



The FAST Approach to Discovering Aviation Futures and Associated Hazards

Methodology Handbook

This work was prepared under the auspices of the Future Aviation Safety Team (FAST), a team associated with the European Aviation Safety Agency (EASA) European Commercial Aviation Safety Team (ECAST) within the European Safety Strategy Initiative (ESSI).

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Revision History:

Introduction

Executive Summary

The Joint Aviation Authorities, Europe (JAA) and the Federal Aviation Administration, USA (FAA) sponsor a number of groups to develop interventions aimed at improving safety of the global aviation system. To further this effort, in early 1998 the JAA launched the JAA Safety Strategy Initiative (JSSI).

The JSSI mission is the continuous improvement of aviation safety in Europe in particular and worldwide in general, leading to further reductions in the annual number of aviation accidents and thus fatalities, irrespective of the fact that air traffic will continue to grow¹.

Safety improvements are first achieved through identification of causal factors, or hazards, and then taking the necessary steps to eliminate, avoid, or mitigate these hazards. Hazards are defined as events and/or conditions that may lead to a dangerous situation or events and/or conditions that may delay or impede the resolution of such situations.

Three complementary approaches are used to identify hazards that affect safety of the global aviation system:

- The “Historic” approach is based on accident and incident investigation and analysis. It uses proven investigative techniques to discover all facts pertinent to a past aviation incident or accident, and thus identify opportunities for improvements meant to avoid future, similar accidents.
- The “Diagnostic” approach is targeted at identifying accident pre-cursors within the larger collections of information in various aviation safety reporting systems. There are many diagnostic processes being developed for application to the global aviation system.
- A “Prognostic” or “Predictive” approach is aimed at discovering future hazards that could result as a consequence of future changes inside or outside the global aviation system and then initiating mitigating action before the hazard is introduced. The prognostic approach is the subject of this document.

In 1999, the JSSI Steering Group established a dedicated working group to develop and implement methods and processes to support the systematic identification and resolution of these future hazards. That group is called the Future Aviation Safety Team (FAST).² This document describes the results of the FAST method for the discovery of future

¹ See: <http://www.jaa.nl/jssi/profile.html>.

² The European Aviation Safety Team (ECAST) and FAST are closely cooperating with the U.S. Commercial Aviation Safety Team (CAST). CAST is composed of members from government, industry and labour. CAST is focusing on analysis of causal factors of historical accidents, incidents and events to develop and prioritize safety enhancements which address identified problems. CAST is also evaluating implementation and related effectiveness of these enhancements. CAST is also moving from the purely historical approach to the development of an enhanced diagnostic approach. The FAST approach is complimentary to CAST.

hazards. The Future Aviation Safety Team core leadership team will be referred as “FAST” for the remainder of this document. FAST is constituted under the European Commercial Aviation Safety Team (ECAST) to support the continual efforts to improve the safety of the global aviation system as it evolves into the future.

Purpose: This Handbook is intended to:

1. Bring together the key elements of the FAST philosophy for understanding by the aviation world
2. Inform FAST “Customers” and “Stakeholders” regarding the FAST method
3. Serve as a reference guide for the FAST process

Global Aviation System

The global aviation system is really a “system of systems.” Examples of “systems” include airplanes, air traffic control systems, company processes, and regulatory systems. The future global aviation system will be fundamentally different than today’s global aviation system because future changes (both evolutionary and sudden) will be introduced continually. A change to any one system could affect other systems. Interactions of several future changes to several systems could likewise affect the whole. These changes could have unanticipated adverse implications to the safety of the global aviation system by creating “future hazards.” It is important that aviation practitioners who are designing future airspace systems have foreknowledge of those hazards. By “discovering” future hazards, those responsible for safe operation of the global aviation system will be able to eliminate, avoid or mitigate the safety consequences of these hazards. Challenges exist in doing so:

- The farther into the future one looks, the less distinct one’s vision will be.
- The future is not necessarily an extrapolation of the past, but knowledge of history can help to inform one’s view of the future.
- Once futures are predicted, hazards associated with each future can then be predicted using domain expertise or modeling and simulation methods.

The FAST Philosophy & Hazard Discovery Processes

In the context of this document, “hazard” refers to any issue or condition that either on its own or in combination with others has the potential to create a safety concern. The objective of any hazard discovery process is to make previously unknown hazardous conditions known. Once these are discovered, ensuing efforts to mitigate the unsafe condition can then be pursued. Historical hazard discovery processes inform hazard intervention processes so that risks can be managed to prevent future accidents. There are three distinct time domains in doing this hazard discovery work.

- **“Historic”** - Identifying existing hazards that have already caused accidents. After the occurrence of an accident, disciplined teams of government and industry specialists investigate to identify the causes(s) of the accident.
- **“Diagnostic”** - Identifying existing hazards before they cause an accident. Prior to an accident, discovery processes attempt to find existing hazards in the global aviation system. These can be termed, “diagnostic hazard discovery processes” because they use precursor and observational information to discover existing

hazards. Diagnostic hazard discovery processes inform diagnostic intervention processes so that risks can be managed to prevent the first accident caused by the discovered hazards.

- **“Prognostic”** - Identifying future hazards before they exist. Prior to a hazard being introduced to the global aviation system, discovery processes attempt to identify those hazards. These processes can be termed, “prognostic hazard discovery processes” because they use reasoning to understand future hazards before they ever exist. Prognostic hazard discovery processes inform design processes so that the hazards can be eliminated from the future, avoided in the future, or mitigated in the future. This is the heart of the FAST philosophy.

Figure 1 illustrates the various states of hazards and how these states relate to discovery and intervention processes. Figure 1 illustrates how FAST fits into the hazard-discovery processes within the global aviation safety system.

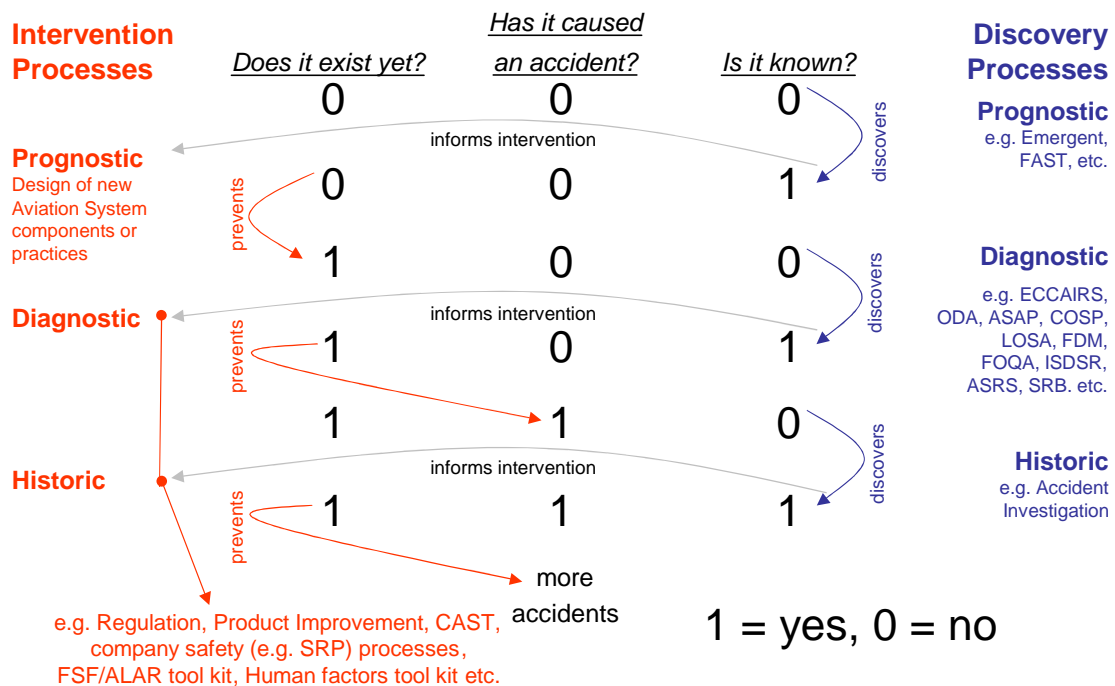


Figure 1 – Hazard States, Discovery and Intervention Processes

In the past, historical and diagnostic hazard discovery processes could keep up with the expectation of society for aviation safety. However, the future aviation system will be stressed in new ways. There is an evolving belief among aviation professionals that an additional prognostic process could more effectively and efficiently prevent future hazards from causing accidents. Ideally, the aviation community will anticipate potential safety hazards before they appear. Those hazards can then be eliminated, avoided or mitigated.

- The future is not necessarily a direct extrapolation of the past. Present and near-term safety interventions that are intended to prevent future accidents caused by previously known hazards may not be enough to prevent new types of accidents from happening in the future.
- A mid-1990's study by a major manufacturer looked at accidents where the airplane systems were involved in an accident or where they could have prevented the event and did not. It was found that in approximately 70% of the accidents involving airplane systems, the original design assumptions were inadequate for the situation existing at the time of the accident due to changes in:
 - the aviation system,
 - airplane operational usage,
 - personnel demographics,
 - evolving infrastructure or other considerations
- The pace of significant changes affecting the aviation system is more rapid than ever before and continues to accelerate. Examples of accelerating changes include the imminent introduction of hundreds of Very Light Jets (VLJ) and Un-crewed Aviation Systems (UAS), Supersonic Business Jets (SBJ), new airline business models, the soaring rate of patent applications and associated litigation, deployment of ever more complex software systems, publishing of certification guidelines for space tourist vehicles, and advanced Communication, Navigation, and Surveillance (CNS) technologies. The FAST method was developed as a proactive, predictive means to identify future hazards that have yet to appear, because the corresponding changes to the aviation system have not yet been implemented. Application of the FAST method will result in the following:
 - A vision of a particular aviation future in question. This vision must be sufficiently precise to allow the discovery of any associated future hazards.
 - List of these future hazards
 - A set of indicators or "Watch Items" that help to indicate which possible aviation futures of interest may be unfolding,
 - Recommendations for actions to take that may prevent or avoid future hazards or mitigate their effects, and
 - An assessment of how proposed hazard mitigations may be affected by the future in which they will be immersed.

Many prognostic hazard discovery processes exist today. For instance, during the design of a new airplane, a manufacturer will spend a substantial amount of engineering effort to identify previously unknown hazards that may be unique to that new design. Building on past experience, using expert understanding of the proposed design, as well as expert conjecture regarding associated hazards, the manufacturer will identify hazards, and then work to eliminate, avoid or mitigate those hazards in the final design. FAST augments existing hazard identification techniques. It doesn't replace them. The FAST method fills gaps in existing processes for identification of novel hazards by taking into account an inventory of future changes within and external to the aviation system. It utilizes these future changes to systematically assess the accumulation of interactions that can create new failures or increase the severity or likelihood of existing ones.

The FAST method augments that process by expanding the search for future hazards beyond just the design of a new aircraft. For example:

- The FAST method encourages consideration of the effects of hazard introduction across the global aviation system, not just within the system for which future change is being considered.
- The FAST method uses the concept of “Areas of Change” (AoCs), considering that several possible futures may interact with the future under study, producing unanticipated hazards. For instance, the future will likely feature the gradual phase out of early-generation jet transports (AoC “a”) coupled with the advent of fleets of micro-jet personal aircraft (AoC “l”). Figure 2 illustrates the concept of how Areas of Change ebb and flow with time and how different futures are composed of different sets of Areas of Change. Areas of Change are the future backdrop, context or milieu in which proposed new concepts, technologies and procedures will be immersed. The current repository of FAST AoC’s can be viewed on the FAST web site at <http://.....>. New AoC’s that come to the attention of aviation professionals should be communicated to FAST via the process shown in Annex VI.
- The FAST method augments functional hazard analyses by providing a method for creative identification of hazards that a strict task analysis may not reveal. In some cases functional descriptions of system operation may not be complete. Indeed, a complete functional description may be excessively complex. If complete descriptions could be written, they might be so complex as to defy analysis. Examples of this include the cultural, legal, economic, and demographic backdrop in which the operational world is immersed, emergent behavior such as complacency or fatigue among human actors in aviation that develops when the system and built-in safety protections are functioning properly, unintended uses of systems discovered and exploited by human/organizational users of the systems, and combinatorial failures such as simultaneous loss of situational awareness by an individual or team coupled with errors made by other actors.

Because changes in aviation affect the entire global aviation system, there is great value in having a global team dedicated to identification of aviation future hazards. The FAST and its sponsoring organization may be this nexus. If so, it must consider the following in supporting the safety of the global aviation system:

- The FAST method needs to be available worldwide.
- The FAST method needs to be available in a proprietary context, but ideally, those contemplating changes that would affect the global aviation system would permit everyone to help to build the future by broad and open FAST participation.
- Ideally, the FAST method will continually improve in both effectiveness and efficiency.

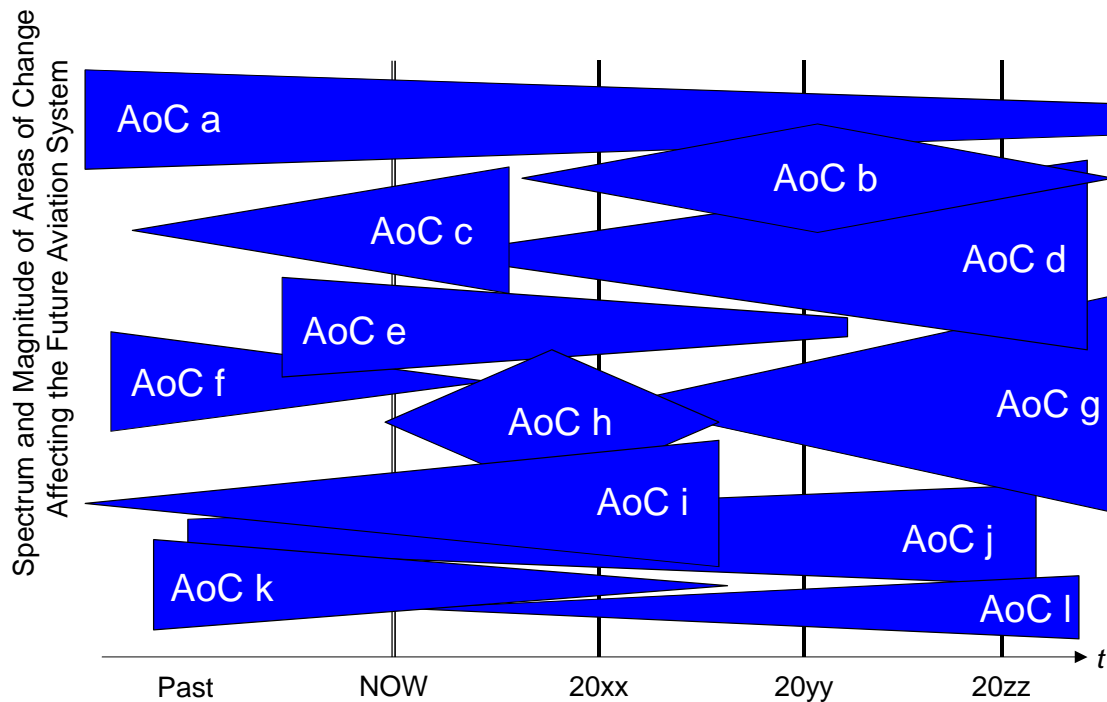


Figure 2: The concept of how Areas of Change ebb and flow with time

FAST Organizational Structure & Definitions

The FAST method will utilize a specific organizational structure to accomplish its mission:

The **FAST Core Team** made up of aviation system leaders to oversee the FAST process. Their oversight consists of guiding facilitators, maintaining the FAST knowledge bases, ensuring that the FAST method is continually enhanced, and ensuring that the FAST method is available to all who need to use it. The FAST aims to be a global center of excellence for prognostic hazard discovery in aviation. FAST functions:

- In cooperation with Fast Customers and Stakeholders, commission Expert Teams to perform Expert Team analyses for future changes.
- Manage and be responsible for the development of the FAST method. The FAST method, as it matures and the aviation world gains experience using it may evolve to be the premier means by which the aviation community does a better job of proactively discovering system-wide aviation future hazards.
- Enhance the FAST method based on experience.
- Guide FAST facilitators in their role.
- Maintain the FAST Area of Change (AoC) list (See Annex I).
- Prioritize AoCs in terms of importance for aviation safety and recommend AoC's that should be further analyzed.
- Maintain repositories of futures of interest, Watch Items and Recommendations.
- Respond to requests for information.

- Communicate clearly with Customers and Expert Teams.

FAST Expert Teams are made up of subject-matter experts from all necessary organizations to study specific futures. These carefully chosen and diverse small teams provide a robust view of futures and hazards. These Expert Teams are the next best thing to a “crystal ball” in prognosticating futures and hazards. An Expert Team is a panel of selected experts from Customer and Stakeholder organizations that is constituted on a temporary basis to address a specific envisioned future. FAST and the Customer collaborate to select the Expert Team, based on the envisioned future being considered. An Expert Team is selected based on specific expertise associated with the future being evaluated. The Expert Team members need not be experienced in the FAST method; the Expert Team consultants and facilitators will attend to those responsibilities.

FAST Consultant - One or more members of the FAST who work with the Expert Team to provide technical support on the FAST method. The Consultant(s) will help the Expert Team understand and follow the FAST method. Additional tools provided by the FAST Consultant could assist the Expert Team. It is recognized that the suite of tools will be continually refined and customized by the Expert Team. The Consultant(s) will provide a link between the Expert Team and the FAST.

The FAST Consultant should ideally have the following qualifications:

- Be commissioned and sanctioned by JSSI/FAST
- Be a member of the FAST Core Team
- Be an expert in the FAST process
- Be sensitive to Customer and Stakeholder issues
- Be quick to understand aviation technical issues
- Be agile of mind for the use of appropriate FAST tools
- Be willing to do the job for the long-term

FAST Facilitator - An individual that will help keep the Expert Team on track as they work toward their goal. A team of experts will have team dynamics in which some members will try to control the discussion and direction of the team. Less forceful members may not be able to present their views. The Facilitator’s knowledge of team dynamics will help ensure active participation of each member. Also the Facilitator will be responsible to limit extraneous discussion and keep the team focused on the task, act as a time keeper, synthesizer of ideas, etc.

The Facilitator should have the following qualifications:

- Be commissioned and sanctioned by JSSI/FAST
- Be viewed as impartial by all
- Be sensitive to Customer and Stakeholder issues
- Be broadly people-centered
- Be trained in group dynamics and leadership

Be willing to do the job for the long-term
Not necessarily be an expert in any particular area

The FAST method will support, and rely upon Customers and Stakeholders, defined as:

- **FAST Customers** are those individuals or organizations that have the authority to either recommend or implement changes to the global aviation system, or are curious regarding changes and the possible introduction of hazards. The “Customer” can also be the at-large aviation community that has a vested interest in safety assessments of transformational approaches being proposed for the air transportation needs of the future. The FAST Customer can be a person, an organization, or a consortium of organizations such as companies, regulatory agencies, or interest groups. Customers should have as a goal, the more effective and efficient elimination, avoidance or mitigation of future hazards based on changes they are considering. Success of the FAST method depends on a Customer asking a question regarding an envisioned future. Clear communication between the Customers, FAST, and the Expert Team is imperative. Simple can be very good! This is particularly true for communication of results.
- **FAST Stakeholders** are those individuals or organizations that may be impacted by an envisioned change to the global aviation system, but that do not have primary responsibility for the implementation of that envisioned change.

The FAST Process

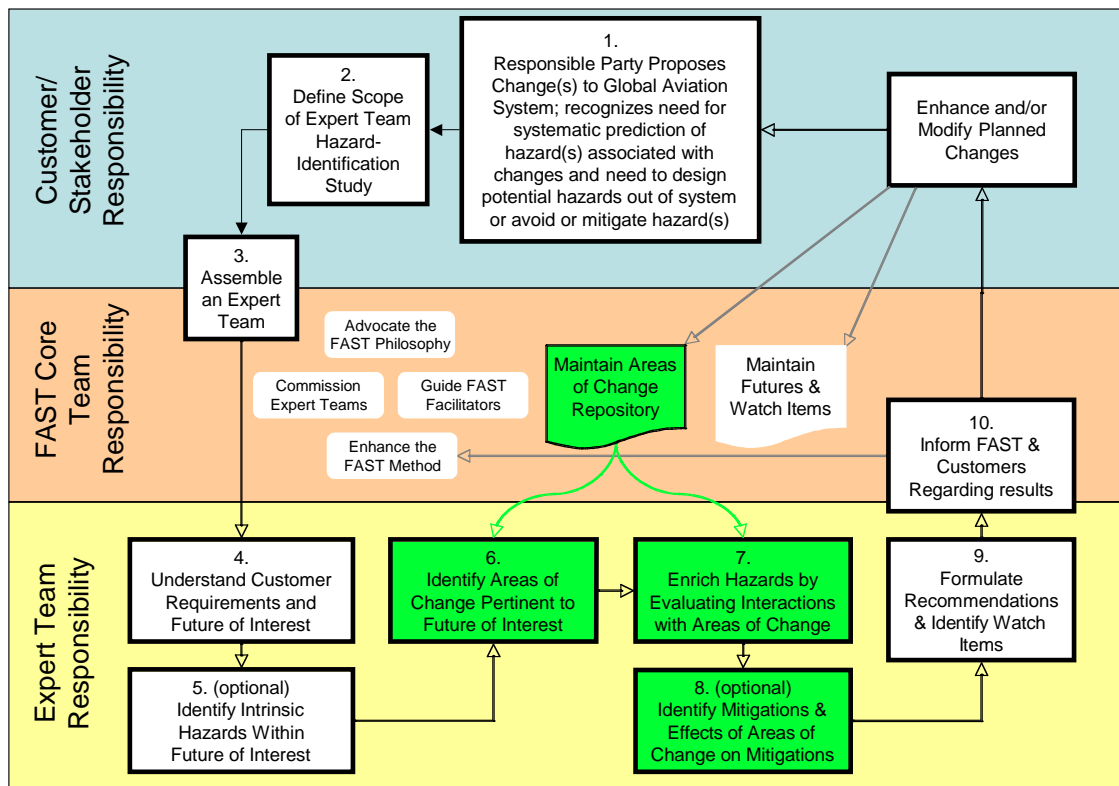


Figure 3: FAST Process for Determining Future Hazards

Step 1: Responsible Party Proposes Implementation of Change(s) to the Global Aviation System

For the Customer

Customer accepts responsibility for the consequences of implementation of global aviation system changes they are proposing – reference Figure 3. They recognize the need for systematic prediction of hazards associated with changes and to design those hazards out of the system or avoid or mitigate the hazard. Consider who the Stakeholders might be, then contact them. Contact FAST for assistance.

Again, a Customer can be a single person, an organization, or a consortium of organizations such as companies, regulatory agencies, or interest groups. If the Customer is a consortium, then the member organizations should assign key leaders who have the authority to work together to define the future in question to...

- work with FAST
- choose Stakeholder organizations
- choose Expert Team members
- define Expert Team deliverables

Step 2: Clearly Define Scope of Expert Team Hazard Identification Study

For FAST and the Customers and Stakeholders

Clearly define the scope of the Expert Team study. The Customer should document their:

- approximate future of interest; hereinafter referred to as the Future
- desired deliverables, including desired report structure
- schedule
- resources

The FAST will suggest name(s) for the FAST Consultant(s) and Facilitator(s) to be assigned to the Expert Team.

Step 3: Assemble an Expert Team

For FAST, assisted by Customers as necessary

Assemble an Expert Team:

- 8 to 10 individuals at most
- Individuals representing diverse perspectives
- Combination of visionary and operational experience
- Include at least one individual from each Customer and each Stakeholder organization
- Combination of engineering, operational, and human factors experience

Step 4: Understand Customer Requirements and Future of Interest

For the Customer and FAST Core Team

The Customer should thoroughly brief the Expert Team and FAST to communicate the identified Future – the full scope of what they plan to introduce in the future. Refine and describe in detail the intended vision of Future. See Annex II for guidelines for drafting a future scenario and an example “vision of the Future.” The following items should be agreed upon at this stage:

- Desired deliverables for the hazard analysis, including suggested report structure
- Schedule
- Resources

Two types of “futures” may be analyzed using the FAST method:

- Generic concepts such as introduction of technology components or systems, new operational concepts or novel business models.
- Specific event sequences such as the execution of a flight from point A to point B using new airspace management and air traffic control technologies and procedures.

In order to identify hazards that may develop when introducing new general concepts, the Customer should draft a concept description paper outlining the salient features of the

proposed novel technology, procedural implementation and/or human-systems integration.

In order to effectively identify hazards for event-sequence “futures”, the Customer should prepare in advance crisp, to-the-point narrative scenarios combining the overall Future and specific changes being proposed including potential branch points within the Future. For instance, future scenarios may be based on perspectives of...

- Pilots, air traffic controllers, dispatchers, etc.
- Airlines
- Manufacturers
- Maintenance Organizations
- Regulators/Certifier
- R&D organizations

Additional practical considerations for this and following steps are described in Annex III.

Step 5: Identify Hazards Intrinsic to Future (optional)

For the Expert Team

Identify the Hazards intrinsic to the Future. Based on the judgment of the Expert Team and the Future, select an appropriate hazard identification method (See Annex IV for hazard identification techniques). Identify “what could possibly go wrong?” when implementing a future technology system, a novel operational concept or new business model. Hazards identified must be associated with a clear and specific vision of the Future to be credible and be set in proper context. General and specific hazards may be related to:

- Systems integration gaps and overlaps
- Concept development, design, and production
- Human-human, human-systems, and organizational interactions
- Procedures and training
- Intersecting futures
- Operations including maintenance
- Decommissioning

Follow the hazard identification instructions of the selected method(s). To enrich hazard identification, more than one method can be used. Different methods may be suitable to different types of realizations (e.g., event chains, nominal and abnormal/emergency scenarios, process or system descriptions). Using more than one approach on diverse types of systems, concepts or models may reveal different types of hazards. Exemplar questions to be used for identifying hazards within the Customer Future are listed at the end of Annex IV.

The Expert Team should identify broad hazards across the various potential temporal domains of the Future (strategic, tactical and operational, for instance) for their element plus identifying associated new AoC’s & Watch Items that emerge during the discussion. To this point, the FAST hazards identification process is no different than

conventional preliminary hazard analyses (PHA).

Only to the extent that a particular FAST Area of Change represents the Future of Interest to the Expert Team are the AoC's used at this stage of the methodology.

NOTE: If the Customer has already performed a preliminary hazard assessment prior to their use of the FAST methodology, then simply skip Step 6 and proceed directly to Step 6, "Identify Areas of Change Pertinent to Future of Interest." If a decision is made to skip Step 5, then the target hazards to be enriched in Step 7 become those previously identified during the earlier Customer PHA.

Step 6: Identify Areas of Change (AoC) Pertinent to Future

For the Expert Team

The Expert Team (which has Customer representatives) should review the full Areas of Change list and make an initial assessment of which AoC's are most likely to be relevant to the generation of hazards within their Future. This is a critically important step because the change phenomena that are either ongoing or that lie ahead may be important catalysts for future hazards. The FAST should be available for consultation with the Expert Team at this stage in the event clarification of specific AoC's is required.

At this stage of the methodology, the Expert Team may wish to assemble a cadre of subject-matter experts to generate a supplementary list of detailed Areas of Change that are within the particular domain of interest. The general AoC list would be augmented and/or replaced by a specific list of AoC identified by the Customer. This list of supplementary AoC's should be as comprehensive as possible within the domain of interest and should be expressed at an appropriate level of detail. Thus, Areas of Change serve three distinct functions within the methodology:

1. A particular AoC may be so potentially disruptive to aviation safety that it should be the subject of its own safety analysis.
2. General AoC's serve as the context in which a particular concept of operation, technology, or set of procedures will be immersed. The ensemble of general AoC's may impact safety assumptions of particular Futures of Interest.
3. Detailed, domain-specific AoC's known only to subject-matter experts examining a particular Future of Interest may be used to enrich the hazard identification process described in subsequent steps of the methodology.
4. A particular AOC may not itself create hazards significant enough to trigger interventions, but may, when combined with other general/specific AOC's or dormant situations in such a way that interactions create a significant threat and require strong, pro-active interventions.

The Expert Team should utilize the following criteria for identifying AoC's relevant to the Future:

- Does this AoC increase the likelihood of well-understood current hazards that will exist in the Future?

- Does this AoC, create new hazards synergistically with other AoC's or with the Future that would not have come into being without the presence of the AoC?
- Does this AoC increase the subjective likelihood of Future hazards to an unacceptable level?
- Does this AoC create increased potential for human error, procedural non-compliance or equipment failure?
- Does this AoC decrease the resilience of the projected safety system?
- Does this AoC render the projected safety systems more brittle to off-nominal conditions?
- Does this AoC decrease safety levels during non-normal or emergency operations within the projected Future?
- What current and projected safety assurance measures within the Future may be lost or rendered ineffective as a result of this AoC?
- Does this AoC require creation of new control measures for critical aspects of the Future? Definition: A control measure is an action or procedure that will reduce, prevent or eliminate a potential hazard.
- Does this AoC adversely affect control measures, critical control points or critical limits? Definitions: A critical control point is a step at which a control measure is applied. A control limit is a maximum and/or minimum value for controlling a physical parameter.
- Will this AoC create new conditions that are currently not part of the design assumptions for the Future systems and procedures?
- Will this AoC result in decreased skill levels and judgment among operators of Future systems?

The objective of this stage of the methodology is solely identification of relevant Areas of Change, not identification of the hazards that result from the change(s). As mentioned previously, Areas of Change are the future backdrop, context or milieu in which proposed new technology systems, operational concepts, and procedures will be immersed. While an individual AoC may have characteristics similar to the Future of interest to a particular aviation constituency, the AoC's are intended to be generic descriptions of the various features of the future aviation environment.

Step 7: Enrich Hazards by Evaluation of Interactions with AoC's

For the Expert Team

Identify hazards generated by interactions between and among Areas of Change that could adversely impact the safety characteristics of the Future. The Expert Team should also attempt to identify and synthesize unusual patterns of AoC interactions that might not have detected if the hazard analysis had not been broadened by examination of the AoC's. A fundamental premise of the FAST method is that interactions and overlaps/gaps among the vision of the Future and the FAST AoC's are the most likely catalysts for revealing and understanding future hazards.

Considering the selected AoC's either in isolation or in combination with other AoC's (or previously-identified intrinsic hazards), the Expert Team should answer the following questions:

- Can we think of any new hazards? (introduction of new hazards)
- Are there any existing hazards we should rewrite? (nature of hazards altered)
- How do these AoC's affect subjective assessments of hazard likelihood and severity?

Enrich the hazards identified during Step 5 (or during a Customer PHA) by postulating key interactions between:

- The AoC's and the Future
- The AoC's and the identified hazards associated with that Future

Interactions are those reciprocal actions or influences between the future and the Areas of Change in which the future of interest is immersed that may generate hazards not otherwise identified by narrow safety analysis methods. The objective of this step is to use domain expertise to identify phenomena that would amplify or diminish the interaction effects. Communicate with FAST and the Customer as necessary to accomplish this step.

AoC's may be internal to the global aviation system or external to the aviation system. AoC's may take the form of technology insertions, human-systems interactions, new operating paradigms, change in the legal or certification/regulatory environment, demographic shifts and/or subtle shifts toward standardization or heterogeneity.

Possible interaction paths are shown in Figure 4. The Expert Team should systematically evaluate the AoC's identified as pertinent to the particular future of interest to the Customer but should also take the time to evaluate the full list of AoC's even though some may at first appear unrelated to the particular future.

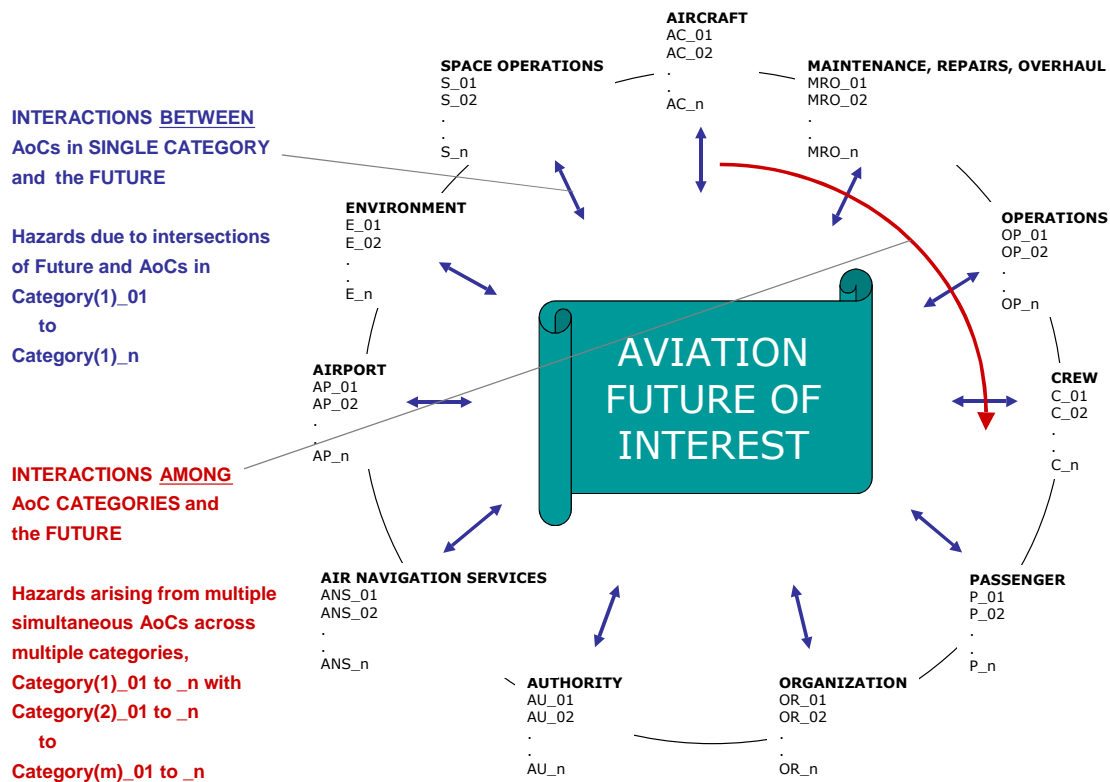


Figure 4: Interactions Between Customer Future of Interest and Areas of Change

Each Area of Change within the circular matrix shown above should be examined to determine its effect on the other categories. This exercise will aid in the identification of crosscutting issues.

Time permitting, the Expert Team should revisit all remaining AoC's not identified as "pertinent" to check whether any of these change phenomena may contribute to generation of low-probability, high-consequence hazards.

Step 8: Identify Hazard Mitigations & AoC Effects on Mitigations (optional)

For the Expert Team

Identify potential mitigations for identified hazards and how efficacy of those mitigations might be modified when interacting with future AoC's. The mitigations may be those developed previously by a Customer or those proposed by the Expert Team in response to the identified hazards.

A key aspect of this step is evaluating potential effect of the FAST Areas of Change on the efficacy of proposed mitigations. Considering the AoC's deemed relevant to the Future of interest by the Expert Team either in isolation or in combination with other AoC's:

- What new mitigations may be required (based on future AoC's)?
- Does any new (or existing) mitigation affect multiple hazards? If so, which ones and how (increasing or decreasing likelihood/severity)?
- How do AoC's affect the nature of mitigations? (mitigations must take into account the future context set by the AoC's)
- How do AoC's affect the efficacy and cost of mitigations? (efficacy and costs, and as a result efficiency of the mitigations, may be affected)
- How do AoC's affect the effect of mitigations over time? (temporal pattern of effects can also be affected)
- What changes need to be made to the new (or existing) mitigations as a result of the AoC phenomena?

NOTE: Step 8 is optional and is to be performed at the discretion of the Customer. Mitigations for existing or potential future hazards are generally the responsibility of the customer or regulatory entity. Expert Team analysis of the effects of AoC's on mitigations for future hazards should be conducted only if the customer sees substantial value in this activity. Such might be the case if the Customer has not yet performed a preliminary hazard assessment. In this case, the Expert Team may be requested to undertake this work and provide possible mitigation recommendations that reflect interaction effects with the AoC's. If the Customer does not desire recommendations for mitigations, simply skip Step 8 and move directly to Step 9 of the methodology.

Step 9: Formulate Recommendations & Identify Watch Items

For the Expert Team

As requested by the Customer, formulate general recommendations. Consider hazard elimination, avoidance, and mitigation strategies. If the Expert Team discovers hazards that currently exist, but are not widely recognized, forward that information to FAST for transmission to the Customer and others as appropriate. Recommendations should identify Stakeholders that may be affected by the hazard and actions that may be needed by the Stakeholder community. If hazard prioritization is seen as beneficial, see Annex V for suggestions for ranking the future hazards.

Determine the Watch Items. These are the telltale indicators of enabling or disruptive technologies, policy or regulatory changes, and/or societal expectations that may foreshadow which future or futures are coming about, and therefore which hazard(s) may appear. These indicators may consist of events and trends either within or external to the aviation environment. Compile and review the Watch Items generated during Step 8 and compare and contrast them with prior Watch Items from earlier FAST Expert Team analyses to look for synergies. This may be especially important for determining coupling among various futures of interest.

Using the hazards and Watch Items that have been identified thus far, organize them into broad themes as well as identifying possible critical safety problems within the Future.

Review any new AoC's that emerged during hazard identification to see how they may fit into these themes.

Step 10: Inform FAST and Customers Regarding Results

For the Expert Team

Inform FAST regarding results:

- Report the following to FAST:
- Future of interest and associated AoC's
- Future hazards and newly-discovered present hazards
- Watch Items
- Recommendations

Inform the Customer regarding results:

- Future of interest and associated AoCs
- Future hazards and newly-discovered present hazards
- Watch Items
- Recommendations for enhancements or modifications to the change(s) being proposed by the Customer

Report the following to FAST:

- Observations and suggestions regarding the FAST method

Suggested Timeline for Expert Team

- Prior to first Expert Team meeting, the Customer and FAST perform Steps 1, 2 and 3
- The Customer arrives at first meeting prepared to submit their conceptual Future that will be the subject of hazard analysis by the Expert Team.
- Step 4, Understand Customer Requirements and Future of interest: one day for introduction and understanding FAST process, two days for presentation of the Future of interest, and one day for overview of Areas of Change. Homework prior to Step 6: Expert Team review of Future and AoC list.
- Step 5, Identify Hazards Intrinsic to Future (optional): At least one meeting of four days. Additional meetings may be required if the Customer has not already performed a Preliminary Hazard Analysis.
- Step 6, Identify Areas of Change (AoC) Pertinent to Future: one days for discussion and agreement on Areas of Change pertinent to the Future, three days for initial identification of hazards due to AoC's – beginning of Step 7.
- Step 7, Enrich Hazards by Evaluation of Interactions with AoC's: one meeting (typical duration: four days)
- Step 8, Identify Hazard Mitigations & AoC Effects on Mitigations (optional): one meeting (typical duration: four days)

- Step 9, Formulate Recommendations & Identify Watch Items: One meeting to be combined with either Step 7 and/or 8.
- Plans for completing Step 10, Inform FAST and Customers Regarding Results: Established at conclusion of Step 9 meeting.
- Suggested time between meetings: one month.

Duration of Expert Team process: no more than approximately three to six months depending on nature of Future.

The objective is to complete identification of future hazards in the most effective and efficient way possible consistent with Customer schedule needs.

Supplementary Information

Annex I - Areas of Change Affecting the Global Aviation System

Identification of Areas of Change (AoC) affecting the aviation system either from within or from external sources

Members of FAST, in concert with regulation authorities, expert advice, and input from interested parties, first developed a list of Areas of Change during a series of workshops hosted by EUROCONTROL in 1999.

Changes may take the form of unintended evolutionary or revolutionary developments. They may also be deliberately planned with the intent of achieving specific results. Changes affecting the aviation system will usually take the form of technology infusions, organizational changes or regulatory modifications and updates. Identification of the postulated changes should be as factual and complete as possible.

Areas of Change are the future backdrop, context or milieu in which proposed new concepts, technologies and procedures will be immersed. While an individual AoC may have characteristics similar to the future of interest to a particular Customer, the AoC's are intended to be generic descriptions of the various features of the future aviation environment.

The time horizon for the AoC's are between 5 to 20 years from the date the list is updated. The list of Areas of Change will be re-audited on a regular basis (every 2 to 3 years) by the FAST Core Team. The exercise will be accomplished in a single meeting by the FAST Core Team supplemented by a group of experts having a broad knowledge of the aviation system.

To bring consistency and coherence to the process, Areas of Change are grouped by categories of components/systems, actors, and organizations affecting the aviation system.

Definitions of the Categories of Areas of Change

Definitions of the Categories of Areas of Change (*excerpted from the November 2008 version of the FAST Handbook*)

The following definitions provide the general scope of each of the eleven (11) categories of areas of changes. There is a minor overlap among certain of the categories but this is deemed acceptable for this prognostic analysis method.

1. AIRCRAFT

This category includes changes that affect the physical aircraft platform. Aircraft can include fixed-wing airplanes, rotorcraft, lighter-than-air, vertical-lift, and other air vehicles such as UAV's. It includes introduction of new aircraft types, or changes to aircraft systems and structures. System changes can relate to mechanical systems, hydraulics, electrical, propulsion, avionics, etc. This also includes any human-vehicle interface changes related to automation, expert systems, active controls, cockpit design, etc. (the main focus here is on systems interfaces related to pilots, cabin crew, maintenance, and service personnel). Aircraft structures changes include

introduction of composites, monolithic structure, non-rigid surfaces, smart structures, etc.

2. MAINTENANCE, REPAIR, OVERHAUL

This category includes changes related to maintenance requirements, procedures, tools (hardware/software) and test equipment, processes, facilities, personnel (in particular in relation with Maintenance Resources Management) and training. This may include maintenance as performed by an airline or other party.

3. OPERATIONS

This category includes changes related to two different types of operations:

1. Overall airline operations, and
2. Single-aircraft operations within the aviation infrastructure.

Under overall airline operations, consider changes related to: route architectures (including network, direct city pairs, long-range routes, etc.), fleet mix, management of daily operations (i.e. dispatch, scheduling, etc.), quality control and vehicle health-management processes (including data handling), freight operations, etc. This could also include operational integration issues for diverse vehicles such as airships, VTOL, supersonic, and uninhabited platforms.

Single-aircraft operations changes may include: new flight routes (i.e. lower/higher altitudes, lower/higher speeds, etc), adverse weather operations, autonomous operations, new navigation and flight-control technologies, etc.

4. CREW

This category includes changes related to the aircraft crew, both cockpit and cabin. This includes considerations of crew demographics (i.e. backgrounds, diversity, culture, education, experience, Crew Resources Management, etc.), training, crew-mix, human factors, and human-vehicle interfaces. Also included are role changes due to changes in the Aviation System.

5. PASSENGER

This category includes changes related to the passengers. This could include changes associated with changing passenger demographics and behavior. Also changing passenger health and safety needs such as issues related to sedentary constraints, child seats, g-seats, escape systems, cabin air, etc.

6. ORGANISATION

Organizations refer non-governmental bodies involved in aviation activities such as design and manufacture, operations and maintenance of aircraft. This category deals with changes related to organizational principles; for example, employment conditions, training, management and business processes. Furthermore it includes alliance/partnership changes, union issues, virtual airlines, airworthiness responsibilities, subcontracting, mergers, etc.

7. AUTHORITY

Authority means the competent body legally responsible for the Safety Regulation of Civil Aviation. In that context regulation means not only the drafting of requirements, but also, though not limited to, such activities as implementation, interpretation and application of the statutory civil aviation requirements.

Changes relative to the authority may include transfer of responsibility, delegation of verification of compliance to third parties and/or approved organizations, development of new regulatory philosophies, privatization, etc.

8. AIR NAVIGATION SYSTEM

Air Navigation System (ANS) is a generic term describing the totality of services provided to ensure the safety, regularity, and efficiency of air navigation and the appropriate functioning of air navigation systems. Air Traffic Management (ATM) is one of the five elements of an Air Navigation System (ANS). The definition of ANS concentrates on the ATM function because it integrates the other four elements. ATM is composed of a ground-based element and airborne components. It should provide a safe, expeditious and orderly flow of air traffic. The ground component can be subdivided: Air Traffic Services (ATS), Air Space Management (ASM) and Air Traffic Flow Management (ATFM). ATS is a generic term referring flight information services, alerting services, air traffic advisory services, and air traffic control services. ASM is a generic term covering any management activity provided for the purpose of achieving the most efficient use of airspace based on actual needs. ATFM is a generic term covering any management activity provided for the purpose of ensuring an optimum flow of traffic to or through areas during times when demand exceed available capacity of Air Traffic Control.

Note: For the sake of completeness, the 4 other elements of the Air Navigation Service (in addition to ATM) are: CNS (Communication Navigation Surveillance); SAR (Search and Rescue); AIS (Aeronautical Information Service) and MET (Meteorology Service).

Changes affecting ANS include: decreased separation standards, increasingly complex interactions between ground systems and aircraft systems, etc.

9. AIRPORT

Airport means a defined area on land or water (including any building, installation and equipment) intended to be used either wholly or in part for the arrival, departure and surface movement of aircraft.

Changes within the Airport category may include new surface traffic flow management technologies; changing characteristics of airport surfaces, airport capacity and terminal congestion, closure of airports, etc.

10. ENVIRONMENT

Environment means the general context in which the aviation system operates.

Among the factors influencing the aviation systems are: economical, social, political, ecological, scientific, judicial factors, etc.

Changes in Environment include: political instability, pressure towards Authorities, increased noise and emission constraints, climate changes, etc...

11. SPACE OPERATIONS

Space Operations include launch, cruise at an altitude beyond 100 km above the earth surface, re-entry (when applicable) and landing. 100 km (62 statute miles) is the NASA discriminator or classifying a flight as a space flight.

Changes to Space Operation include the development of commercial space operations, introduction of new space vehicles, introduction of space tourism, etc...

Prioritization and selection of highest priority AoCs for subsequent analysis

The objective of this step is to reduce the scope of the task to a manageable level and to determine which AoCs are most relevant to Customer needs. The prioritization of the areas of change depend on numerous criteria, i.e., nature and scope of the change, any trends or profiles present or anticipated timing of the particular change, interactions with other areas, and the sensitivity of the AoC to interactions with other AoCs. This composite criterion is a reflection of the importance of a particular AoC for aviation safety.

To lend mathematical rigor to this prioritization process, it is highly recommended that the Expert Team utilize the Analytic Hierarchy Process (AHP) to accomplish the prioritization step. The rationale for this recommended approach is based upon the following considerations:

- The Expert Team will use both individual judgments (Delphi) and open panel discussions.
- This approach will permit dynamic discussion providing judgments by mutual agreement and revision of views.
- The Expert Team will decide upon the variables appropriate to the particular domain of interest, and
- Qualitative judgments will be assigned a scalar value from 1 to 9 allowing varying degrees of choice on an issue.

This prioritization shall be performed during the same session and by the same Expert Team that performed the analysis of the potential new Areas of Change pertinent to the domain of the study.

Note on AHP and prioritization tools:

The Analytic Hierarchy Process (AHP), developed by Dr. Thomas L. Saaty, can be described as a multi-criteria decision-making methodology that considers both subjective and objective factors³. It gives a rational and defensible basis for decision-making. The decision maker often faces complex problems. AHP breaks down a problem into a hierarchy of top down (from a general goal or focus to its components,

³ See <http://www.expertchoice.com> for additional information.

subcomponents and choices) and/or bottom up (from alternatives or choices to their primary factors or functions). This allows the most complex decisions and judgments to be broken down into multiple “bite size” pair-wise comparisons. This also permits each person’s preferences to influence the decision in a fair and equitable way, i.e., each vote (within the defined structure) counts and influences the final decision. The AHP process also incorporates mechanism to identify self-inconsistencies in an individual’s comparisons thus enabling the AHP coordinator to query the individual and correct their inputs. AHP has been successfully employed in planning, prediction, setting priorities and conflict resolution. Among its many applications, AHP was used in an analysis of terrorism for the U.S. Arms Control and Disarmament Agency and resource allocation decisions for large private, governmental and international concerns. It is based on sound mathematical methods (Matrix Algebra) and enables the decision maker to incorporate subjective experience and knowledge into their judgments.

Note: Caution should be exercised when using AHP to minimize the effects of the following pitfalls:

1. Bias toward the first examined issue (primary effect)
2. Influence of the latest information over what went on before (recency effect)
3. Panel members assume they have the knowledge and experience of others (out-of-role behaviour)
4. One member excessively influences the group decision making (personal bias)

Other methods of prioritization can also be used such as the “vote allocation” system. For example, members may be given a fixed number of votes (usually between one third and one half of the possible options to be voted upon). They then are entitled to distribute these votes as they wish (e.g. put all votes on only one option; distribute their votes among several options).

Annex II - Drafting of a Vision of the Future

In order to effectively identify distant future hazards within a specific domain area of interest to an Expert Team, FAST recommends drafting one or more scenarios or story lines describing the future of interest. A scenario format allows us to plan for the future by developing stories with a purpose. Scenarios go beyond forecasts that extrapolate outward from current data. According to Peter Schwartz, scenarios can be used as teaching devices that present several alternative images of the future based on present and potential future developments⁴. They are tools for taking a long view. They convey the means and impact of events more vividly than standard forecasting methods.

People, even aerospace engineers, think most easily in scenarios. Characterizing the futures of interest as stories or scenarios will help members of the Expert Team discuss the possibilities inherent in the scenario. It will be much easier for the Expert Team to communicate the genesis of potential future hazards using scenarios rather than presenting data and logic to support the analysis. This is a case where simpler is better.

The scenarios should have an internal consistency in their logic, but do not require proof at this stage of the analysis. In fact, the Expert Team need not even assert that the story or scenario is valid. As long as it is accepted that the scenario could be valid, it will serve to illuminate the future. Characterizing the various branch options that might take place in the future as “story lines” helps ensure that they are not perceived as individual opinions, as biases or as unsubstantiated speculation. They are simply ways of describing possible futures that do not require proof in order to be useful for identification of possible hazards. Using stories or scenarios helps ensure that all futures are included in the analysis of the Expert Team, and that the more radical out-of-the-box ideas are put on the table. The FAST Expert Team process will underachieve if the range of possible futures is limited at the front end.⁵ Focusing first on scenario development will help avoid the tendency of moving too quickly to the solution space – the “table-top mitigation” phenomenon.

While the future cannot be convincingly predicted, events, trends and historic factors can be identified within an imagined scenario that set the stage for what might happen. As aviation professionals, we should be at the forefront of anticipating, recognizing, evaluating and controlling safety hazards. The better we are able to analyze issues and forces that surround our work and to see how they are a part of a system, the greater leverage we will have on our future. Planning models enable us to see the big picture and to create stories of our future by analyzing trends and forces shaping tomorrow's world – technologic, global, social/cultural, demographic, economic and political/legal.

The following example illustrates the scope and detail of a potential future. Futures of interest must be defined in this manner in order to serve as a scenario or operations

⁴ Scenario building was originally developed by Peter Swartz in The Art of the Long View

⁵ Courtesy Martin, Roger L., The Responsibility Virus, © 2002, Basic Books, p. 119

concept from which potential hazards can be effectively and efficiently extracted. This example is meant to be illustrative only, and though it is drawn from an operationally realistic setting, is not intended to reflect real hazards.

If at some point in the past, a study of the potential future hazards related to Reduced Vertical Separation Minima (RVSM) had been conducted, the Expert Team performing the analysis would likely have needed to generate the following description of the potential consequences of implementation of RVSM in order to extract potential future hazards...

"Assuming that each airplane has physical enhancements and each crew has procedures to properly manage vertical separation less than current rules, we believe that increased collision hazard is not likely. There however is a slight hazard increase due to wake turbulence descending from overhead airplanes and causing loss of control of encountering aircraft. We therefore recommend that there is a study done of all existing airplanes to determine the likelihood of a strong cruise wake descending to flight levels occupied by other aircraft, minus the altitude uncertainty. Altitude uncertainty must be considered and quantified in the study however, because actual separation may be much less than the candidate reduced value. We also recommend review of TCAS/ACAS protection with the FAA to ensure that the TCAS will not significantly contribute to collision likelihood. We want to avoid TCAS causing an accident. We hear however that the Military will be fielding new navigation technology, GPS, which if applied to civilian airplanes, will significantly increase the lateral precision with which airplanes will fly intended airways. Airplanes will then be closer to each other vertically and laterally. In this case, collision and/or wake vortex upset risk may significantly increase. If you see intentions to adopt GPS technology for civil transport navigation (watch item), then we recommend that studies are conducted and the Industry agrees to mitigating practices such as intentional cross-track stagger. Care should be taken when doing so to ensure that wind direction is considered in the study."

This example contains the following important elements:

- general assumptions related to the operational context
- clear description of a possible operational scenario
- preliminary assessment of possible hazards
- recommendations for technical studies needed to document the reality of the postulated hazard-generation mechanism
- recommendations for review of existing mitigations
- indicators that may point to the onset of enabling technologies or operational paradigms that will create a fertile environment for emergence of as-yet-unidentified hazards

These ingredients are essential to frame the hazard-analysis study, and give it a sense of reality. The above example illustrates how an Expert Team focusing on a particular topic area needs to clearly and concisely describe their “vision for the future.” This example may also be termed an operational concept, a scenario, or a task analysis/event sequence. Scenarios may describe a preferred future, a probable future or an undesirable future.

The FAST Core Team recommends using the following set of questions to illuminate the details of the scenario as it pertains to Area(s) of Change that may influence it:

Why?

The “Why” question aims at identifying the principal motivators behind the Area(s) of Change that may be interaction within the context of a global Air, Ground & Space system in such a fashion to create hazards.

How?

While the “Why” question aims at identifying the principal motivators of each of the Areas of Change, the “How” question will identify the means by which these intentions and actions will be achieved. In addition, the “How” question raises a set of conceptual or paradigmatic prerequisites, and functional, technical and operational aspects required for implementation.

What?

The “What” question aims at grasping the full scope of domains impacted, directly or indirectly, by the Area of Change.

Who?

The “Who” question seeks to identify the various participatory or secondary actors or agents of that global system either producing or being impacted by the Area of Change.

When?

The “When” question invites the Expert Team to consider the time phases of the global air, ground & space system life cycle impacted, at various degrees, by the Area of Change. Virtually all phases of design, certification, operations and post-operations may need to be considered in this addressing this interrogative. In addition to nominal operations, special concerns may arise in the case of abnormal, failure, emergency, and system crisis management situations.

Where?

The “Where” question aims at listing the main physical locations, organizational functions or activities within the global Air, Ground and Space system directly or indirectly impacted by the Area of Change.

The following steps may facilitate extraction of key future hazards from the scenario(s) of interest:

Step 1. Identify a critical issue or decision to be made. What keeps decision-makers awake at night?

Step 2. List key industry and/or governmental actors. How do these players affect

the Stakeholders?

Step 3. Explore "what is happening" in the general environment beyond the immediate domain. What events external to the domain may affect the likelihood and severity of the future hazard?

- Demographics
- Political/legal issues
- Social/cultural concerns
- Economic trends
- Global conditions

Step 4. Rank the key factors and trends using suitable criteria

Annex III - Practical Considerations for Expert Teams

Step 3:

In reviewing the prior work of the FAST, Expert Team size was found to be an important factor. The Expert Team should be large enough and of sufficiently broad representation such that relevant hazards from various domains can surface. On the other hand, the Expert Team needs to be small enough to prevent the tendency to break up into separate discussions. Within too large an Expert Team, less forceful individuals may feel that they might not have an opportunity to present their views.

A recent study⁶ has shown that it is not necessary to have a large group of experts assembled for such an activity. In fact, the quality of the output generally decreases with the size of the group. This has to do with 'blocking' (when person A speaks, persons B, C, D, ... do not speak, and may even forget what they wanted to say) and 'responsibility' (in a large group approximately half of the people afford themselves the luxury of not speaking at all). In practice, a group of three to six experts, with at least an air traffic controller and a pilot, may be most effective. This composition may vary depending on the domain of interest.

Step 5:

During this step, the Expert Team should agree upon a systematic process that will be consistently used to identify all reasonably foreseeable major direct and indirect hazards specific to the scenario(s) of interest. This systematic process should be used to identify where a combination or sequence of events could lead to a major accident or incident. The sequence of particular activities and their relationship (in time) with other foreseeable future activities in relation to the envisioned scenario should be considered as potential major hazard-initiating events.

Most present aviation accidents and incidents involve causal factors attributed to human designers and operators. Therefore, particular emphasis must be placed on the unintended consequences of unusual but possible future combinations of events involving prescribed or problem-solving actions by humans within the scenario. Human performance in closed-loop systems can often be noisy, delayed, erroneous, adaptive, anticipatory, and predictive. These characteristics of human agents must be factored into safety analyses of novel systems.

If additional hazard analysis is needed, the Expert Team identifies supplementary data and/or expertise required to complete the exercise.

In addition to the above procedure, consider the use of other means to effectively extract

⁶ B.A. Nijstad, How the group affects the mind: effects of communication in idea generating groups, PhD Thesis Interuniversity Center for Social Science Theory and methodology (ICS) of Utrecht University, The Netherlands, 2001

the hazards: Delphi Method, Preliminary Hazard Analysis and Preliminary Hazard Listing, Hazard and Operability studies, Hazard Analysis, Failure Modes, Effects, and Criticality Analysis, Fault Tree Analysis, Common Cause Failure Analysis, Sneak Circuit analysis, Energy Trace analysis, etc⁷. The hazard identification methods applied should be appropriate to the magnitude and scope of the domain involved. Hazard discovery methodologies that are currently used to discover hazards in near-future technology systems may or may not be suitable for discovery of distant-future hazards.

A highly relevant NLR report by H.H. de Jong on practical hazard-identification techniques entitled "GUIDANCE MATERIAL: IDENTIFICATION OF HAZARDS - How to make imaginable the hazards that are 'functionally unimaginable'," Contract Report NLR-CR-2004-094, National Aerospace Laboratory NLR, 2004, is available for download at the EUROCONTROL website:

<http://www.eurocontrol.int/safety/downloads/sam/Level2/FHA%20V2.0/FHA%20V2-0%20Chapter%203%20Guidance%20B2.doc>

Optional Sub-step:

INTERACTION OF PROJECTED FUTURE HAZARDS WITH PAST FAST ANALYSES.

Review relevant prior Expert Team results. For instance, the results from analyses of Increasing Crew Reliance on Flight Deck Automation study (AC_13) and Introduction of New Concepts for Airspace Management (ANS)_01) should be reviewed to determine if there are key interactions between the Future and these other phenomena. This step is essential since it serves to connect current Expert Team analyses with the existing FAST Master Hazards, Watch Items, and Recommendations.

Hazard prioritization and the work necessary to achieve this ranking may not be necessary for certain domains of interest to a particular Customer. In these cases, the Customer may deem it sufficient to have a short non-prioritized list of potential future hazards with which to work. Hazards identified by FAST analyses could feed risk assessment (severity coupled with likelihood/frequency of occurrence) to be performed in subsequent analyses.

Step 6:

The FAST will systematically and thoroughly brief the Expert Team on the pertinent Areas of Change in light of the Future of interest to the Customer. The Expert Team will then review each AoC and use the full list to expand the Future into domains that the Customer might not have considered before. Each AoC may illuminate the original vision of the Future with fresh perspectives. During this step, the AoC list is used as a checklist. It serves to expand the scope of the analysis into unexplored domains.

⁷ A survey of potentially relevant hazard analysis techniques is listed in the FAA System Safety Handbook, Chapter 9: Analysis Techniques, http://www.faa.gov/library/manuals/aviation/risk_management/ss_handbook

The judgment about the relative relevance of a particular AoC will ideally not be made a priori. Apparently obvious dismissals should be questioned. For instance, the Expert Team will ideally avoid any tendency to make assumptions such as "We don't consider a maintenance-related AoC relevant to our Future because we are addressing a flight crew issue." This scope-expanding function is critical to the success of the Expert Team hazard-identification process. That being said, the Expert Team must have the freedom to eliminate irrelevant AoCs. This will simplify work and focus resources.

The Expert Team should determine whether the Customer-provided list captures all relevant AoC's. Subject-matter experts on the Expert Team may suggest other potentially relevant AoC's that the Customer didn't initially identify. This step serves to introduce the concept of brainstorming and the ground rules that go along with a brainstorming session (not letting dominant personalities rule, making sure everyone gets heard, etc.) During its work, the Expert Team may identify new AoCs that are not on the FAST master AoC list. This is encouraged. These new AoC's should be communicated to FAST and the Customer via the process shown in Annex VI.

Step 9:

One major form of recommendation might be for follow-on risk assessment of the hazards identified in Steps 6 or 7. Estimates of the risks associated with identified future hazards are necessary to gain a full appreciation of the safety issues inherent in the Future of interest to the Customer. Several techniques are available for ranking risks in order to prioritize management action. These include both qualitative and quantitative approaches. Qualitative risk levels can be accomplished using a tailored set of prompt lists and questionnaires, followed by structured brainstorming and interviews with key Customer and Stakeholder representatives. Fast-time Simulations with multiple actors incorporating models of human performance can be used for quantitative risk assessment. The nature of the Future of interest to the customer may indicate a preferred approach.

Step 10:

FAST and the Customer may wish to perform periodic assessments of the validity of the results. These assessments would ideally be conducted using resources from within the Expert Team as well as external sources in order to establish confidence in the identified hazards and high-level recommendations. The internal validation process will consist of expert opinion assessments and comparisons of the target hazards and recommendations with the full list of AoCs and with the Watch Items. The validity of the results will also be assessed by comparison of the results with targeted surveys of the affected aviation-community constituencies (like line pilots, for instance) and by comparison of the FAST results with the outputs of other industry/government safety analyses (like the CAST Problem Statements, for instance).

A note regarding proprietary issues for Customers and Stakeholders...

The original assignment of the FAST was to develop a proactive approach to identifying future hazards based on envisioned futures. If any person or organization is contemplating introduction of an aviation system change, then they ought to have access to the best prognostic method available to do that task. This is true even if the person or organization wants to do so on a proprietary basis. The FAST method may be the most robust prognostic method available in aviation, and should be available to all, regardless of proprietary concerns.

Annex IV - The FAST Process in the Context of Other Hazard Analysis Techniques⁸

Techniques for discovery and analysis of hazards in near-term technology systems are customarily divided into four groups:

- Hazard Identification
- Static Assessment
- Dynamic Assessment
- Human Reliability

Each of these groups has techniques, which can be applied to the safety evaluation of a particular future of interest. The appropriate methodology to perform hazard discovery and analysis within the context of the FAST process may, in fact, be based on a synthesis of several of these techniques combined with the FAST approach involving scenario development and interaction analysis. The FAST process may cover elements missing from established approaches such as the analysis portion of Event Tree Analysis.

The Hazard Identification Group consists of techniques used to systematically identify hazards. These techniques can be employed in the context of future scenarios to predict, identify, and/or diagnose what in the system or the procedures may create an increased risk of an accident or incident. All the conventional techniques in this Group are qualitative and deductive, and most do not incorporate a systematic method for taking dependencies into account, as does the FAST method. The FAST method, by design, is intended to identify hazards arising from the gaps and overlaps among various agents and organizations, components and systems, as well as between aviation and other forces in society.

While at first blush the FAST process may appear less structured than other techniques within this group, it may be qualitatively richer because it involves systematic assessments of a wide range of interactions among the Areas of Change affecting the aviation system as well as interactions among the various domains of aviation.

Like Preliminary Hazard Analysis (PHA), the FAST process identifies hazardous conditions or accident scenarios, as well as suggesting potential mitigation measures. A key strength of the FAST process is that it includes a means to identify catalysts (called “Technology Watch Items”) that may signal the advent of hazardous futures.

The FAST process is in some ways qualitatively similar to the Zonal Analysis technique that considers common causes and interactions. Zonal Analysis lends itself quite well to analysis of mechanical systems while the FAST process applies interaction analysis at a higher, “meta” level by systematically examining interactions among systems and organizations. A key value of the FAST process lies in its fundamental intent to track and record such meta-level interactions in the

⁸ based on project MUFTIS (which was a project for the European Commission), reference: M.H.C. Everdij, M.B. Klompstra, H.A.P. Blom, O.N. Fota, 'MUFTIS work package report 3.2, Final report on safety model, Part 1: Evaluation of hazard analysis techniques for application to en route ATM, NLR report TR 96196 L, 1996

continuously updated FAST archives.

The Static Assessment Group includes qualitative and quantitative techniques that do not incorporate any dynamics. The most well known techniques in this Group are Fault Tree Analysis (FTA) and Event Tree Analysis (ETA). In a Fault Tree Analysis, a failure or fault of interest (top event) is defined, and faults or failures of components or subsystems, which lead to the top event, are identified. The failure is often that of a complex system, comprised of sub-systems, components, and human operators. The top event may also be the failure of a single component or even the degradation of performance of an operator or human error. This technique assumes independence of the events at each level of the tree. Failure dependencies are factored in by incorporating them within the definition of an event. Often, risk in complex systems is underestimated due to the existence of significant unidentified dependencies. The FAST process is structured approach for identifying significant static dependencies.

The main drawbacks of static assessments are that failures are assumed to be binary in nature with no time dependency, and that the analysis does not consider the order of occurrence of events, in others words, there is no chronological order of failure occurrences. A limitation of techniques such as FTA technique is the lack of dynamics: the relationships of the tree events are assumed to remain unchanged with time. Temporal aspects are often embedded in both Fault trees and Event trees: from the bottom to the top for fault (cause) trees and from left to right for event (consequences) trees. Often this temporal relation is not explicitly mentioned as a feature of the risk analysis technique.

The emphasis on definition of potentially hazardous operational scenarios (the “what ifs?” that keep decision-makers up at night) that is at the core of the FAST process makes it a structured method for identifying these dynamic dependencies. This is an important feature of the FAST process but is not its principle added value.

For this reason, the FAST approach is similar to Event Tree Analysis models in that the possible consequences of a given hazardous situation (the initiating event) are defined and set in an operational context. It can therefore be used in identifying measures to minimize the consequences of a future hazardous situation. When completed, both the FAST process and the ETA tree show how the different systems are influenced by the initiating event as well as the final outcome of the functioning/malfunctioning of all interrelated systems. Unlike ETA in which generally only binary events can be modeled, and only non-recoverable generic event sequences with non-recoverable initiating events can be described, the FAST process permits a series of possible scenarios with different intersecting futures and outcomes. It is important to note that the capability of a particular risk analysis tool to identify multiple, branching outcomes may not be influenced so much by the underlying structure of the tool as how it is employed by domain experts.

Other techniques such as Cause Consequence Diagrams, Probabilistic Safety Assessment, and Reliability Block Diagrams, all based on FTA or ETA, also belong to this Static Assessment Group.

The Dynamic Assessment Group comprises techniques that can deal with temporal relationships and model systems where time has an influence on the system behavior.

Examples of these techniques are Discrete State Space Graphs (DSSG), Petri Nets, Monte Carlo Simulations, Discrete Event Simulations, Dynamic Event Tree Analysis, and Hybrid-State Markov Processes.

DSSG models the behavior of a system and its failures by modeling its discrete states (functional or degraded). The FAST process does not require a solely quantitative assessment of transition probabilities characteristic of some of these other methods, but rather a “what-if” description of the system components and how those human and systems agents interact. DSSG and Petri Nets methods encompass both a qualitative description of states and transitions and b) a quantitative assessment.

The FAST process does not claim to perform deterministic and stochastic evolution of a system nor does it require elaborate mathematical techniques for evaluation of future hazards. The FAST process may appear less rigorous than the numeric simulations within this group, but it may be qualitatively richer as a result of the breadth of interactions represented in the FAST approach that cannot be discretely modeled with dynamic simulation techniques. There are certainly state-of-the-art dynamic simulation techniques⁹ that can be used to assess hazards and consequences from a risk perspective. These techniques require a high-level description of the scenario of interest, and the procedures and multi-agent interactions contained therein, in order to evaluate the accident risk associated with the scenario, due to the occurrence of previously identified hazards as well as those that are discovered as a result of running the simulation. The FAST process yields scenarios and futures that are less well-defined but nonetheless quite rich in terms of novel hazard genesis mechanisms.

The last group, the Human Reliability Group, consists of techniques that account for the broad spectrum of factors that come into play when human agent behaviors are included in the analysis. These techniques are helpful in the context of overall risk analysis, where humans, in particular designers, pilots, controllers, and maintainers, play major roles. Indeed, these techniques are also applied in other industries such as nuclear electricity production, process industry, ground transportation systems, etc.

This Group includes Action Error Analysis (AEA), Human Error Assessment and Reduction Technique (HEART), Technique for Human Error Rate Prediction (THERP), Human Interaction Timeline (HITLINE), Operator Action Trees (OATS), Human Cognitive Reliability model (HCR), Empirical Technique to Estimate Operator Errors (TESEO), Absolute Probability Judgment (APJ), Paired Comparisons (PC), Success Likelihood Index Methodology (SLIM), and Influence Diagram Approach (IDA).

Although the FAST process does not quantify human errors in operator tasks, it does attempt to qualitatively estimate the likelihood of hazardous conditions developing within a specific operational scenario due to weaknesses in design, procedures and training based on domain expert opinion. Furthermore, the FAST method can be used to evaluate the safety degradation of man-machine systems caused by or

⁹ project HYBRIDGE at <http://hosted.nlr.nl/public/hosted-sites/hybridge/>, pages 331-256 of the final report

connected to human errors.

Like Paired Comparisons, the FAST process employs the judgment of domain experts to infer knowledge-based prioritization of influences and risks. The FAST process is more oriented towards comparisons between the operational characteristics of different man-machine systems and operational contexts, rather than absolute probabilities. A particular strength of the FAST level of analysis is that it addresses the Multi-Agent Systems paradigm, where Agents are broadly defined as software programs, automata or humans (pilots, controllers, maintenance engineers, ground staff, managers, designers, etc. – all the human actors in the system). In general multi-agent systems are functional systems in which several semi-autonomous agents (human and non-human) interact or work together to perform some set of tasks or satisfy some set of goals. Building dependable multi-agent aviation systems that function safely in dynamic environments is difficult. Building large-scale distributed software systems is likewise difficult. The relatively few attempts to combine these two tasks confirm that successfully building large-scale distributed systems with predictable dependability properties is exceptionally difficult especially when human agents must interact with such semi-intelligent systems.

The FAST method can be considered an adjunct to recent databases of safety analysis techniques such as that maintained by the NLR

http://www.nlr.nl/documents/flyers/SATdb_03.pdf

or the EEC reports on which this particular database was based: EEC, Review of techniques to support the EATMP Safety Assessment Methodology, Volume I and II, EEC Note No. 01 / 04, Project SRD-3-E1, M.H.C. Everdij, January 2004. The FAA/EUROCONTROL Action Plan 15 toolbox contains additional detail on this compendium of safety analysis techniques. These documents are located at:

<http://www.eurocontrol.fr/public/reports/eecnotes/2004/01.pdf>

<http://www.eurocontrol.int/eec/publications/eecnotes/2004/01b.pdf>

Exemplar questions to be used in Step 6, “Identify Hazards Intrinsic to Future” for identifying hazards within the Customer Future:

- How does the Future increase the likelihood of well-understood present hazards? By what mechanism(s)?
- What can possibly go wrong within the Future? What safety concerns are most apparent in the Future?
- What hazards may be created due to breakdown or degradation of the operational functionality envisioned for the Future?
- By what mechanisms will existing and planned systems protections and safety layers be potentially compromised by the Future?
- What potential hazards are created when the Future interacts synergistically with future Areas of Change?
- How does the Future create increased potential for human error, procedural non-compliance or equipment failure?
- How does the Future:

- decrease the resilience of the projected safety system?
- render the projected system performance and safety protections more brittle to off-nominal conditions?
- decrease safety levels during non-normal or emergency operations within the projected Future?
- What current and projected safety assurance measures will be lost or rendered ineffective as a result of the Future?
- What hazards within the Future will require creation of new control measures for critical aspects of the Future? Definition: A control measure is an action or procedure that will reduce, prevent or eliminate a potential hazard.
- How does the Future adversely affect control measures, critical control points or critical limits? Definitions: A critical control point is a step at which a control measure is applied. A control limit is a maximum and/or minimum value for controlling a physical parameter.
- What new conditions that are currently not part of the design assumptions for currently planned systems and procedures will be created by the Future?
- What will be the effect on the Future due to changes in demographics, skill levels and judgment among its operators?

Annex V - Techniques for Prioritizing Recommendations

A template containing the following elements may be useful in describing the future hazard:

1. Perspective – the particular world-view of the Customer requesting the analysis
2. Discussion – a declarative statement setting the context of the new hazard with respect to current hazards and existing mitigation strategies
3. Amplified hazard statement
4. Future technology Watch Items

Ranking of hazard mitigation strategies may be done using the following criteria drawn from the work plan of the Joint Safety Analysis Teams of the Commercial Aviation Safety Team (CAST)

1. Importance (I): fractional value from 0-1 (“Importance” is defined as the potential of a particular hazard to create novel accidents and/or incidents that could undermine the confidence in users and operators of the aviation system.)
2. Power (P): ordinal value from 0-6
3. Confidence (C): ordinal value from 0-6

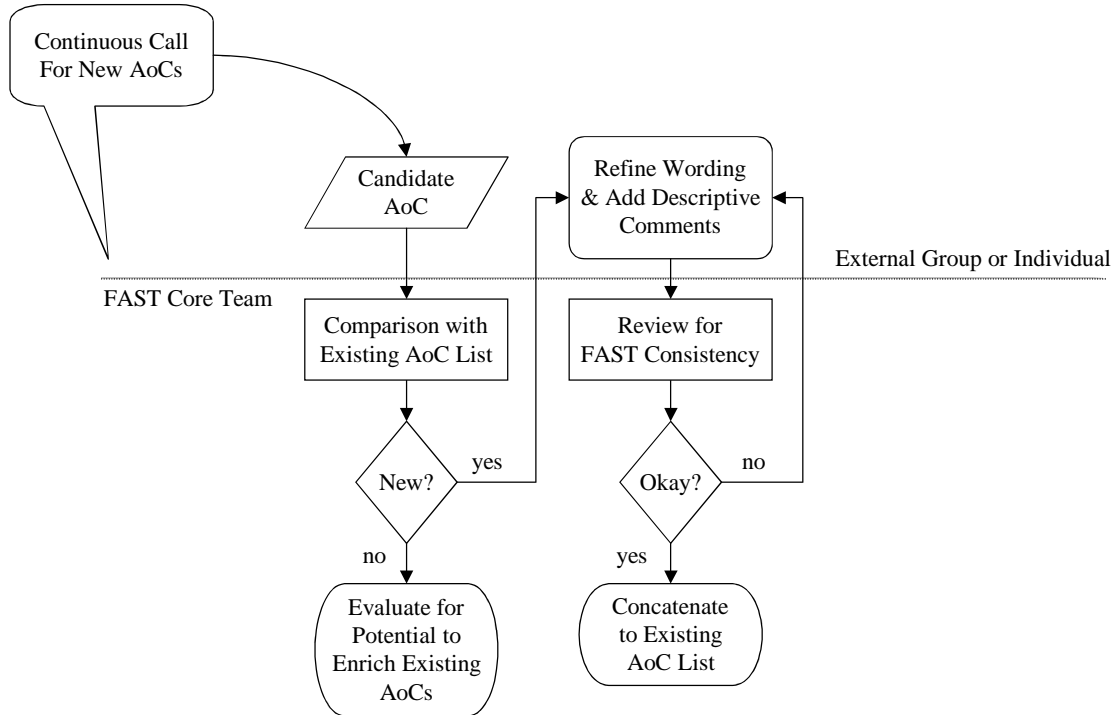
The “value” of a recommendation is obtained by the product: $I \times P \times C = \text{Value}$

I, P and C are defined as follows:

1. Importance
Defines the relative importance that the FAST Expert Team assigns the respective related hazard
2. Power
Establishes the effectiveness of the specific mitigation strategy in reducing the likelihood of a specific accident had the recommendation been in place and operating as intended
3. Confidence
Indicates the level of confidence that a specific mitigation strategy will have the desired effect if implemented properly

The recommended mitigation strategies are then simply ranked based on their “value” score.

Annex VI – Area of Change Submission Process



The FAST continuously solicits submission of new, candidate Areas of Change affecting the aviation system, Submission of new AoC's should be made to Rudi den Hertog, Chief Engineer, Fokker Services, FAST Co-chair, rudi.denhertog@stork.com