome Forecast is for below limit conditions at the destination and for above limit conditions at the preferred alternate.

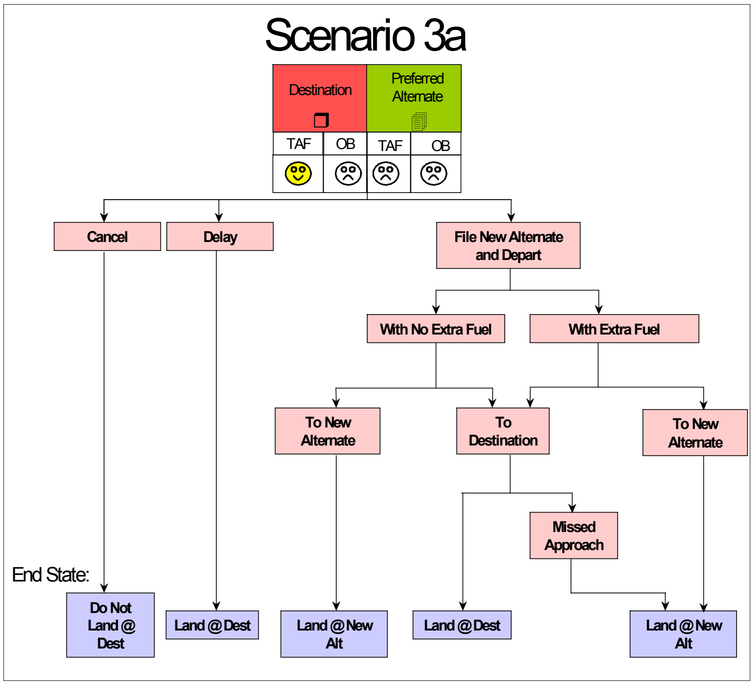


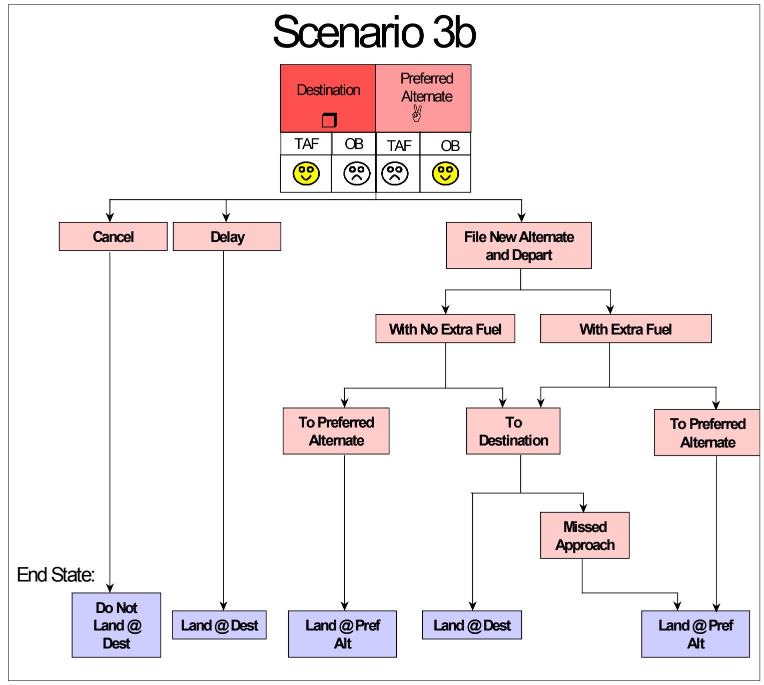


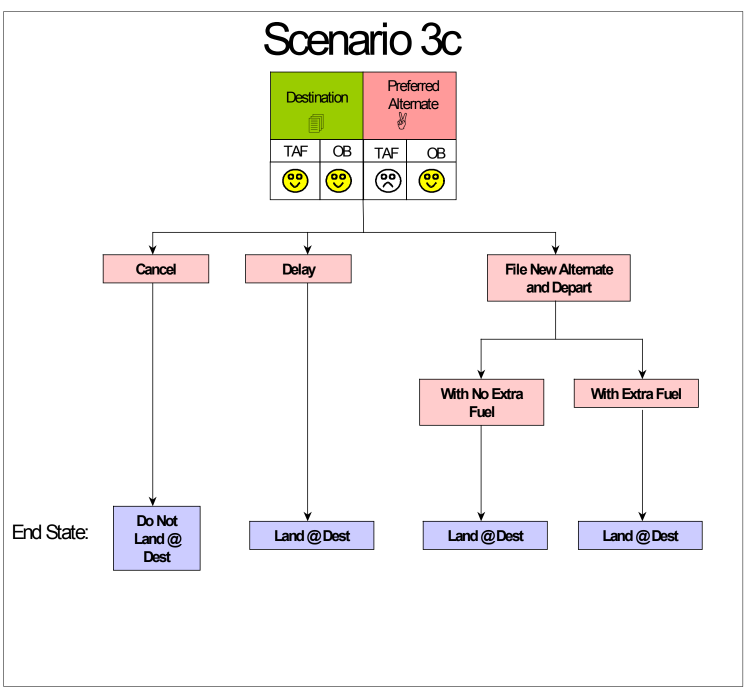


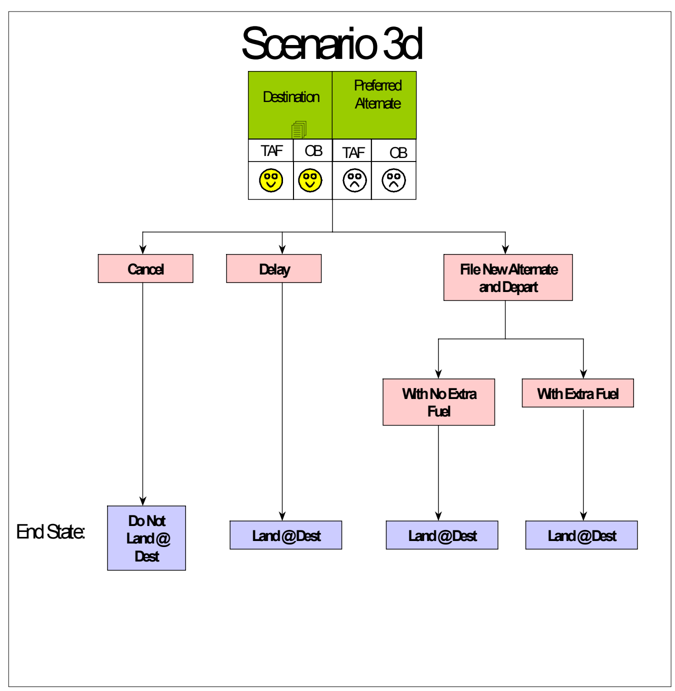


Scenario Three: The Aerodrome Forecast is for above limit conditions at the destination and for below limit conditions at the preferred alternate.

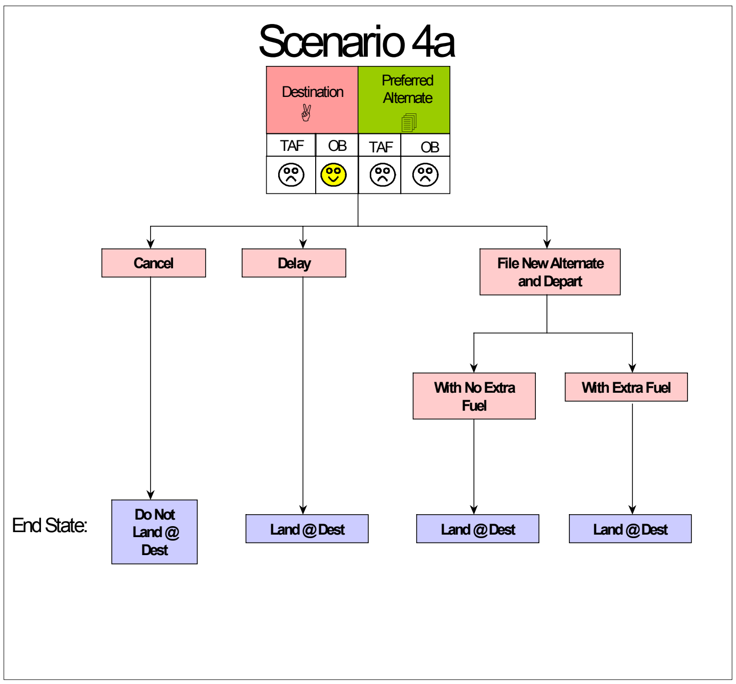


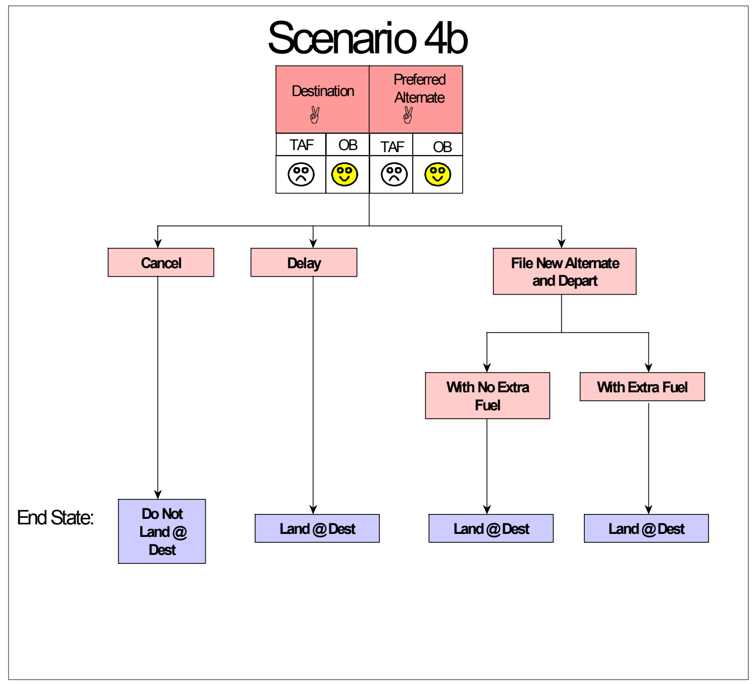


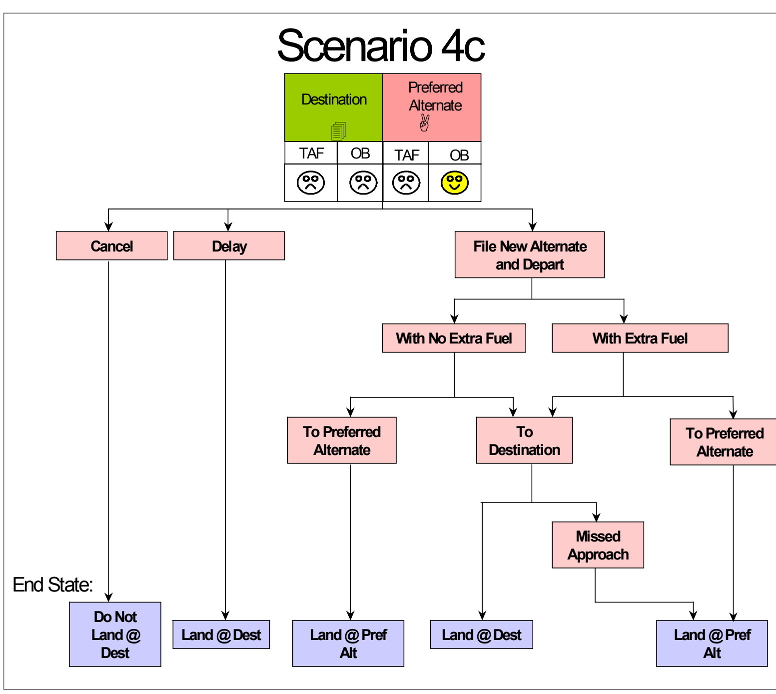


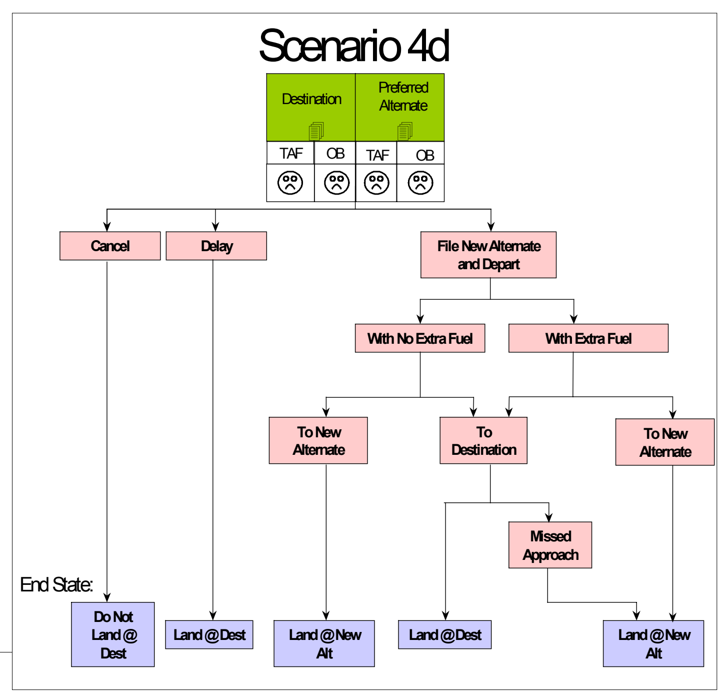


Scenario Four: The Aerodrome Forecast is for below limit conditions at the destination and at the preferred alternate.









APPENDIX THREE: Visit to Air Canada's System Operations Centre (SOC)

The project team toured Air Canada's SOC to obtain insight on the flight planning process, and to gauge the project team's approach to describing and assessing TAF accuracy impacts. It also served to confirm how the TAFs are used, and the importance of their accuracy in flight planning. Each project team member was paired with a flight dispatcher for about six hours. The following is a summary of their observations:

- TAFs are critical input to their flight planning process (of the three displays located at each workstation, the middle display contained all of the relevant weather information, including TAFs and weather observations). The flight dispatcher continually referred to the TAFs and weather observations, even after flight departure.
- The most critical surface variables for flight planning purposes are ceiling and visibility, although wind is critical at certain airports, such as Toronto where runway capacity can be significantly reduced by the necessity to shift from one runway to another. Toronto is somewhat unique in this regard in comparison to other major Canadian airports.
- TAFs issued on three-hour cycles are preferred over those issued on six-hour cycles since they are more accurate.
- Accurate forecasts are required well in advance of flight departure. Planning for each flight is done two to three hours prior to departure depending upon the length of the flight.
- A change in the TAF can mean the entire flight must be re-planned, or dispatchers are recalculating fuel-load to ensure alternates are available. If the TAF changes more than once, from issue to issue, or due to an amendment, it can significantly increase the dispatcher's workload.
- TAFs are critical for the selection of alternates. They are also important for destinations in that they will determine whether a flight can go "contact", i.e. no alternate IFR. An inaccurate TAF may require the filing of another alternate, or the selection of a non-optimal one.
- If a destination is forecast below a ceiling 600 feet and visibility of 2 statute miles, pilots tend to get nervous and request additional fuel in the event of a missed approach.
- The only situation where an aircraft will stop for fuel en route is when the ceiling and/or visibility of the filed alternate drop below alternate limits and another alternate with an acceptable ceiling and visibility can not be found within the remaining fuel. A flight will not stop for additional fuel if the destination is below limits, provided the alternate remains above alternate limits.
- International flights are not often cancelled due to forecast or current weather. On non-international flight delays are more common as they may wait until conditions improve. Diversions are rare, but are preferable to stopping en route for fuel.

APPENDIX FOUR: The Meteorological Analysis

The following table of destination airports represents the ten busiest airports in Canada, based on movement statistics. The most frequently filed alternates are given for each of the destination airports, and are based on analysis of a four-week sample of flight plans.

For each destination airport there are potentially three different categories of limits that are critical to end-user operations and, therefore assessed in the meteorological analysis:

1)Normal limits for landing and alternate – as defined in MANAIR
2)Lowest published limits for Category II or III airports, where applicable to the airline and destination
3)No alternate IFR limits – as defined by the airlines, where applicable. Note that 'no alternate IFR' means that an alternate is not required for the flight.

Altitude: AGL; Visibility: Statute Miles

Destination	Alternates
Toronto/ LBPIA (CYYZ)	
Normal Limit: Ceiling – 200; Visibility – ½	Hamilton CYHM: Ceiling – 600, Visibility – 2 Ottawa CYOW: Ceiling – 400, Visibility – 1 London CYXU: Ceiling – 600, Visibility – 2
CAT 3 Limit: Ceiling – 0; RVR – 600	Hamilton CYHM: Ceiling – 600, Visibility – 2 Ottawa CYOW: Ceiling – 400, Visibility – 1 London CYXU: Ceiling – 600, Visibility – 2
No Alternate IFR Limit: Ceiling – 1500, Visibility - 6	No alternate required.
Vancouver Intl (CYVR)	
Normal Limit: Ceiling – 200, Visibility – ½ CAT 3 Limit: Ceiling – 0, RVR – 600 No Alternate IFR Limit: Ceiling – 1500, Visibility – 6	Victoria CYYJ: Ceiling – 400, Visibility – 1 Abbotsford: Ceiling – 600, Visibility – 2 Victoria CYYJ: Ceiling – 400, Visibility – 1 Abbotsford: Ceiling – 600, Visibility – 2 No alternate required.
Montreal Intl – Dorval (CYUL)	
Normal Limit: Ceiling – 200, Visibility – ½	Montreal Mirabel CYMX: Ceiling - 400, Visibility – 1 Ottawa Intl CYOW: Ceiling – 400, Visibility – 1 Quebec CYQB: Ceiling - 600, Visibility - 2
CAT 3 Limit: Ceiling – 100, RVR – 1200	Montreal Mirabel CYMX: Ceiling - 400, Visibility – 1 Ottawa Intl CYOW: Ceiling – 400, Visibility – 1 Quebec CYQB: Ceiling - 600, Visibility - 2
No Alternate IFR Limit: Ceiling – 1500, Visibility – 6	No alternate required.
Calgary Intl (CYYC)	

Destination	Alternates
Normal Limit: Ceiling - 200, Visibility – 1/2	Edmonton Intl CYEG: Ceiling – 400, Visibility – 1 Lethbridge CYQL: Ceiling – 600, Visibility - 2
CAT 3 Limit: N/A	N/A
No Alternate IFR Limit: Ceiling – 1500, Visibility – 6	No alternate required.
Edmonton Intl (CYEG	
Normal Limit: Ceiling - 200, Visibility – 1/2	Calgary CYYC: Ceiling - 400, Visibility – 1 Edmonton City Centre CYXD: Ceiling – 600, Visibility - 2
CAT 3 Limit: N/A	N/A
No Alternate IFR Limit: Ceiling – 1500, Visibility – 6	No alternate required.
Halifax Intl (CYHZ)	
Normal Limit: Ceiling - 200, Visibility – 1/2	Moncton CYQM: Ceiling – 400, Visibility – 1 Fredericton CYFC: Ceiling – 600, Visibility – 2 Sydney CYQY: Ceiling 400, Visibility - 1
CAT 3 Limit: Ceiling – 100, RVR - 1200	Moncton CYQM: Ceiling – 400, Visibility – 1 Fredericton CYFC: Ceiling – 600, Visibility – 2 Sydney CYQY: Ceiling 400, Visibility - 1
No Alternate IFR Limit: Ceiling – 1500, Visibility – 6	No alternate required.
Ottawa Intl (CYOW)	
Normal Limit: Ceiling - 200, Visibility – 1/2	Montreal Dorval CYUL: Ceiling - 400, Visibility – 1 Toronto Intl CYYZ: Ceiling -400, Visibility - 1
CAT 3 Limit: N/A	N/A
No Alternate IFR Limit: Ceiling – 1500, Visibility – 6	No alternate required.
Quebec Intl (CYQB)	
Normal Limit: Ceiling - 200, Visibility – 1/2	Montreal Dorval CYUL: Ceiling – 400, Visibility – 1 Bagotville CYBG: Ceiling - 600, Visibility – 2
CAT 3 Limit: N/A	N/A
No Alternate IFR Limit: Ceiling – 1500, Visibility – 6	No alternate required.
Saskatoon (CYXE)	
Normal Limit: Ceiling - 200, Visibility – 1/2	Regina CYQR: Ceiling - 600, Visibility – 2 Prince Albert CYPA: Ceiling – 600, Visibility - 2
CAT 3 Limit: N/A	N/A
No Alternate IFR Limit: Ceiling – 1500, Visibility – 6	No alternate required.
Winnipeg Intl (CYWG)	

Destination	Alternates
Normal Limit: Ceiling - 200, Visibility – 1/2	Brandon CYBR: Ceiling - 800, Visibility –2 Regina CYQR: Ceiling - 600, Visibility - 2 Kenora CYQK: Ceiling - 800, Visibility – 2
CAT 3 Limit: Ceiling – 100, RVR - 1200	Brandon CYBR: Ceiling - 800, Visibility –2 Regina CYQR: Ceiling - 600, Visibility - 2 Kenora CYQK: Ceiling - 800, Visibility – 2
No Alternate IFR Limit: Ceiling – 1500, Visibility – 6	No alternate required.

APPENDIX FIVE: "No Alternate IFR" Scenarios and Analysis

For eligible destinations and airlines, a flight plan can be filed without an alternate if various conditions are satisfied. The airlines were asked to estimate the percent of such occurrences for each airport since using the weather limit condition alone would likely lead to its over-estimation.

There are six scenarios considered in analyzing "no Alternate IFR" are as follows:

Scenario	Forecast		Observed		Result	Incremental Impact
	Contact Limits	Landing Limits	Contact Limits	Landing Limits		
No Alt 1	Above	Above	Above	Above	Accurate AL	None
No Alt 2	Above	Above	Below	Above	Missed Event	Possible Fuel Stop
No Alt 3	Above	Above	Below	Below	Missed Event	Possible Diversion
No Alt 4	Below	Above	Above	Above	False Alarm	Unnecessary Alternate
No Alt 5	Below	Below	Above	Above	False Alarm	Unnecessary Alternate
No Alt 6	Below		Below		Accurate BL	Necessary Alternate

Only "no alternate IFR" Scenarios 1, 2 and 3 are potential candidates for a "no alternate IFR" situation since they all forecast above contact limits (limits for "no alternate IFR" conditions). Accordingly, the estimated percent of "no alternate IFR" provided by the airlines is distributed among these three scenarios based on the proportions resulting from the met analysis.

"No alternate IFR" Scenarios 4, 5 and 6 all require an alternate to be filed, and under a perfect forecast situation, a portion of Scenarios 4 and 5 would revert to Scenario 1. However, the percentages derived from the met analysis need to be adjusted downward to reflect the other factors the airlines take into consideration when filing an alternate.

It should be noted that the meteorology analysis for the "no alternate IFR" condition was undertaken independently of the initial 16 scenarios. This was done because several airports and airlines do not allow their use, and to simplify the met analysis.

In the example presented in the table below, the airline has indicated that about 30 percent of the flights arriving at this airport do not require an alternate to be filed. The column titled "Initial Minutes" is the result of the meteorology analysis, and the corresponding percent "Initial Percent" is derived from this. Since the met analysis was performed independently for this condition, the initial percentages will add to 100. They are subsequently adjusted to reflect airline practice.

The met analysis has the first three "no alternate IFR" scenarios adding to 48.4 and 54.1 percent for the long and short route categories, respectively, whereas they should only occur 30 percent of the time. Factors of 0.62 and 0.55 applied to the initial minutes produce the desired result (i.e. an alternate is filed 38 and 45 percent of the occasions where the weather limits allow "no alternate IFR" due to other reasons).

In the "perfect forecast" option, "no alternate IFR" Scenarios 4 and 5 do not exist and the adjusted minutes revert to "no alternate IFR" Scenario 1. In other words, with a perfect forecast, the occasion for "no alternate IFR" increases by about 8 to 13 percentage points (i.e. the sum of the Scenario 4 and 5 adjusted percentages).

Since the met analysis was conducted independently, the minutes and corresponding percentages for the six "no alternate IFR" scenarios cannot simply be added to the original 16 "with alternate" scenarios. In order to obtain the correct total minutes and percentages, the adjusted minutes in the "no alternate IFR" scenarios have to be drawn from the 16 original scenarios.

In the example, the 92 minutes from "no alternate IFR" Scenarios 1 and 2 are drawn from Scenarios 1c, 1d, 3c and 3d (since they all have "above-above" TAF and observed conditions) in the same proportion in which they are observed to occur from the met analysis. The procedure is repeated for "no alternate IFR" scenarios 3, 4 and 5. Note that "no alternate IFR" Scenario 6 will always require an alternate, and is, therefore, already considered in the original 16 scenarios.

		Route Category	Initial Minutes	Initial Percent	Adjusted Minutes	Adjusted Percent
NO ALTERNATE SCEN -- 30%						
No Alt 1	**Above CL**	**Long**	**145**	46.8%	**90**	29.0%
No Incr Cost	**Above CL**	**Short**	**165**	53.2%	**91**	29.5%
	Removed from Sc 1c, 1d, 3c, 3d					
No Alt 2	**Above CL**	**Long**	**3**	1.0%	**2**	0.6%
Fuel Stop Req	**Be CL/Ab LL**	**Short**	**2**	0.6%	**1**	0.4%
	Removed from Sc 1c, 1d, 3c, 3d					
No Alt 3	**Above CL**	**Long**	**2**	0.6%	**1**	0.4%
Fuel Stop/Divert	**Below LL**	**Short**	**1**	0.3%	**1**	0.2%
	Removed from Sc 1a, 1b, 3a, 3b					
No Alt 4	**Bel CL/Ab LL**	**Long**	**50**	16.1%	**31**	10.1%
Unnecessary Alt	**Above CL**	**Short**	**35**	11.3%	**19**	6.3%
	Removed from Sc 1c, 1d, 3c, 3d					
No Alt 5	**Below LL**	**Long**	**15**	4.8%	**9**	3.0%
Unnecessary Alt	**Above CL**	**Short**	**10**	3.2%	**6**	1.8%
	Removed from Sc 2a, 2b, 4a, 4b					
No Alt 6	**Below CL**	**Long**	**95**	30.6%	**0**	0.0%
Necessary Alt	**Below CL**	**Short**	**97**	31.3%	**0**	0.0%
			310	**100%**	**93**	**30.0%**

APPENDIX SIX: Operational Impacts

Flights that are cancelled, delayed or diverted incur a cost resulting from actions taken to mitigate the impacts. The actions, in turn, affect one of three general "stakeholder" groups – aircraft, crew and passengers

The tables below depict the methodology used in quantifying the costs associated with a cancelled, delayed or diverted flight. It was critical to capture this information from a weather perspective since operator policy may dictate specific actions and costs for different causes of the event. For example, some airlines employ a "condition code" that is announced pre-departure of the possibility of not making the destination due to weather. In such cases, the airline is absolved of any costs to passengers who decide to continue with the flight if it is diverted to the alternate. For cancellations and delays, airlines may chose not to compensate passengers since the event is considered to be beyond the airline's control.

Cancellation

Choices for Aircraft include deadheading the aircraft to another airport, redeploying it from the departure airport to another destination or on the next scheduled flight to the same destination, or parking it for some other purpose (excluding maintenance). In each case, there is likely to be some idle time for the aircraft with a corresponding opportunity cost.

Crew options closely align with the aircraft choices, although the probabilities may not.

Passenger costs represent either "out-of-pockets" for meals, accommodation and compensation, or lost net revenues if he decides not to re-book.

	Cancellation Aircraft Impacts and Costs				
	Deadhead	Redeploy at Existing Airport			
	Ferry to Another Airport	To Another Destination	On Next Flight to Same Destination	Park Aircraft	Other
Probability (%)					
Extra Flight Time (hrs)					
Idle Time (hrs)					
Extra Ground Handling, Push Back ($/flt)					
Additional Airport/ANS Fees ($/flt)					

	Cancellation Crew Impacts and Costs				
	Send to Another Airport (Deadhead)	Redeploy at Existing			
		To Another Destination	On Next Flight to Same Destination	Send Home	Send to Hotel
Probability (%)					
Cabin Crew Show Time (hrs)					
FD Crew Show Time (hrs)					
Cabin Crew Additional Time (hrs)					
FD Crew Additional Time (hrs)					
Crew Per Diem Time (hrs)					
Crew Hotel ($/person)					
Crew Transportation ($/person)					

	Cancellation Passenger Impacts and Costs				
	Meals	Accom-modation	Compens-ation	Lost Net Revenue	Alternate Transportation
% Passengers Affected (per cancelled flight)					
Cost per Passenger[1]					
Cost per Flight[1]					

Delay

Choices for Aircraft if the flight is delayed are limited to two: delay until the weather is forecast to improve and depart; or delay until weather is forecast to improve, but miss the slot. The latter only occurs on flights with busy destinations and is not a common occurrence. However, when it does occur, the delay can be significant.

Crew choices are greater, and include the possibility of sending the crew home and bring in a new crew.

As with flight cancellations, passenger costs represent either "out-of-pockets" for meals, accommodation and compensation, or lost revenues if he decides to cancel the trip or continue with another operator (or mode).

	Delay Aircraft Impacts and Costs	
	Wait for New Departure Time	**Wait and Miss Slot**
Probability (%)		
Idle Time (hrs)		
Extra Ground Handling, Push Back ($/flt)		

	Delay Crew Impacts and Costs			
	Wait for New Departure Time	**Redeploy on Another Flight**	**Send Home**	**Send to Hotel**
Probability (%)				
Cabin Crew Show Time (hrs)				
Cabin Crew Additional Time (hrs)				
Cabin Crew Per Diem Time (hrs)				
FD Crew Show Time (hrs)				
FD Crew Additional Time (hrs)				
FD Crew Per Diem Time (hrs)				
Crew Hotel ($/person)				

	Delay Passenger Impacts and Costs			
	Meals	**Compensation**	**Lost Revenue**	**Other**
% Passengers Affected (per delayed flight)				
Cost per Passenger[1]				
Cost per Flight[1]				

Note 1: Enter either Cost per Passenger or Cost per Flight

Divert/Fuel Stop

Diverting a flight, generally, is the choice having the greatest cost, especially for aircraft and crew. For Aircraft, the options waiting at the alternate until the weather improves at the destination, deadheading to another airport (without the passengers) or returning to the origin.

Crew choices are greater, but it may also require the introduction of a fresh crew, which can increase costs significantly.

As with flight cancellations, passenger costs represent either "out-of-pockets" for meals, compensation, or alternative transportation. Note that the passenger is "hostage" at this point and does not have the option of cancelling.

	Divert Aircraft Impacts and Costs		
	Continue to Destination	Ferry to Another Airport (Deadhead)	Return to Origin
Probability (%)			
Extra Flight Time (hrs)			
Idle Time (hrs)			
Extra Ground Handling, Push Back ($/flt)			
Additional Airport/ANS Fees ($/flt)			

	Divert Crew Impacts and Costs				
	Continue to Dest. with Old Crew	Continue to Dest. with New Crew	Deadhead To Other Airport with Old Crew	Return to Origin, Bring in New Crew	Return to Origin, Keep Old Crew
Probability (%)					
Old Crew Show Time (hrs)					
Old Crew Additional Time (hrs)					
Old Crew Per Diem Time (hrs)					
Old Crew Hotel ($/person)					
Old Crew Transportation ($/person)					
New Crew Show Time (hrs)					
New Crew Additional Time (hrs)					
New Crew Per Diem Time (hrs)					
New Crew Hotel ($/person)					
New Crew Transportation ($/person)					

	Divert Passenger Impacts and Costs			
	Meals	Compensation	Transportation from Alternate	Transportation from Origin
% Passengers Affected (per diverted flight)				
Cost per Passenger[1]				
Cost per Flight[1]				

APPENDIX SEVEN: References

[1]*The Influence of Weather on Flight Operations at the Atlanta Hartsfield International Airport"*, by Peter J. Robinson in American Meteorological Society, December, 1989, pages 461-468;

[2]*"Economic benefits of Terminal Aerodrome Forecasts (TAFs) for Sydney Airport, Australia"*, by R.J. Leigh, Climatic Impacts Centre and Graduate School of the Environment, Macquarie University, Sydney, New South Wales 2109, Australia;

[3]*"The Economic Benefits of Aviation Weather Services: Competitive Advantage"*, by Chris Doyle, Environment Canada, November 1994;

[4]*"Regulation and the Economic Benefit of Aviation Weather Products"*, by Chris Doyle and Mike Campbell, Environment Canada, November 1994;

[5]*"Calculating the value of forecast availability at aerodromes in Canada: the potential cost of no information"*, by Chris Doyle, Environment Canada;

[6] *"Assessing the Economic Value of Weather Forecasts: An Overview of Methods, Results and Issues"*, by A.H. Murphy, Meteorological Institute, University of Hamburg, Germany in Meteorology Applications, 1994, pages 69-73;

[7] *"Impact of Weather on and Use of Weather Information by Commercial Airline Operations"*, by Warren L. Quallry, Manager Weather Services, American Airlines, DFW Airport, Texas, U.S;

[8] *"On the Relationship between the Accuracy and Value of Forecasts in the Cost-Loss Ration Situation"*, by A.H. Murphy and Martin Ehrendorfer, Department of Atmospheric Sciences, Oregon State University, in American Meteorology Society, September, 1987, pages 243-251;

[9] *"Budget-Cutting and the Value of Weather Services"*, by C.A. Doswell III and H.E. Brooks, NOAA/ERL National Severe Storms Laboratory, Norman Oklahoma, in Weather and Forecasting, Vol 13, pages 206-212;

[10] *"The Value of Climate Data in Relation to Extreme Weather Events"* , by M.H. Dore and D. Phil, Commissioned by Environment Canada, March 26, 2000.