Pilot Feedback for an Automated Planning Aid System in the Cockpit

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Abstract

It is the primary responsibility of the airline pilot to safely complete a flight plan and safely land the airplane. This task can become very difficult in the face of an onboard emergency. One of the challenging tasks faced by the pilots in case of an emergency is the determination of an appropriate landing site as well as the development of a safe trajectory to reach that site. An Automated Planning Aid (APA) can assist the pilot with the tasks of selecting a landing site and developing a suitable trajectory to land. In order to evaluate such an APA, a survey of airline pilots was conducted during the late summer of 2008. The participants were presented with several questions related to the task of planning a path during a performance altering emergency, a non-performance altering emergency and an unforeseen emergency. Participants were also presented with questions about how they would prefer to interact with an APA in the cockpit and the circumstances under which such a device might be most useful. The results of the survey showed that time was the most important criterion to consider, however the methods pilots use to complete the landing site selection and trajectory development tasks vary with the type of emergency and the pilot's familiarity with the circumstances. The results of the survey are used to understand the mental processes currently used by the pilots to complete the path planning task as well as to provide insights to how an APA could be most useful during an onboard emergency.

1 Introduction

Modern air transportation has a very good record of flight safety. When failures do occur in flight, the training and experience of the pilots almost always provide for a safe landing.

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This is evidenced by a rate of only 1.35 accidents per one million hours flown in 2007 by US air carriers [1]. Despite this excellent record, the pilot's responsibility to land safely in case of an emergency can be very demanding. There are a number of tasks which demand the pilots' attention. Among these is the planning and execution of a trajectory that will result in a safe landing. Moreover, all these tasks must be accomplished in a stressful environment under great pressure [2].

The purpose of this research is to better understanding how pilots currently go about the tasks of choosing an appropriate landing site, and planning a safe path to the ground. Additionally, the research will provide suitable directions for the development of an intelligent flight guidance and path planning tool to aid the pilot in this process. To this end, a survey of airline pilots was conducted to gather information in support of these goals. This paper will first present a review of research related to the task of emergency path planning. Afterwards, the results of the survey will be presented and an analysis of the results will be given. Finally, conclusions will be drawn and suggestions for future research will be made.

2 Background

The responsibility of the safe completion of each flight rests with the pilot-in-command. In an emergency situation, this can be a very challenging task. The pilots must monitor the aircraft systems, detect and resolve any failures, control an aircraft with possibly degraded performance, as well as coordinate with the cabin crew, airline dispatchers, and air traffic control. In addition to these tasks, the pilots must also plan and execute a trajectory that will result in a safe landing. These tasks are made even more difficult by the circumstances. For example, the pilots may feel a sense of physical danger, or the cabin environment may be a distraction due to smoke, heat or noise. Additionally, the aircraft's performance may be affected, resulting in degraded or inadequate handling qualities. This limits the relevance of past experience to the current situation.

In order to understand the some of the difficulties that these circumstances present, a number of cognitive engineering models have been developed in the literature and are briefly reviewed in this section. The complex nature of the decision making task can be described using the Naturalistic Decision Making (NDM) framework. Zsambok [3] describes NDM as, "the way people use their experience to make decisions in field settings." Experts are often able to make excellent decisions based on experience and intuition. However, stress can have negative effects on the decision maker's cognition. The Cognitive Control Model (CCM) describes how the context of the emergency dictates the way in which the planning task is handled [4]. This model describes the degree of control a person has as dependent on the context of the situation. The degree of control is determined in large part by the amount of subjectively available time that the pilot perceives, and the familiarity of the situation [5].

Subjectively available time refers to the amount of time that a person perceives that he or she has available to take appropriate action. The amount of time perceived may depend on the objective amount of available time, the predicted changes in the system, the person's level of arousal as well as other factors. The degree of control is discretized into four control modes: scrambled, opportunistic, tactical, and strategic.

The simplest and most dangerous mode is the scrambled mode, which generally represents a person in a state of panic. When a pilot is in this mode, he or she is effectively paralyzed and actions are not part of a plan, and may be unpredictable or irrational, resulting in a lack of control. When a pilot has adequate subjectively available time, his situation may be described by the tactical mode. In this mode the pilot has a greater sense of control. The pilot is more likely to develop a plan or modify an existing plan in order to fit the current situation. The resulting plan may take into account the potential effects of candidate actions. This mode corresponds to "normal" performance. During an emergency situation, a pilot's control mode will be somewhere in between the scrambled and strategic modes, described by the opportunistic mode. In this mode, pilots may use the plans and procedures available to them; however, they may not be used correctly.

The amount of subjectively available time that a pilot perceives may be influenced by a number of factors. These include phase of flight during which the emergency occurs, the type of emergency, the number of actions the pilot is required to complete, and the stress level. This stress may be physical, such as smoke in the cabin or loud noises, or it may be psychological, such as the fear of impending danger.

The stress of a situation impacts the manner in which the pilot makes decisions. While the pilot may be able to quickly develop a plan of action based on experience and intuition, stress can lead him to fixate on one solution, and fail to compare alternatives [6, 7]. Additionally, the pilot may simply increase the speed with which he processes information, potentially leading to errors. He may also reduce the amount of information that is sought and processed, known as filtration [8, 9].

Stress may also lead the pilot to rely too heavily on an automated tool. He may assume that a plan generated by automation is best, without verifying its feasibility or exploring other options [10]. Also, the pilot may seek only information which confirms the automation-generated solution as the best, while discounting other information (confirmation bias). Alternatively, rather than simply discount conflicting information, he may attempt to mentally force all available information to fit the automation-generated solution (assimilation bias)[11]. These stress-related factors can cause pilots to make poor decisions, despite the fact that they would be able to make acceptable decisions under normal circumstances. These poor decisions may cause incidents to become accidents.

3 Review of Accidents

Between 1997 and 2006 there were a total of 89 fatal accidents on board commercial jet aircraft worldwide [12]. More than fourty percent of these accidents categorized as either "Loss of Control - In Flight" or "Controlled Flight into or Toward Terrain." Some of these incidents may not have become fatal accidents if the pilots had been able to quickly plan and execute a satisfactory trajectory in order to complete a safe landing.

One such example is the crash of Swissair flight 111, which encountered smoke in the cockpit during its flight from New York to Geneva (see Figure 1). When the pilots noticed the smoke, they declared an emergency. After making an initial turn toward Boston, the controller recommended that they divert to Halifax instead. It was four minutes later when the pilots received the Halifax approach plates and realized that they were too high and needed to lose altitude. So they decided to circle around and dump fuel near Peggy's Cove, Nova Scotia. After the aircraft had turned away from the airport to dump fuel and lose altitude, the fire spread and disabled a number of aircraft systems, which led to the aircraft crashing into the water. It is possible that if the pilots had initially recognized Halifax as the most appropriate landing location and been able to quickly devise a trajectory to land there, then the plane may have been able to land before the fire disabled the avionics systems.

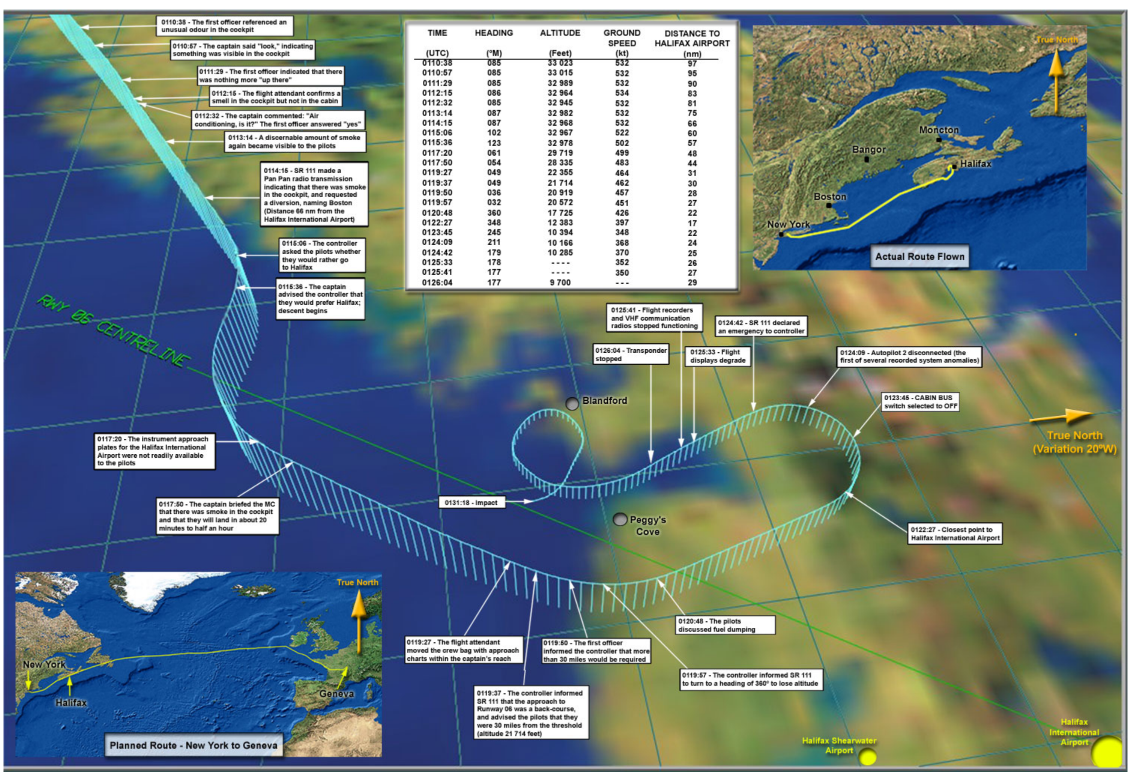

Figure 1: Flight path of Swissair Flight 111. Taken from [13].

As the previous example illustrates, once an emergency has occurred on board a civil airplane, the selection of a landing site and a safe trajectory to that site are of critical importance. The pilot's high workload and a human's limited computational capacity obviate the need to provide automated assistance. However, the highly complex nature of the selection and planning tasks, as well as the uniqueness of each emergency, makes automation difficult. The input and oversight of a human operator is required.

4 Related Work

In order for an automated planning aid to be most useful, there are at least two primary tasks which it must be able to accomplish; first, it must be able to accurately predict the most appropriate alternative landing site, as well as the most efficient trajectory to land at that site. The completion of this task requires that the aid determine the overall feasibility of a trajectory, avoiding the case of a controlled flight into terrain because of not reaching the destination, or overshooting it. A feasible trajectory must also avoid obstacles, which may be static, such as a mountain, or dynamic such as a severe weather system. The consideration of static obstacles avoids controlled flight into terrain, whereas the consideration of dynamic obstacles avoids accidents as a result of flight into convective weather. The determination of such a trajectory must be made by taking into account the aircraft's abnormal aerodynamics. Finally, the trajectory must minimize the time to land, which is important in all cases, such as the aforementioned Swissair accident. The second task an automated planning aid must be able to accomplish is to provide an interface with the pilot through which information is shared in both directions. Most research to date has primarily focused on one or the other of these tasks.

The landing site selection task has been suggested as a candidate for automation. Atkins, Portillo and Strube [14] have developed a method to complete this task. First, the footprint containing all feasible landing sites is calculated. Then the list is prioritized according to a number of weighted criteria, such as runway length, airport facilities available, etc. In their research, the authors choose example values for the criteria weights, but acknowledge that the criteria weights would ultimately be based on expert knowledge and would vary by emergency type.

The need for the pilot and the automated planning aid to interact with each other has also been investigated. The Emergency Flight Planner (EFP) by Chen and Pritchett [2] has been proposed as a prototype interface between the pilot and an aid. The EFP is designed to allow the pilot to easily enter a plan. The ensuing trajectory is then predicted and evaluated. The EFP also provides an additional mode, in which the pilot is presented with a preloaded trajectory, which he may then accept, modify, or delete. The results of testing with the EFP emphasized that generated plans must incorporate the structure and objectives used by pilots in order to be effective.

Research by Layton, Smith and McCoy [15] in their study of a cooperative problem-solving system for en-route flight planning investigated three possible system modes of pilot-system interaction. In that study, pilots and air traffic controllers were both used as subjects. The study evaluated three possible modes. The first mode was a sketching-only system, in which a plan devised by the subject was evaluated by the system and feedback was provided. The second was a sketching system with the additional capability for the user to specify constraints on the plan and allow the system to propose a solution which matched those constraints. In the third mode, the system proposed a plan based on system-specified constraints. The results showed that in the second and third mode, users explored more possible options; however they were also biased toward the system-generated alternative. The same study also highlighted the fact that the use of a fully automated aid could be detrimental if it performs suboptimally.

The previous results show that in order to increase the usefulness of an automated planning aid, the process by which pilots select an alternative landing location and plan a path must be better understood. In addition, it must be understood how the pilot can best be aided by such a tool. It is expected that an aid that accepts and provides information in a manner that is most consonant with the pilot's mental process will be most effective. The results of the current paper will be useful for the design of a suitable interface by determining the most important inputs to the system, as well as the most useful format for the output.

5 Commercial Airline Pilot Survey

A survey was conducted by the authors in order to better understand the tasks and priorities of pilots during an emergency situation. The first section of the survey was intended to elicit information about the primary factors that pilots consider in the process of planning a landing trajectory. This involves choosing the most appropriate destination at which to land, and then determining a trajectory to reach the ground safely. The trajectory planning task also requires attention to certain en route considerations, such as severe weather and hazardous terrain.

The first section of the survey was structured to cover two general types of emergencies: 1) a performance altering scenario, in which the aircraft's performance was non-nominal, and 2) a non-performance altering scenario, in which the aircraft's performance was normal, but an immediate landing was necessary. For the non-performance altering scenario, the participants were presented with the following information:

> You are the captain of a civil transport aircraft. A fire has been detected in the

> cargo hold. The appropriate checklists have been performed, but the fire has not been completely extinguished. The first officer is controlling the aircraft, allowing you to plan a course of action.

For the performance altering scenario, the participants were presented with the following information:

> You are the captain of a civil transport aircraft. The right engine of your twin-engine aircraft has failed. The appropriate checklists have been performed. The first officer is controlling the aircraft, allowing you to plan a course of action.

The same set of questions was used in each of the two scenarios. The performance altering scenario also included an additional question, which addressed how the pilot would assess the feasibility of a trajectory given the aircraft's degraded performance.

The second section introduced the concept of an Automated Planning Aid (APA). The questions built upon the performance altering scenario from the first section, with the following additional information:

> Now an Automated Planning Aid (APA) is available to assist you with the selection (and perhaps execution) of a suitable plan of action.

This section was intended to obtain information about how the participants might use an APA. In particular, how participants prefer to convey information to the APA and furthermore how they prefer to review the information provided by the APA. Finally, this section presented questions meant to ascertain the amount of confidence that participants would have in the APA.

The third section was designed to collect further information about how an APA might be used. The participants were presented with the following information:

> Consider an emergency scenario which is unforeseen (i.e., you have not received any pertinent training). The aircraft's performance is now altered and/or degraded in some way. You are the captain, and the first officer is controlling the aircraft, allowing you to plan a course of action. In this scenario you do not have an Automated Planning Aid (APA) available to assist you.

This scenario was included because it provides some insight into how the participants will make a plan in a situation where they cannot rely on any prior training or procedures to guide them through the process.

The final section included general questions about the participants' opinions of the proposed APA concept. These questions asked about the scenarios under which the participants would be more willing or less willing to seek help from an APA and how the participants would like the plan to be updated. This section also included biographical questions in order to determine the demographic make up of the participants.

5.1 Methodology and Participants' Profile

The survey was conducted using an on-line service. The service was used to create, format, and monitor the survey. It was also used to host the survey and collect responses from the participants. In order to generate responses from several airline pilots, a link to the online survey was distributed via email to a number of pilots. In addition to the email, a link was posted on the airline pilot association's message board requesting participation. Responses were collected over the course of approximately six weeks between August and September 2008.

Responses were received from twenty-one participants. One of the respondents declined to include biographical information, however all twenty-one responses were used in the results. The demographic analysis therefore only includes twenty respondents. All participants held the position of either captain or first officer and had been in their current position for an average of 9.5 years. Eighty-five percent were flying a Boeing aircraft (737, 757, 767, or 777) at the time of the survey. All pilots had at least 6,500 flight hours with an average of 12,979 flight hours.

6 Results

Due to the small number of responses, slight variations in the number of responses for a given option were neglected as statistically insignificant. However, each question also included an open-ended option where the participants were free to provide more information. These responses often provided additional valuable insights into the participants' thoughts that could not be captured by the multiple choice responses provided.

The first section of the survey included a set of questions about how pilots currently make decisions in an emergency situation. The question set was first given for a non-performance altering scenario, and then repeated for a performance altering scenario, as described previously. Participants were asked to indicate the priority (high, medium, low, or not a consideration) associated with a number of factors when choosing the airport to which the respondent would divert. Under the non-performance altering scenario, the most important factor indicated was the proximity of the airport in terms of time. Weather conditions at the airport, the length of the runway and the proximity of the airport in terms of distance were also given relatively high priority. These results can be seen in Figure 2. Under the performance altering scenario, the results were largely the same; however the importance of proximity in terms of time was not differentiable from that of other factors, as seen in Figure 3. One free response comment for the non-performance altering case also indicated that runway lighting and the availability of navigational aids were additional important considerations.

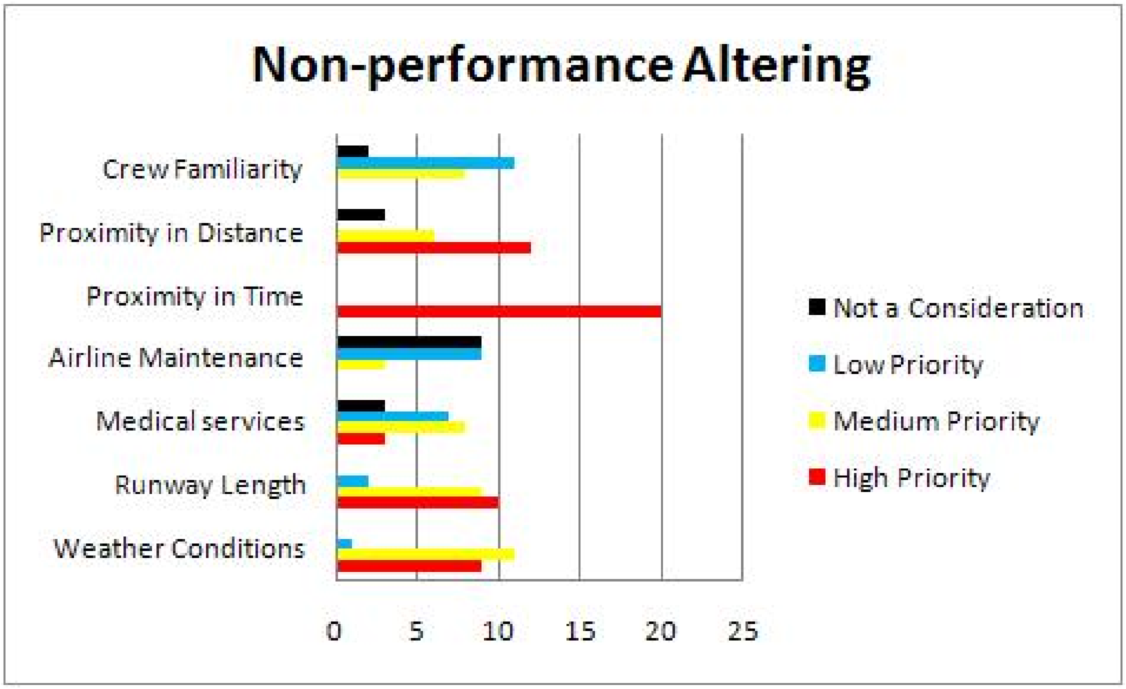

Figure 2: Prioritization of landing site criteria for non-performance altering case.

A similar question was posed for each scenario in which participants were asked to indicate the priority (high, medium, low or not a consideration) associated with a number of factors when planning a safe path. For both scenarios, en route weather and the avoidance of hazardous terrain were given the same priority, and low priority was given to traffic routes. This is not surprising because once an emergency is declared, the pilot need not comply with ordinary routes and approach procedures.

The performance altering scenario differs from the non-performance altering scenario in that the pilot's experience and knowledge of the aircraft may have limited applicability to the current situation. For this reason, the pilot's "first instinct" may be the best plan given normal performance, but may not be feasible given the degraded capabilities of the aircraft. Participants said that they were most likely to judge the feasibility of a maneuver by running the scenario mentally or seeking help from the dispatcher. Many pilots would also consult the performance manuals. These responses indicate that an automated planning aid may be

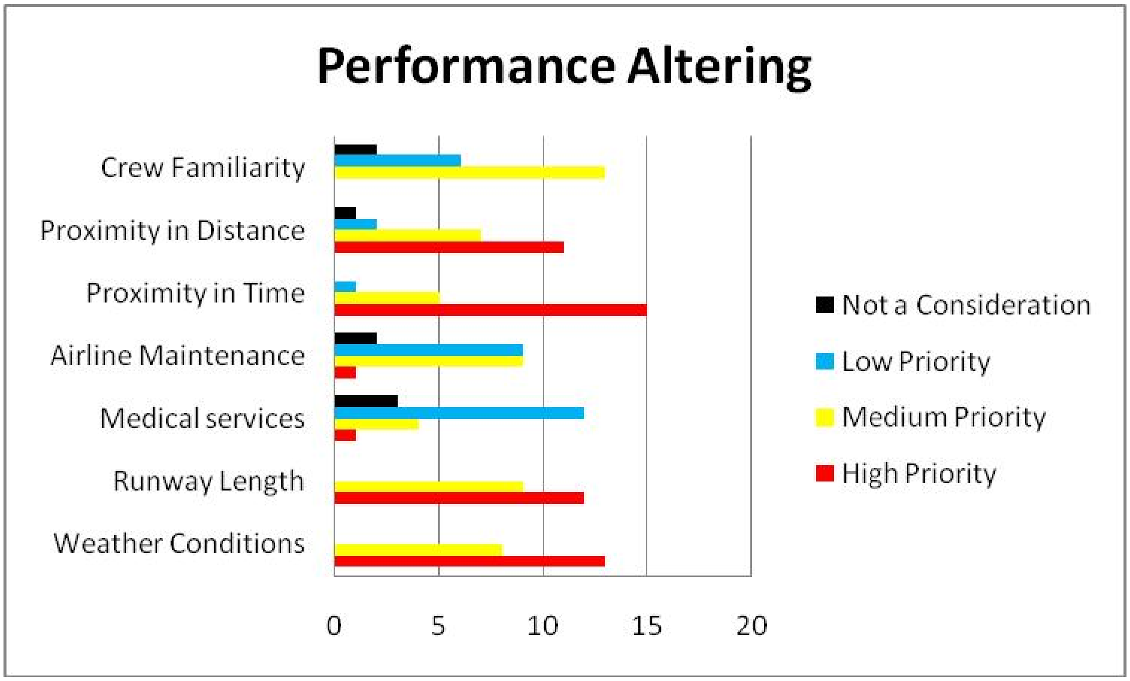

Figure 3: Prioritization of landing site criteria for performance altering case.

particularly helpful in situations where the aircraft's performance is not normal.

Participants were then asked to consider whether they would completely determine a plan before taking any action. The alternative would be for the pilot to alter the current course immediately based upon his "first instinct." Many of the respondents took advantage of the open-ended option to describe some other considerations that affect how they would proceed. For instance, when flying in a mountainous area such as Quito, Ecuador, planning ahead is essential. Others indicated that they would first coordinate with Air Traffic Control (ATC) before taking action or completing a plan of action. Those who would first take some action responded that they would all turn toward the nearest airport. None would begin descending. For the non-performance altering scenario, most of the pilots reported that they would change the current course immediately. However, in the performance altering scenario, most would develop a plan first before altering the current course. This may indicate that pilots are more comfortable taking immediate action in a more familiar situation, as opposed to a novel scenario. For instance, pilots have trained for an engine failure scenario and would have a relatively good idea of how to control the aircraft. However, in the event of a control surface malfunction, they would not be as familiar with the aircraft's post-failure performance and may be less likely to take immediate action before planning.

The final question of this section addressed the parts of a potential plan with which the participants would be most careful (i.e., provide more specific attention, add more detail, etc.). The pilots were asked to indicate the priority (high, medium, low, not a consideration) associated with portions of the plan. The results are shown in Figures 4 and 5. In both scenarios, pilots reported that the highest priority is around severe weather and hazardous terrain. Medium priority was given to the area around the aircraft's current location. In the case of the performance altering scenario, medium priority was also given to the area around the destination.

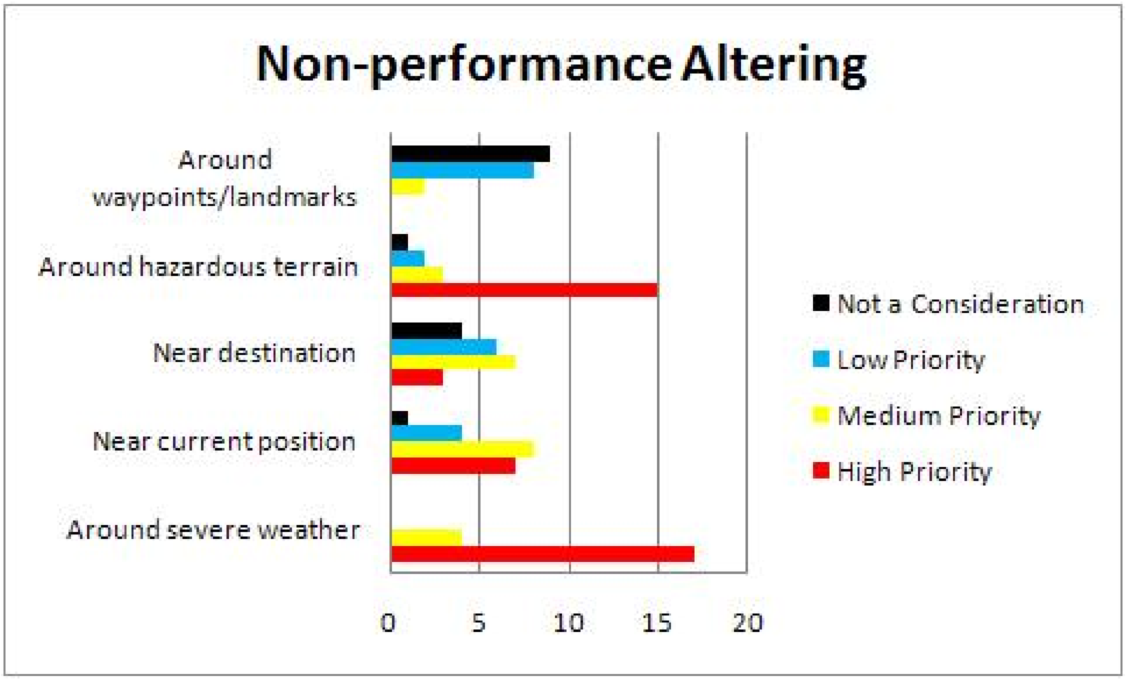

Figure 4: Parts of the plan pilots consider with detail for non-performance altering case.

The first questions of the section dealing with an Automated Planning Aid (APA) address the interface between the pilot and the APA. Pilots described a number of inputs as either highly preferable, somewhat preferable or not preferable. Pilots will need to be able to provide priority information to the APA in order for it to be aware of the current situation. Participants indicated that they would prefer to accomplish this either through the Flight Management System (FMS) pages, through a separate dedicated interface, or through a data link from the airline operations center. When the APA has developed a plan, the pilot must be able to review this plan. The respondents indicated that they would prefer to review the plan as a set of automatically generated FMS entries. The pilots would also favor a horizontal graphical representation of the proposed trajectory, possibly accompanied by a vertical profile of the proposed trajectory.

In order to effectively evaluate the proposed plan provided by the APA, pilots will have certain metrics in mind which will be used to make the evaluation. Participants were asked to indicate how important certain metrics are when evaluating the plan (highly important, somewhat important or not important). The most important metric was the cumulative

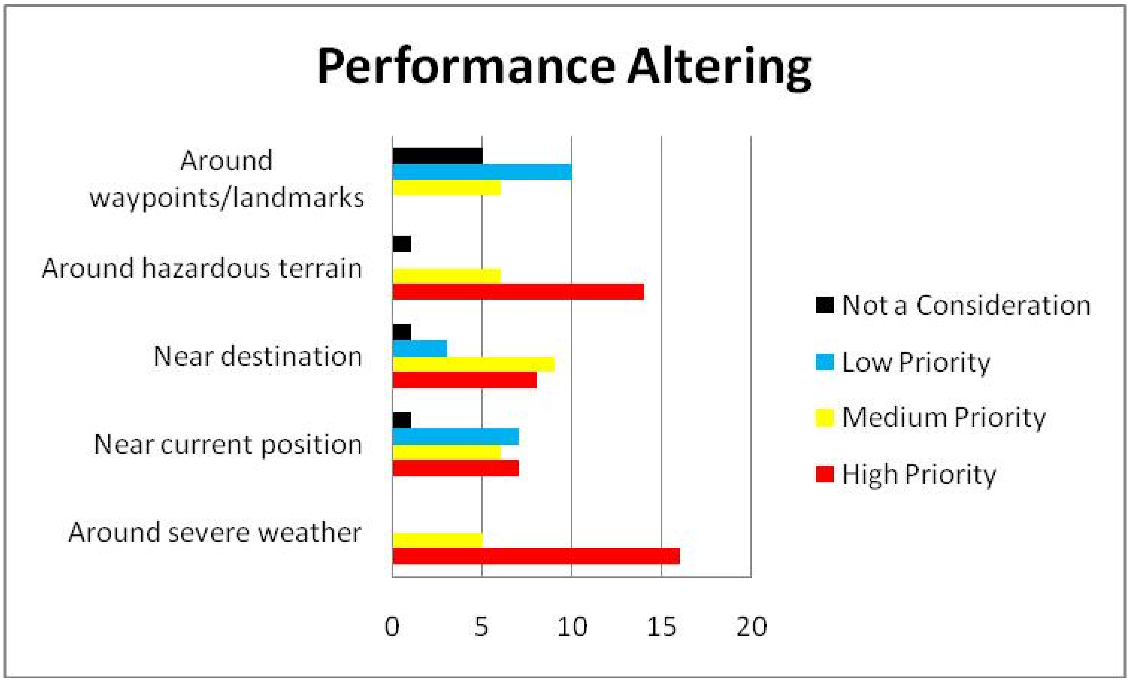

Figure 5: Parts of the plan pilots consider with detail for performance altering case.

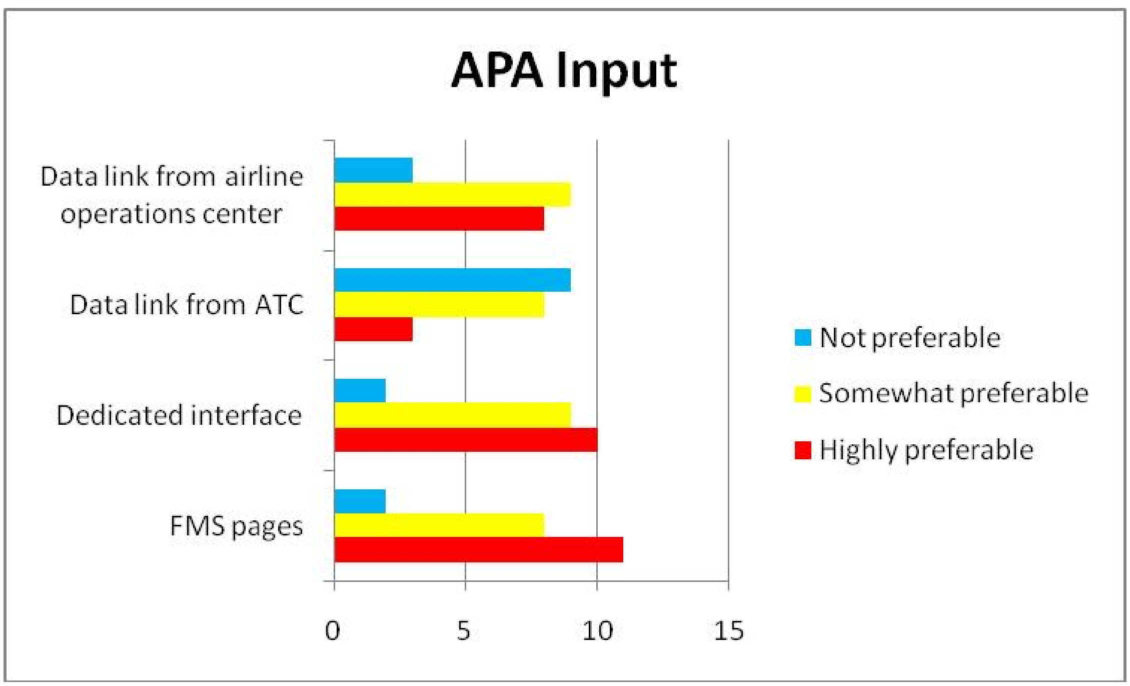

Figure 6: Preference for APA method of input.

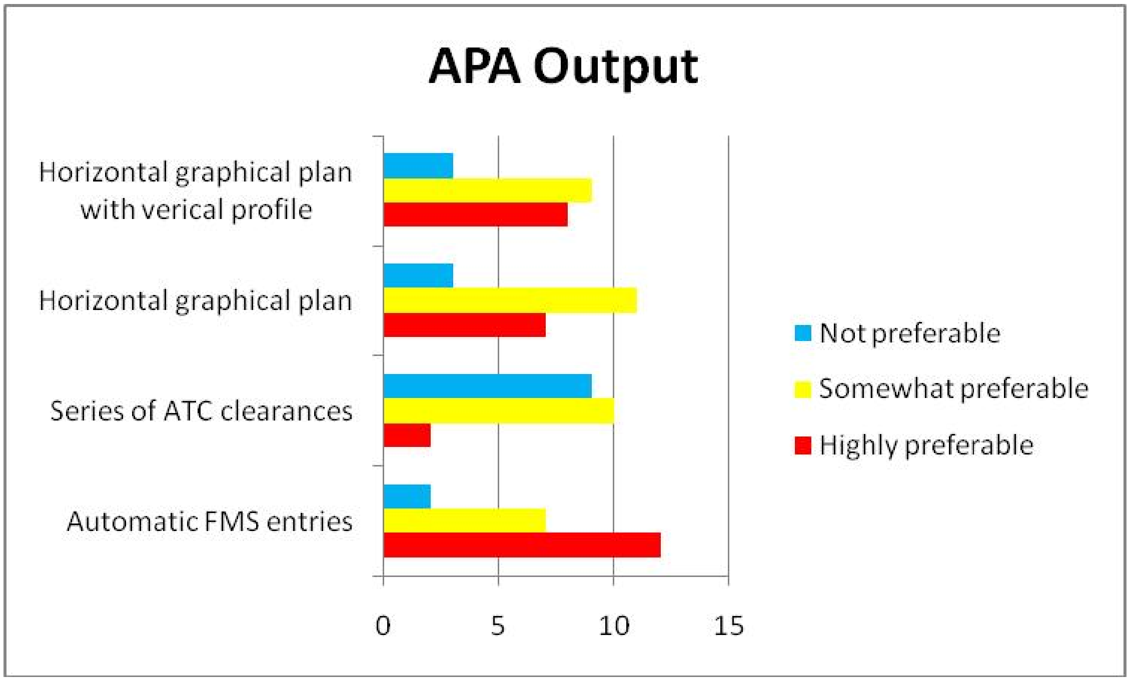

Figure 7: Preference for APA method of output.

time/distance and fuel information. A comparison against alternatives was also considered an important metric.

Responses showed that the pilots will not unconditionally follow the plan generated by the APA, especially if the plan if different from their "first instinct." Most participants said that they would follow an APA-generated plan that was different from their own when the APA plan required a significantly shorter amount of time to execute. Some pilots also said that they would follow the APA plan if it remained well within the flight envelope limitations and encountered significantly less severe weather. Nearly all of the pilots indicated that they would only use the APA-generated plan as an aid; that is, they would take it into account while re-evaluating their own plans of action, but would neither completely accept nor reject an APA-generated plan.

In the final section, the participants were given an unforeseen emergency, as described previously. As in the performance altering scenario, the majority of respondents would completely develop a plan before altering their course. Many participants again took advantage of the open-ended response option to indicate that the primary factor in deciding whether to take immediate action would be the urgency of the situation. Of those who would immediately alter the current course, most would turn toward the nearest airport.

In a situation in which the pilot has accepted the plan, but has deviated from it, a new, more efficient, plan may be calculated as a result of the deviation. Pilots were asked to choose

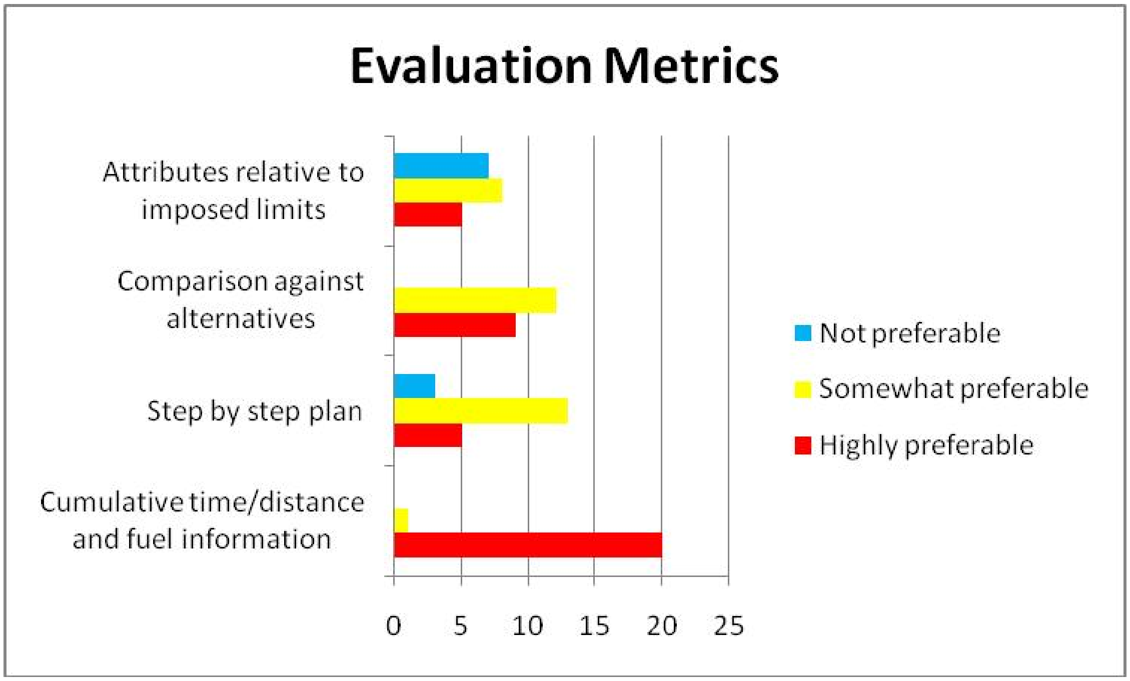

Figure 8: Metrics used to evaluate a plan.

between a number of conditions under which they would like for the APA to provide a new plan. The results are shown in Figure 9. Most pilots indicated that they would prefer to only receive a new plan from the APA when they asked for one.

Not surprisingly, the majority of pilots reported that the situation in which they would be most likely to rely heavily on the APA is one for which they have not had any prior training or experience, as shown in Figure 10. Some indicated that they would not rely on the APA in either a familiar or unfamiliar situation, while others said that they would rely on the APA in both situations. This may be due to the lack of clarity with regard to reliance. It seems, based on these comments, that many of the pilots would use the APA as an aid, but they would be hesitant to simply follow its plan without some verification of their own.

7 Analysis

The multiple choice nature of the responses made the mathematical results simpler to discern; however, the more enlightening portion of the responses were the open-ended options, which allowed the participants to include their thoughts on each of the questions provided. These responses provided insights into the pilots' expectations about how an APA should function and how it could be most useful.

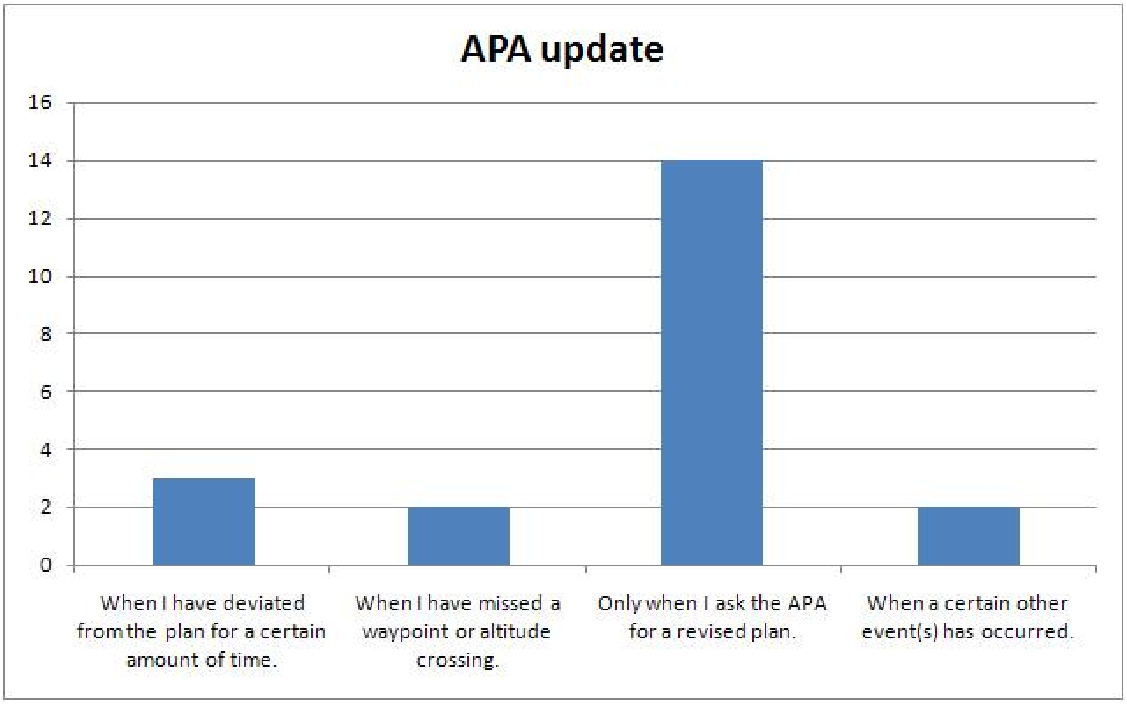

Figure 9: Conditions under which the APA should provide an updated plan.

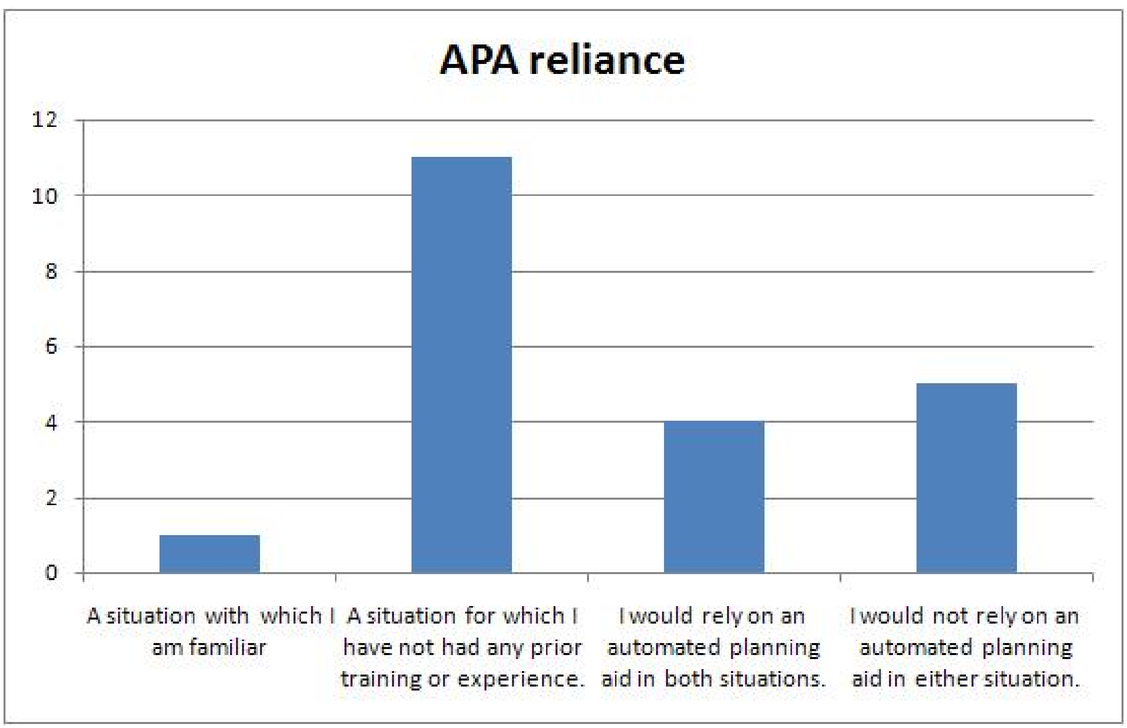

Figure 10: Situations in which an APA would be most heavily relied upon.

As mentioned previously, the pilot's workload is very high during an emergency. A number of comments indicated that pilots are wary of any factor(s) that would necessitate more work during a stressful time. This is reinforced by the respondents' preference for interacting with the APA through the FMS, a device they use for other purposes, and with which they are familiar. Most participants preferred to review the plan as automatically-generated FMS entries, which would allow the autopilot to follow the APA path with very little additional work required by the pilot. Respondents emphasized that the APA should be an efficient source of information which is currently disparate, if available at all. One pilot commented that, "it should offer information, but not demand any acceptance or response."

In general, commercial pilots have a good working knowledge of the areas in which they normally fly. For this reason, the pilots' "first instinct" is often very good. The results concur with this conclusion, as evidenced by the fact that pilots were more likely to alter the current course without a complete development of a plan in the non-performance altering case and much less so in the unforeseen case. A number of comments revealed that in some cases pilots simply need a tool to validate their plans and point out to them any options that they may have missed. A tool such as this may have been helpful in the case of Swissair flight 111, which initially turned toward Boston when an emergency was declared despite being closer to Halifax, Nova Scotia [13].

When determining the best landing site, as well as the best path to that site, a number of pilots found the list of factors provided to be insufficient. Certainly, the factors mentioned are important, however, some comments emphasized the reliance on outside sources. Once an emergency has been declared, pilots work very closely with Air Traffic Control (ATC) to receive their input to determine the most appropriate path. Pilots' comments also indicated that they will seek advice from the airline dispatcher in order to determine the most appropriate landing site. The scenario for which the pilot has not had any training or prior experience garnered a number of additional comments. These emphasized the interactive nature of the planning task by pointing out that the process must include ATC, airline dispatcher, other crew members, and possibly the manufacturer.

Many comments addressed the role of the APA in the planning process. In addition to keeping the workload as low as possible, many pilots do not want to view an APA-generated path as a directive. Rather, they prefer to view it simply as one input into the process of developing their own plan. This supports the result seen previously in the literature, in which nearly all participants said that they would take the automated plan into account while re-evaluating their own plan. The comments emphasized that the path planning task is complicated and that the automated tool may not have the ability to gather a complete understanding of the situation at hand. These comments imply that pilots would like to have an APA that makes critical information easy to access in a timely manner, but which does not dictate actions for the pilot to follow.

Due to the uniqueness of each emergency, one respondent proposed an approach which would likely be supported by other pilots. The pilot said, "You should be able to manipulate individual variables and compare solutions." The priority of certain criteria may change, depending on the emergency, and pilots need to be able to indicate this to the APA. For instance, airport fire and rescue services are more important in a fire emergency. Runway length may be more important in a flap or landing gear malfunction. The recognition that there are a number of variables which must be taken into account was echoed by a number of comments. Also, the ability to compare alternatives was considered an important metric.

A fundamental requirement of an APA is that the pilots must trust it and must be willing to use it. One pilot addressed this issue by saying that, "I must know how the automated plan is generated to be able to trust its output. Once I have confidence in the APA planning process, I would be more likely to trust its output, particularly in a time-critical emergency situation." This sentiment would surely be echoed by other pilots who will be hesitant to trust any tool with which they disagree. It is these disagreements that provide the usefulness for an APA; if the generated plan always agrees with the plan the pilot has in mind, then the tool has provided only a very limited service. However, if the pilot and the tool disagree, the tool must be able to demonstrate to the pilot that his plan can be improved upon. It must also be ensured that the pilot, working with the APA, does in fact generate a better plan than the pilot could on his own. This must be done without causing the pilot to completely rely on the system through biasing or over-reliance [16].

7.1 Criteria Weighting

In order for an Automated Planning Aid to develop a recommended path, the automation must be able to develop a prioritization among the possible landing sites. Such a prioritization may be based on the minimization of a utility function, such as Equation 1.

$$U = C_1 * \frac{t}{t_{max}} + C_2 * \frac{d}{d_{max}} + C_3 * \frac{r_{l,max} - r_l}{r_{l,max}} + C_4 * w_{wx} + C_5 * w_{cf} + C_6 * w_{med} + C_7 * w_{rep} \quad (1)$$

In this equation, the seven parameters are: time required to land t, distance from the current location d, runway length r_l, weather conditions w_{wx}, crew familiarity with the landing site w_{cf}, medical services available w_{med}, and airline maintenance and repairs available w_{rep}. The time t and distance d are nondimensionalized by their maximum possible values given the aircrafts performance t_{max} and d_{max}. The availability of medical services and airline maintenance are static attributes of each airport which could be encoded on a scale from zero to one. The value for the crew familiarity factor could also be assigned before a flight

	Nonperformance Altering	Performance Altering
Proximity in Time	0.21	0.19
Proximity in Distance	0.17	0.16
Runway Length	0.18	0.18
Weather Conditions	0.18	0.18
Crew Familiarity	0.10	0.11
Medical services	0.11	0.08
Airline Maintenance	0.05	0.10

Table 1: Resulting criteria weights based on survey results

by the pilots. The weather factor must be determined in real-time, based on the probability and severity of adverse weather conditions.

This leaves the determination of the criteria weights C_i. In the survey, each of the landing site criteria were assigned a priority; high, medium, low, or not a consideration. For this analysis, each of these options was assigned a value, three for 'high', two for 'medium', one for 'low' and zero for 'not a consideration.' The responses were summed based on the assigned values, giving a total for each criteria. In order to normalize these values, each was divided by the sum of the total scores for all criteria, as in 2. The subscripts of *score* in Equation 2 refer to the score assigned by respondent r for criteria i. The resulting values for the criteria weights are shown in Table 1.

$$C_i = \frac{\sum\limits_{r=responses} score_{r,i}}{\sum\limits_{j=criteria} \sum\limits_{r=responses} score_{r,j}} \quad (2)$$

This is just one possible utility function. There are certainly other criteria that could be considered. For instance, one comment indicated that runway lighting and the availability of instrument landing system equipment may also be taken into consideration. This survey has provided one possible starting point for the relative weighting of these criteria. However, the determination of the most appropriate weighting and utility function must be investigated further before it can be considered for implementation.

8 Conclusions

This paper has investigated the pilots' tasks in the event of an in-flight emergency, namely the tasks of choosing a safe landing site, and developing a safe trajectory to reach that site. The survey has produced results that give some perspective into the current methods and priorities pilots use to accomplish this task. Some insights into the manner in which an automated planning aid may be most effective have also been obtained.

During an airborne emergency, the need to land quickly is always of high priority. Therefore, the most important factor considered by the pilots when selecting an alternative landing site is proximity in terms of time. Additionally, the weather at the airport, the length of the runway and the distance from the current location are also important criteria. The most important en route factors are the avoidance of severe weather and hazardous terrain. However, each emergency presents a unique and complex scenario. When these criteria conflict with each other, the pilot must alter these priorities according to the situation at hand. It is the dynamic priorities based on situational awareness and experience that is difficult to capture and automate in a general sense.

A pilot's experience and expert judgment make him an effective decision maker in the face of emergencies. In a situation with which a pilot is familiar, such as a non-performance altering scenario, the pilot is more likely to make an accurate analysis and act quickly. Alternatively, in a situation with which he is unfamiliar, he will likely be more cautious and seek the assistance of an automated planning aid. In either case, an APA can be a valuable resource for the pilot to receive information and evaluate plans.

When the pilot is evaluating a plan, time is the highest priority. Therefore, the most important metric used is the cumulative time required to land. However, due to the complex nature of most emergency situations, tradeoffs should be allowable or even necessary. Consequently, the ability to compare a plan to other alternatives is also useful.

One of the most important aspects to be considered in an emergency situation is the high workload, time-critical, stressful nature of the situation. Accordingly, one significant feature of any proposed aid is that it should reduce workload, rather than increase it. The aid must provide useful information in a coherent manner, without burdening the pilot with requests. Similarly, pilots view the aid only as a tool, not as a directive. Pilots will use an automatically generated plan in conjunction with their own experience and intuition. Ultimately, the pilot has the final decision-making authority.

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