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National Aerospace Laboratory NLR

EUROCONTROL

EUROPEAN ORGANISATION FOR THE SAFETY OF AIR NAVIGATION

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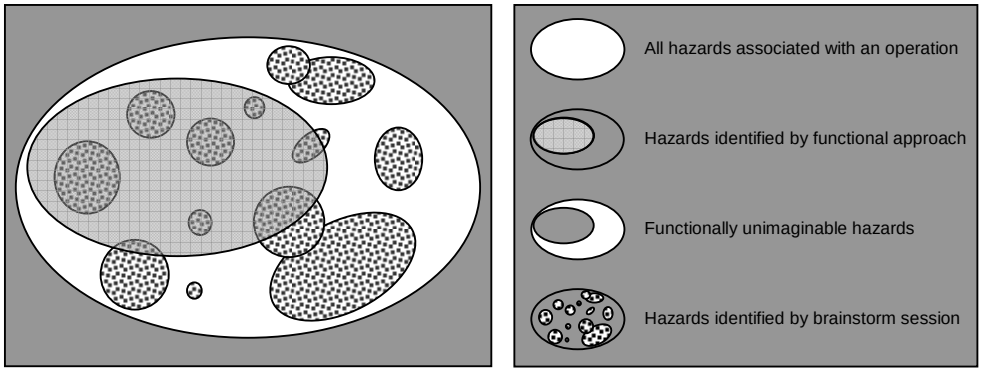
Guidelines for the identification of hazards

How to make unimaginable hazards imaginable?

H.H. de Jong



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Summary

This report gives guidelines on how to perform hazard identification brainstorms. Such brainstorms are intended as an approach to hazard identification complementing the functional approach to hazard identification from EUROCONTROL's well-known FHA sessions.

A brief overview of the main tasks of such a functional hazard identification is given – this proceeds from the defined ATM system's functions, via functional failures and their operational consequences to the potential effects on the safety of the operation.
Reasons are given why it is not expected that all ATM system related hazards are obtained by means of these sessions. Hazards that are hard or impossible to identify using functional hazard identification sessions are called (functionally) unimaginable.
Hazard identification brainstorms are intended to establish an approach for identifying also these unimaginable hazards. Guidelines for the performance of such brainstorms are given. These guidelines are based on experience at NLR and supplemented with other knowledge judged valuable.
Combinations of functional and brainstorming approaches to hazard identification are expected to be valuable, due to the different subsets of hazards these methods yield. It is recommended and motivated to perform brainstorms first.

The first appendix sketches an operation that has been subject of a risk assessment with hazard identification. Some example hazards identified by brainstorming sessions are given, as well as some observations on the functional or unimaginable nature of these hazards. The second appendix gives a largely graphical overview of the guidelines for hazard identification presented in this report.

Contents

(37 pages in total)

1 Introduction

1.1 Background

On April 25th, 2003, Patrick Mana (EUROCONTROL/ European ATM Programmes/ Safety Enhancement) and Fabrice Drogoul (EUROCONTROL Research Centre/ Safety Analysis and Scientific) visited NLR to discuss the subject of "Hazard Identification Brainstorming" (see [1] for the minutes of meeting). EUROCONTROL requested the meeting to become acquainted with NLR's approach to lead hazard identification brainstorming sessions. EUROCONTROL's interest in this matter was raised during the "Safety Methods Survey" project that NLR has performed for EUROCONTROL (see [10]).

During the meeting, NLR presented its methodology for the identification of hazards of Air Traffic Management operations (see [2]). The objective of NLR's methodology is to identify as many and diverse hazards as possible, with due attention for identification of so-called unimaginable hazards.

EUROCONTROL, within the context of the European Air Traffic Management Programme (EATMP), is in the process of developing a Safety Assessment Methodology (SAM) for Air Navigation Systems. The first step of this methodology, the Functional Hazard Assessment (FHA), has been issued as [3]. The FHA recognises brainstorming (called FHA sessions) as a preferred tool for hazard identification. Guidance material for planning and conducting FHA sessions has been issued as part of the methodology (see [4]).

EUROCONTROL feels that its current guidance material does not adequately cover the identification of particular types of hazards, especially those that NLR refers to as unimaginable hazards. EUROCONTROL is interested in expanding/ improving its current guidance material to include the identification of that type of hazards. The expanded/ improved guidance will be in Edition 2.0 of the FHA, see [13]. In the meeting of April 25th, EUROCONTROL expressed its interest to contract NLR for the development of SAM guidance material on hazard identification using brainstorming techniques with the focus on so-called unimaginable hazards.

On 28 July 2003, EUROCONTROL issued EATMP-TRS/104/03 "Delivery of SAM guidance material on hazard identification using brainstorming techniques with the focus on so-called unimaginable hazards" [6], to which NLR has responded with a proposal [7]. Subsequently, EUROCONTROL and NLR have entered into a contract, and the present document is one of two deliverables of that, the other deliverable being a PowerPoint ® presentation [8].

1.2 Objectives

The objectives of the agreed contract are (see [7]):

1. Expand existing SAM guidance material on conducting hazard identification brainstorm sessions to cover the identification of unimaginable hazards using NLR's methodology;

2. Provide examples to enhance the understanding of the methodology using NLR existing material;
3. Propose ways to combine systematic hazard identification and unimaginable hazard brainstorming sessions;
4. Indicate benefits and drawbacks of these combinations; and
5. Add a description in the guidance setting out the options for brainstorming and explain for each option its pros and cons, and how and by whom to apply the option.

1.3 Organization of document

This document gives guidelines for the identification of unimaginable hazards, based on some of NLR's experience with hazard identification and some background material on risk assessment and brainstorming from cognitive science.
The structure of the document is as follows:

- Section 2 gives an overview of the functional approach to hazard identification;
- Section 3 gives the rationale for a complementary approach and introduces the concept of an unimaginable hazard;
- Section 4 gives guidelines for the identification of hazards along such a complementary approach, which is mainly based on NLR experience;
- Section 5 suggest ways to combine functional and brainstorming approaches to hazard identification and gives quality criteria/ checklists for planning, preparation and evaluating hazard identification;
- Section 6 concludes the main body of this report;
- Appendix A sketches an operation that has been subject of a risk assessment with hazard identification; some example hazards identified by brainstorming sessions are given, as well as some observations on the functional and unimaginable hazards; and
- Appendix B finally gives a largely graphical overview of this report's guidelines for the identification of hazards.

1.4 Readership table

In order to facilitate quick access to the most important information, the table below suggests reading the following sections for a few key types of readers:

Aspect:	Key person Sections	Project manager	Safety manager	Safety analyst	Moderator	ATCo and pilot	Scientist
Background:	1.1-2, 2, A	N/A	✓	🕮	✓	N/A	✓
Approach:	2, 3, 4.1-5, 5.1	N/A	🕮	🕮	✓	N/A	✓
Planning:	4.6, 5.2, B.2	🕮	✓	✓	✓	N/A	N/A

Aspect:	Sections	Key person	Project manager	Safety manager	Safety analyst	Moderator	ATCo and pilot	Scientist
Preparation:	4.6, 4.7, 5.3, B.2	N/A	N/A	🕮	🕮	N/A	N/A	
Performance:	4.6, 4.8, B.2	N/A	✓	✓	🕮	✓	N/A	
Evaluation:	4.9, 5.4, B.2	N/A	🕮	🕮	🕮	N/A	✓	
Overview:	B1	🕮	✓	✓	✓	N/A	N/A	
Conclusion:	6	✓	🕮	🕮	✓	✓	🕮	

🕮: detailed knowledge	✓: aware	N/A: not applicable

Table 1: Readership table

The following profiles are associated with the key types of readers mentioned above:

- Project manager: Person responsible for changing the operation by means of a project (hazard identification is via a safety assessment a part of this project);
- Safety manager: Person responsible for the safety deliverables of the project;
- Safety analyst: Person performing the safety analysis related to the operational change;
- Moderator: Person facilitating the hazard identification brainstorming session;
- ATCo and pilot: Air traffic controller or pilot participating in the hazard identification brainstorming session; and
- Scientist: Person with general interest in risk assessment, hazard identification and/ or brainstorming.

2 The functional approach to hazard identification within FHA

EUROCONTROL's Safety Assessment Methodology (SAM) consists of three parts:

- the Functional Hazard Assessment (FHA), see [3] for an extensive manual;
- the Preliminary Safety Assessment (PSSA); and
- the System Safety Assessment (SSA).

Although hazard identification plays a role in all parts, the material [3] related to hazard identification contained in the FHA is the most developed, well-known and widely applied. In this report, this is called the functional approach to hazard identification. The guidelines developed in the present report serve to complement the functional approach. In Edition 2.0 of FHA (reference [13], to appear early in 2004) the FHA will be developed to incorporate the brainstorming approach to hazard identification.

In this section, a short overview of Edition 1.0 of the FHA is given, extracted from http://www.eurocontrol.int/safety/downloads/Gui_Saf_Assess/index.htm (follow the links to "Basics of Safety Assessment" and "FHA"). In advance of the developing FHA, the overview is extended in a minimal way to take into account that hazards are not only identified by the functional approach – hazard identification brainstorming sessions are performed as well. These extensions have been indicated by underlining them.

FHA

Functional Hazard Assessment is conducted during the System Definition phase of development. The purpose of the System Definition phase is to identify and specify the requirements that the system needs to fulfil. The phase begins with the establishment of the basic operational objectives and operational scenarios for the foreseen Air Navigation System. One then identifies the functions required to achieve the operational objectives and the functional and physical interfaces with the system environment. FHA complements the system specification by deriving how safe does the system need to be?

The Functional Hazard Assessment:

- Identifies as many hazards related to the operation as possible;
- Identifies potential hazards resulting from the loss or degradation of system functions (system failures);
- Evaluates the consequences of the hazard occurrence on aircraft operations and to determine the severity of these consequences;
- For each identified potential hazard of a given severity, the Safety Objective specifies its maximum tolerable probability of its occurrence.

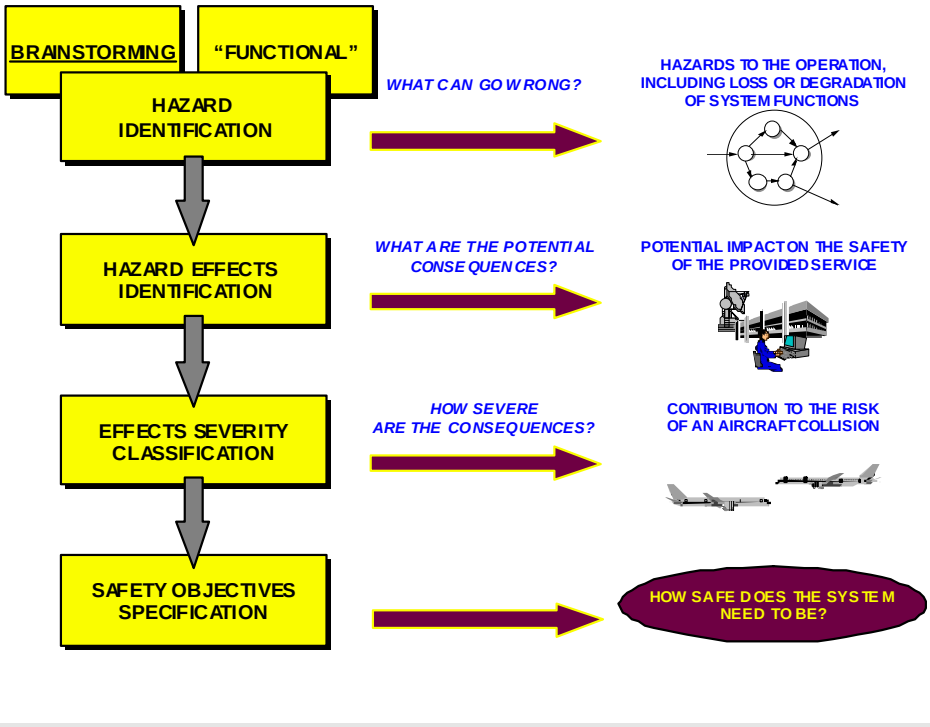

Figure 1: The major tasks in a Functional Hazard Assessment

It should be noted that the steps of the FHA after the hazard identification most probably need further development to account for the wider scope of hazards identified by using brainstorming as well. There may for instance be hazards related to the operation whose risks are insensitive to changes to the ATM system. If such risks are large, it will be hard or impossible to control them by putting more strict safety objectives on the ATM system. Other aspects of the operation have to be redeveloped then, which in turn may change the starting point of the ATM system's definition.

The development of further steps of the FHA to deal with these more general hazards is outside the scope of the present report.

3 Rationale for hazard identification complementary to the functional approach

There are hazards that are hard to identify by means of the functional approach. Such hazards are called “functionally unimaginable” or shortly “unimaginable” hazards.

Characteristic of the functional approach to hazard identification in the FHA is that one

- Starts from the functions of the system to be developed;
- Next identifies the system failures (such as loss or degradation of functions); and
- Then identifies potential hazards associated with the failures.

A precise definition of “hazard” is not given in the FHA [3], but it is clear that, within this context, hazard identification is about systematic consideration of the potential impact of failures (and external event occurrences, see [3]) on the safety of the provided service/ aircraft operations.

Although this establishes a systematic approach to the identification of hazards related to functional failures, it is questionable whether all potential impacts on safety related to the system under development are identified in this way. Some reasons why not all hazards may be identified in this way are:

- There may be hazards associated with a system functioning well, for example:
  - Air traffic controllers might become overly reliant on a well-functioning alerting system;
  - There may also be functions that are good for most circumstances, but disturbing for other;
- There may be hazards not associated with functional failures:
  - Situational awareness problems of pilots may have nothing to do with functional failures of the ATM system;
- There may be hazards that are only remotely associated with functional failures:
  - In hindsight, such hazards may be attributed to functions and failures, but it is difficult to conceive such hazards starting from the functions and failures; and
- The functional description may not be complete:
  - There may be implicit functions relevant for the safety of the provided service/ aircraft operations, which are only recognized after failure; and
  - It moreover appears hard to catch air traffic controllers’ and pilots’ effectiveness with respect to safety completely in terms of a functional description. Indeed, a complete functional description may be excessively complex.

See Appendix A for a hazard identification with some examples of unimaginable hazards.

It is well recognized in [3] that hazard identification, even from a functional failure point of view, is not a task that can be fully accomplished by “logical thinking”. Creative input, generated by means of FHA sessions is an essential ingredient.

4 Guidelines for hazard identification based on NLR's brainstorming approach

4.1 Introduction

In this section, guidelines for hazard identification are given that further exploit the creative approach already partially acknowledged in the functional approach of the FHA. Instead of functions and failures, the starting point of the identification is the safety of the operation: a hazard is anything that might negatively influence the operation's safety. The experience and imagination of the users of the operation (air traffic controllers and pilots) are exploited via brainstorming sessions to identify as many hazard as possible.

The guidelines given here are mainly based on experience at NLR with hazard identification. At some points additional experience or material has been employed with the aim to optimize the quality of the guidelines.

The reader with very little time may choose to concentrate on headings and boxed texts in the following.

4.2 A risk assessment context

Hazard identification is usually done as one of the steps of a risk assessment of an operation. Figure 2 gives an overview of the steps in a proven way to perform risk assessments.

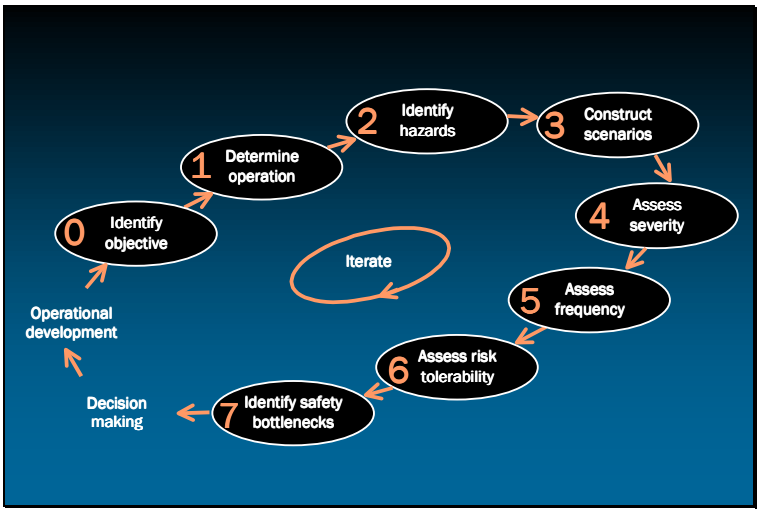

Figure 2: Overview of risk assessment steps

Hazard identification takes place after the objective of the risk assessment has been precisely specified (Step 0) in accordance with the client, and the developed operation has been understood, summarized and frozen (at least for a cycle of the risk assessment) by the risk assessors in accordance with the operational developers (Step 1).

After the hazards are identified (in Step 2), these are structured (Step 3), and the resulting structures are assessed with respect to severity, frequency and risk tolerability (Steps 4, 5 and 6). In case of "high" risks, it is attempted to explain what hazards and conditions give rise to these high risks (Step 7) in order to give operational developers a clue how to adapt the operation.

This kind of risk assessment is usually performed when there is a more or less mature description of the operation, because hazard identification and the further steps in the assessment may depend sensitively on operation specific issues such as human roles and responsibilities, procedures and technical systems. Assessing an operation that is more general may yield larger uncertainties in the assessed level of risks, which makes the outcome of the assessment unsuitable as a basis for decision making. However, it is prudent to perform hazard identification in an early stage: not all hazards depend sensitively on the operational details, and if there are significant hazards associated with an operational development, it is better to know them early, when redevelopments to the operation can still be made relatively easily.

4.3 What is a hazard?

ESARR 4 [13] contains the following definition of the term "hazard": Any condition, event, or circumstance which could induce an accident. The FHA manual [3] and the EATMP glossary [15] do not contain a definition of hazard.

In this report we use a notion that generalizes the possible effect of an accident to negative influence on safety:

> A hazard is anything that might negatively influence safety.

A more extensive version could be:

A hazard is an event/ state that may

- lead to a dangerous situation, or
- hamper resolution of such a situation,

possibly in combination with other hazards or under certain conditions.

It is important to note that the notion of hazard is defined in relation to *safety*. This makes it a much more general notion than "something going wrong", which is rather related to reliability.

4.4 Goal of hazard identification

> The goal of the hazard identification step is to obtain as many hazards as possible applicable to the operation, within the scope of the risk assessment.

The quality of the risk assessment, and consequently also the quality of its feedback to the operational developers, depends strongly on the productivity of the brainstorm: hazards that are not identified cannot be assessed. In a more general context, it is known about brainstorming (see [11] for references) that "quantity breeds quality". It should be noted that a productive brainstorm is not an indication of an unsafe operation: the risk assessment of the hazards is still to be done. Again, if there are hazards pointing towards flaws in the operation, it is better to know them early than late.

4.5 Means of hazard identification

Primary means to identify hazards is to perform hazard identification brainstorming sessions with operational experts (air traffic controllers and pilots).

Experience shows that hazard identification brainstorming sessions are a rich source of hazards, not only in quantity but also in quality: brainstorming sessions often yield hazards that would not easily be obtained by other means, such as the functional approach to hazard identification in FHA. Such functionally unimaginable hazards could not have been obtained by logical thinking in terms of functions and failures, but their identification depends in an essential way on the creativity of operational experts.

Two basic rules of hazard identification brainstorming are: 1. Identify as many hazards as possible; and 2. Criticism and/ or analysis are forbidden during the brainstorm.

References [11] and [12] motivate these basic rules from cognitive science. Moreover, it is known from experience that analysis is very time-consuming (analyzing a single hazard may well take much more than a session) and should be done by the safety analysts alone. Criticism moreover easily kills the open atmosphere necessary for productive brainstorming. Identified hazards that appear unimportant to somebody will be filtered out later in the risk assessment. All time should be used for generating hazards.

Although usually not suitable as sole source of hazards, there are other sources for hazard identification, such as

- Hazard databases;
- Literature (hazard identification and safety analyses studies such as FHA's of similar air traffic operations); and
- Incident/ accident databases.

These sources are valuable in preparing brainstorming sessions, assessing their effectiveness and for completing them.

4.6 Participants of a hazard identification brainstorm

A good group of participants to a hazard identification brainstorming session is:

- An air traffic controller;
- A pilot;
- A moderator;
- Somebody taking notes;
- An expert on the operation (preferably coinciding with the person taking notes); and
- A safety analyst (if possible coinciding with the moderator).

4.6.1 Operational experts

- It is essential that the operational experts (air traffic controller and pilot) have NOT otherwise involved in the development of the operation.
- The operational experts have to be willing and able to play devil's advocates.
- Select air traffic controller of the kind (area, approach, tower or ground control) most appropriate for the operational scope of the brainstorm.
- Vary with the appropriate kind of pilots (heavy/ medium/ light, scheduled/ charter, foreign/ home carrier) if there are more brainstorms.

Operational experts (air traffic controllers and pilots) are essential participants to hazard identification brainstorms: without these participants it may not be expected to obtain a reasonably complete list of hazards. Experience not only shows that air traffic controllers and pilots are rich sources of hazards, but also that they are often quite different people and that it is valuable and enjoyable to have these people together in a brainstorm.
The operational experts have to be willing and able to play devil's advocates in the sense that they are creative in identifying hazards, i.e., anything that *might* negatively influence safety. The "might" is crucial: some operational experts will only mention a hazard when they think it has a significant risk; however, such mental risk assessment slow down the identification process enormously and are insufficiently reliable anyway.
Naturally, the kind of air traffic controller (area, approach, tower or ground control) should be selected that best covers the scope of the operation to be assessed. This holds to a lesser extent for pilots, although there is some difference between pilots regarding the kind of aircraft they fly (heavy, medium or light) and the types of flights they are dealing with (scheduled or chartered;

the latter type of flight more often involves smaller and less modern airports). When several brainstorms are performed it is a good idea to vary with the kinds of pilots.
It is preferred to involve active instead of retired operational experts, although retired operational experts may be very valuable participants.
It is essential that the operational experts have NOT been involved with development of the operation, because if they have, they will generally be unable to play the devil's advocate for the operation they have developed and this will largely drain the energy from the hazard identification process. Another pitfall is to have a superior of the operational experts present as expert on the operation, for instance. This again significantly impedes the right attitude of the operational experts to play the devil's advocates.

4.6.2 Moderator

- A moderator has the complex task to make the brainstorm as effective as possible.
- Experience helps and due preparation is essential.
- It would be good if a safety analyst of the project is the moderator.

The moderator's main task is to make the brainstorming session as productive as possible. This is a complex task as it involves strictly watching the basic rules of brainstorming, making short notes of the hazards on a flipover and subtly steering the hazard identification process along the many dimensions of the operation and possible kinds of hazards. Especially if the brainstorm is a one-time opportunity due to scarce availability of the operational experts, experience and background in brainstorming as well as extensive preparation is important. This report should be especially valuable for moderators, as its primary goal is to provide guidelines for moderating hazard identification brainstorming sessions.

4.6.3 Somebody taking notes

- Somebody else than the moderator has to make more detailed notes of the hazards identified.
- It would be good if a safety analyst of the project takes notes.

Although different recording means are conceivable, simply having somebody note down the hazards (in more detail than the moderator does on the flip over) is a good way.

An untested alternative is to use a notebook computer in combination with a beamer. This may have the following advantages:

- Formulations can be checked right away;

- The moderator can be relieved from summarizing the hazards on a flipover; and
- Projecting the full description of hazards might especially be useful in a multinational context, where correct understanding is more difficult to achieve.

Disadvantages are:

- Correct formulation takes a lot of time (perhaps more than is available at the brainstorm); and
- Correct formulation may distract participants too much from identification: rather 100 hazards of which 5 wrongly formulated and misunderstood than 20 perfectly formulated hazards!

4.6.4 An expert on the operation

- If the operation is complex, it is good to have an expert give the operational oversight presentation and answer questions about it.
- It would be good if the expert on the operation takes notes.

An expert on the operation may be useful for giving a quick oversight (at most half an hour) of the operation and for addressing possible questions about it. This could well be the same person as the person taking notes.

4.6.5 A safety analyst

- A safety analyst of the project is necessary to make sure the hazard identification brainstorm delivers what the sequel of the safety assessment needs.
- It is effective and efficient if safety analyst and moderator coincide.

It is important that a safety analyst of the project is present at the brainstorming session. He/ she is the most suitable person to make sure that the brainstorm delivers what the sequel of the safety assessment needs – as many hazards to the operation as possible.
If possible, the safety analyst and moderator should coincide, as the moderator is most effective with respect to the outcome of the brainstorm. Coinciding moderator and safety analyst will also reduce the amount of preparation the moderator needs. A blank moderator will have to learn many safety issues that are basic to a safety analyst. An example is the difference between hazard, cause and effect. Finally it would take extra effort to transfer the understanding and background of the hazards if none of the safety analysts of the project is at the brainstorm.

An alternative way to keep the number of participants minimal would be to have note taker and safety analyst coincide.

4.6.6 Number of participants to brainstorming sessions

Experience has learned that the aforementioned group of four to six people is quite adequate for brainstorming; it should rather be considered as a maximal than a minimal group!

As mentioned before, experience indicates that the above group of four to six people is quite adequate for brainstorming; with the way of working presented here, it should rather be considered as a maximal than a minimal group. The reason for this is that air traffic controllers and pilots are the main sources of hazards, adding more people to the group will rather hamper these operational experts than help them. More generally, it is well-known in cognitive science (see [11] and [12]) that the productivity of brainstorming groups generally does not grow proportionally with the number of participants. As a matter of fact, there are only a few settings in which the productivity of a brainstorming group surpasses or even equals that of situation where the participants would brainstorm *alone*! For this reason it is advised not to have the project leader participate in the brainstorm: such a session flourishes with a minimal set of persons with necessary expertise (ATCo and pilot) or skills (moderator), which the project leader most probably does not carry.
Larger groups can even severely damage the brainstorm for instance in case some of the additional people are very talkative while the operational experts are shy – group composition is of large influence.
However, sometimes other interests make it necessary to perform brainstorms with more people. In Section 4.7.6 a few hints are given to help making the best of brainstorming with large groups.

4.7 Preparing a hazard identification brainstorm

The preparation of a hazard identification brainstorm involves several aspects:

- Select and arrange the participants, especially the operational experts;
- Prepare an oversight presentation of the operation;
- Prepare the brainstorming approach;
- Prepare the content of the hazard identification (presentation and hazard categorization); and
- Practical aspects of the hazard identification brainstorming.

4.7.1 Selecting and arranging participants

Although selecting and arranging participants to the hazard identification brainstorming session is an obvious thing to do, it should be started long before the actual session, ideally already when developing the project.

Active air traffic controllers and pilots have busy schedules and their time is very precious. Recognition of the project's importance by the employing air traffic service provider or airline is almost essential for obtaining operational expert involvement. Certain types of air traffic controllers may be harder to arrange than others. The demand on approach and tower controllers may be large, while their supply is usually small with respect to that of area controllers.

4.7.2 Prepare an oversight presentation of the operation

Prepare a concise (at most half an hour) presentation of the operation covering:

- The objective of the developed operation;
- Operational context (geometrical description, timeframe, and traffic characteristics);
- Human roles and responsibilities (ATC and pilot point of view);
- Procedures (ATC and pilot point of view); and
- Technical systems (communication, navigation and surveillance).

Use pictures (airspace/ airport layout, schematic diagrams, in- and outbound routes, ...)!

As the operational experts (air traffic controller and pilot) must not be involved in the development of the operation, they have to be informed about the operation in order to know what to brainstorm about. In view of their usually very busy schedules, the best way to do that is to start the session with an overview presentation. This should cover all aspects of the operation but not in a very detailed way. The presentation should be short (say half an hour at most) and preferably use pictures and schemes. Such pictures are useful in guiding the brainstorm as well. Experience shows that it is advantageous to make posters (large paper printouts) of the layout of the airspace or airport under assessment, of inbound and outbound routes, et cetera. Such posters make it possible that different participants think about/ look at different things at the same time, make drawings, et cetera.
The presentation could well be given by the person taking notes or by the moderator. They should understand the concept very well and it is advisable to have the presentation discussed with the operational developers to make sure it is correct and reasonably complete. If the concept is complex, it may be good to have an expert on the operation give the presentation and answer possible questions. In that case the moderator should be consulted before the presentation is actually given, to make sure that it is fit for the brainstorm.

4.7.3 Prepare the brainstorming approach

The moderator should choose a way to brainstorm that will be most productive for the planned group of participants. Most of the information below will be for the standard group of four or five participants. When there are more, the way of brainstorming may have to be adapted, more on this in at the end of Section 4.7.6.

4.7.4 Prepare the contents of the hazard identification

Prepare a presentation introducing hazard identification brainstorming:

- What is a hazard?
- The goal of brainstorming;
- The basic rules; and
- The way of working.

The moderator should make a few presentation slides explaining the goal of the brainstorm, the basic rules and the actual way of working. A notion of the concept of hazard should be given and an indication of the scope of the hazards that have to be identified. No need to define very strictly: that costs time and might restrict the participants of the brainstorm; a few hazards identified outside the scope can easily be filtered out afterwards.

Prepare hazard categorizations according to:

- Operational aspects (see Section 4.7.2);
- Potential conflict types (such as conflicts between two departures, taxiing aircraft and vehicle, ...; which conflict types are conceivable); and
- Flight phases, combinations of flight phases and phases in a conflict situation.

Prepare these categorizations and populate them with hazards using:

- Preliminary scoping brainstorms (performed individually, or by moderator and a safety analyst); and
- Hazard and incident/ accident databases and relevant literature.

Preliminary brainstorming, searching hazard and incident/ accident databases and inspecting literature on related subjects will help to make a preliminary oversight of hazards. This oversight is important to have in the back of the head during the actual brainstorming session as it enables the moderator to steer subtly the hazard identification along the possible categories. Care should be taken in steering the brainstorm: when giving examples it is important to be diverse; and it is better to indicate a category (could there be anything dangerous related to the conflict type where...) than specific hazards. It does not appear advisable to restrict preliminary scoping brainstorms to functional hazards only: the more diverse the prepared hazards and categories are the better for steering the main brainstorm.

4.7.5 Practical aspects of brainstorming

Practical things to arrange for a brainstorm for the standard group of four/ five participants are:

- A quiet room for the period of the brainstorming session;
- A flip-over to let the moderator make notes of the hazards;
- A beamer or overhead projector for presenting; and
- Drinks in (the close vicinity of) the room, so that it is possible to have short breaks.

The quiet room preferably has a round table configuration. Note that the location of the room is important: outside their own premises, participants will be less tempted to check email, talk to colleagues, et cetera.

4.7.6 How to brainstorm with large groups if you must

If you must brainstorm with larger groups:

- Split the group and brainstorm in pairs; or
- Apply “brainwriting”: have the participants silently write down each hazard on a note and pass this to the left neighbour until the note contains four hazards; or
- Before doing a normal brainstorming session, have the participants brainstorm a few minutes for themselves, so that each has a list of hazards; and
- Give the participants notes so they can write down hazard they generate while somebody else is talking.

It is well known from cognitive science (see [11] and [12]) that brainstorming in groups of more than one person has significant production decreasing effects. An important effect is “blocking”: when person A speaks, person B listens and does not invent new hazards himself, and moreover, has his hazard invention process disturbed and has to spend valuable resources in remembering his not yet mentioned hazards.
If the group of participants is bigger than the standard group of four, five or maximally six, measures have to be taken to make the brainstorm productive. Various ways to do that are:

- One of the conclusions of [11] is: if you do brainstorm in groups, brainstorm in PAIRS: Split up the group in pairs of participants that brainstorm with each other;
- From [12]: Have the group sit in a circle, let the participants invent hazards for themselves and note these down on a piece of paper, which they pass to their left neighbour when they have added one hazard. When there are say four hazards on a sheet of paper, this sheet is not given to the neighbour but put on the middle of the table (or handed to the moderator). In this way, there is mutual stimulation, but still sufficient space for participants’ own hazard identification processes.

- From experience: Start each part of the brainstorming session with 5 or 10 minutes during which the participants invent hazards by themselves and note them down; and
- It may be helpful to give the participants notes on which they can quickly note down hazards they invented while somebody else was talking.

Bigger groups of participants may necessitate a different set-up of the brainstorm may have to be chosen in order to make it productive:

- Several rooms or a bigger one with quiet corners, such that subgroups of can do brainstorm separately; and
- A pile of notes or sheets of papers and markers, so that participants can write down a few hazards per note or sheet themselves.

4.8 Performing a hazard identification brainstorm

4.8.1 Program

A good example program for a hazard identification brainstorming session with the standard group of participants would be:

Example program for a hazard identification brainstorming session

- 9:00 – 9:15: Introduction
- 9:15 – 9:35: Present overview of the operation
- 9:35 – 9:45: Present introduction to brainstorming
- 9:45 – 10:15: Brainstorming session part 1
- 10:15 – 10:25: Short break
- 10:25 – 10:55: Brainstorming session part 2
- 10:55 – 11:05: Short break;
- 11:05 – 11:35: Brainstorming session part 3
- 11:35 – 11:45: Short break;
- 11:45 – 12:15: Brainstorming session part 4
- 12:15 – 12:30: Closing of the session: appointment for new session?

- In the introduction there is a short round in which people introduce themselves and a short introduction of the context of the hazard identification: risk assessment of the developed concept of operation;
- About the timing of the whole session, note that, generally, the morning is more suitable for brainstorming than the afternoon – people are fresher and more energetic;
- The introduction to brainstorming should present goal, rules and way of working. Explain that, by playing the devil's advocates the operational experts will actually help operational development;

- The short breaks are just intended to take a coffee, stretch the legs, have a quick chat or visit the bathroom. This may not work for Southern European participants who are used to breaks of at least 25 minutes. Some people may need to smoke;
- In the closing of the session, explanation of the aftermath of the session is given:
  - The note taker will work out hazard list and distribute among the participants with the question to check and adapt where necessary;
  - There will be an evaluation of the effectiveness of the brainstorm and possibly a decision to have another session. If it is already clear at the end of the session that additional brainstorming is necessary, for instance because various hazard categories have not been covered: use the opportunity to make a new appointment; and
  - Thanks to operational experts for their precious time and valuable effort!

4.8.2 Guiding the brainstorm

Tasks of the moderator during hazard identification brainstorming:

- Take strictly care that the basic rules of brainstorming are respected (as many hazards as possible and no analysis/ criticism);
- Make short notes of the mentioned hazards on the flip over using the format “hazard id (number) and short description” and watch that hazards are correctly understood;
- Take subtly care that “all” aspects of the operation and possible hazard categories are covered; and
- Apply short breaks *before* productivity drops significantly, such that the participants can free their memory.

Taking care that “all” aspects of the operation and possible hazard categories are covered is indeed a subtle activity. Instead of mentioning prepared hazards to shift the participants’ attention to operational aspects to be covered, the moderator better mentions a hazard category, in order not to hamper the participants’ imagination by a particular hazard type. Hence the moderator could:

- Draw attention to a not yet covered aspect of the operation on the overview sheet;
- Ask the participants whether there could be hazards related to conflict type…
- Asking the participants to look for hazards related to hazard category…

Note that this needs good preparation of the moderator!

Usually the productivity of hazard identification brainstorming sessions decreases in time. Although this may lead participants to feel that they have come up with most of the hazards they will come up with, this phenomenon is rather caused by participants getting blocked in certain hazard types and operational aspects. A quick break makes them free their memory and makes

hazard production return at the initial high values. Moreover, the moderator can use the quick breaks to check what parts of the operation, what conflict types and what hazard categories are covered well, and which ones deserve attention. Hence, rather than loosing valuable time, the quick breaks increase production, see [12] for more information.
Sometimes, bottles of wine have been promised and rewarded for the most creative and for the last (!) hazard.

4.9 The aftermath of a hazard identification brainstorming session

The following activities are to be performed after the hazard identification brainstorming session:

After the brainstorm session

- Within a few days make and distribute the minutes of the meeting with the numbered list of hazards among the participants, asking them for corrections and additions;
- Check the effectiveness of the brainstorm; and
- Decide if additional hazard identification brainstorming is necessary.

The person that has taken notes converts these to minutes of meeting which are distributed by email to the participants within at most a few days with the request to correct if necessary. Hazards conceived after the brainstorming session are welcome too. It is better to have a few important comments back in a few days than many comments in a few weeks (or not at all).

The moderator and safety analyst check how effective the brainstorm has been:

- Have all prepared operational aspects, conflict types, hazard categories been covered?
- Have hazards necessitating new conflict types and hazard categories been identified? (If not, the moderator has either prepared extremely well, or more probably restricted the brainstorm too much to his prepared material…
- Have most hazards identified in the preparation been re-identified during the brainstorm?
- Are there no, a few or a significant percentage of unimaginable hazards?

Based on this evaluation, it may be necessary to have additional brainstorms.

5 Additional material

In this section, the following issues asked by EUROCONTROL, and described in respectively [7] respectively [9], are dealt with:

- How to combine functional and brainstorming approaches to hazard identification? and
- Quality criteria/ checklists for planning, preparing and evaluating hazard identification.

5.1 Combine functional and brainstorming approaches to hazard identification

Suppose that for a given operational development there will be held a session for functional hazard identification as well as a hazard identification brainstorm. Questions are:

- Could this be useful?
- What would be the best order of functional and brainstorming sessions? and
- Should the same or different people participate?

Before these questions are answered, a more general sketch is given how different approaches to problem solving explore the space of the problem's solutions, based on [12]. It is important that the problem at hand cannot be solved by "logical" methods. It should rather be a problem for which many potential solutions may exist. In such cases it is reasonable to identify many of these in order to obtain a large set of potential solutions, which then can be assessed at a later stage. In the picture below, the abstract space of all solutions to a problem is indicated with a large oval. Various ways of working may be used to explore the solution space. Here, an indication is given of the parts of the solution space that would be covered by a systematic approach (grey shading) and by a brainstorming approach (dotted shading).
The idea is that a systematic approach is able to explore a limited part (the grey oval at the left side of the large oval) of the solution space in a rather dense way, and that a brainstorming approach covers more various parts (the smaller dotted ovals) of the solution space.

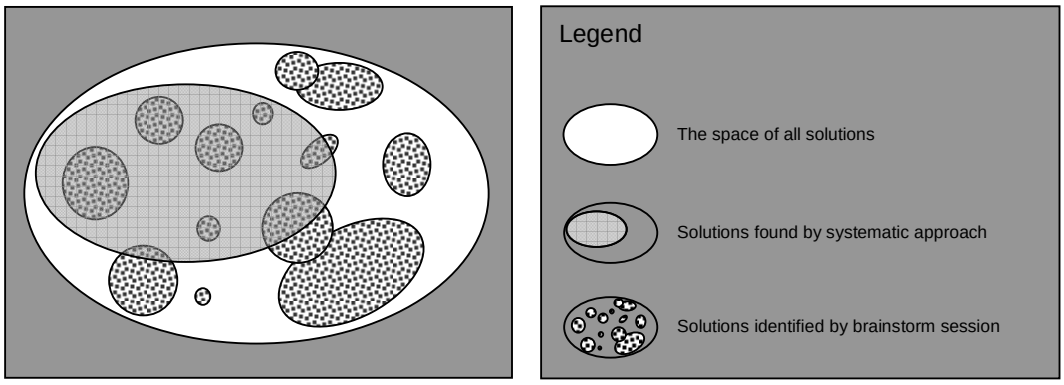

Figure 3: Exploring the solution space in various ways

5.1.1 Could it be useful to combine the functional and brainstorming approach

It is useful to combine functional and brainstorming approaches to hazard identification.

Under the association of:

- The problem with identification of the hazards associated with a new/ adapted operation/ ATM system,
- The systematic approach to the functional approach to identify hazards, and
- The brainstorming approach with hazard identification brainstorming sessions,

the above schematic notion of exploring solution space suggests that it is indeed useful to combine functional hazard identification sessions with hazard identification brainstorming sessions, as they yield different subsets of hazards associated with a new operation. The functional approach will yield a more complete subset of the hazards directly associated with functional failures, hazard identification brainstorming will yield a more various subset of hazards.

5.1.2 What would be the best order of functional and brainstorming sessions?

- The best order of a functional and a brainstorming hazard identification session is to have the brainstorming session first.
- If the other order is used, new operational experts are necessary for the brainstorm.

From [12]: for the systematic functional approach it does not matter much if it has been preceded by a hazard identification brainstorm, the search is systematic anyway. However, if the participants are not completely different, it is detrimental for a hazard identification brainstorm session if it has been preceded by a functional hazard identification session. The reason is that participants of the functional sessions have most probably been fixated in the subset of functional hazards making them much less productive in the brainstorm (see [12]).

First having a brainstorm also has the advantage that it yields a varied subset of the hazards, which helps to spend operational development effort wisely. If a hazard identification brainstorm for instance yields important non-functional hazards, it may not be wise to spend all effort in performing a functional hazard identification session before the operation is redeveloped.

As noted above, if a functional hazard identification session has already been performed and if a hazard identification brainstorming session is to be held, it is absolutely crucial to involve different participants.

In the other case, where a brainstorming session has been held and where functional sessions will be held, it is an open question what people are best involved.

Involving the same people may have a modest efficiency advantage as some things do not have to be told again, but the brainstorming experience probably rather disturbs than helps. It may also be that the best participants for brainstorms and functional sessions are different kinds of people, due to the difference between the more creative and the more systematic approach.

5.2 Quality criteria/checklist for planning hazard identification in the project

Due to dependence on operational concept development and required participation of scarce operational experts, successful hazard identification brainstorming needs to be addressed in the planning phase of an operational development project:

Checklist item	Explanation
Planning 1: Will sufficiently many suitable operational experts (ATCo's and pilots) be available for hazard identification brainstorming?	• Per brainstorming session (more than one session may be necessary) one air traffic controller and pilot are necessary. • For hazard identification brainstorming, it is essential to have "fresh" operational experts that have not been involved in the development of the operation or possible FHA sessions (see Sections 4.6.1 and 5.1.2). • In order to have sufficient operational experts for brainstorming (and other tasks in the safety assessment, such as for instance interviews for studying severity and frequency of hazards), it greatly helps if air traffic service providers and airlines are interested and directly involved in the operational development.
Planning 2: Will there be a sufficiently mature description of the operation before the hazard identification?	• If the role of the hazard identification is to get a quick impression of the hazards, for instance to choose between various options for development of the operation, a less detailed description is sufficient. • A description can also be too mature: hazards identified for a general operation will also hold for a more detailed elaboration (though it may be necessary to zoom in further), but the hazards identified for detailed operation A may not be appropriate for detailed operation B. • If the hazard identification is part of a full safety assessment, the description of the operation has to be quite mature, as it will have to remain frozen throughout the safety assessment. • Whether a description is specific or general, it has to be complete in the sense that all of its aspects (see Section

	4.7.2) are covered. If only parts of the operation are changed, there should be references to descriptions of the other, unchanged, parts.

5.3 Quality criteria/ checklist for preparing hazard identification

Successful performance of hazard identification brainstorming needs careful preparation, typically to be started from a few weeks to months before the actual hazard identification brainstorming sessions.

Checklist item	Explanation
Preparing 1: Has a suitable moderator been arranged sufficiently early?	Moderation is a crucial function in hazard identification, and "ownership" of the way to moderate is crucial, too. Therefore: • A moderator should be involved several weeks before the hazard identification brainstorms, such that he/ she can prepare him-/ herself for moderating in general (especially if he/ she is not experienced), and such that he/ she can do most of the preparation of the brainstorms. • In principle, a safety analyst of the project would be an efficient choice of moderator.
Preparing 2: Have a suitable air traffic controller and pilot been arranged?	• Air traffic controller and pilot must NOT be involved in the development of the operation; • Air traffic controller and pilot must NOT have participated in possible FHA sessions before; • Match the kind of controller (ACC, Approach, ...) and the operation under assessment; vary with the kind of pilots. • Air traffic controller and pilot in active service are preferred.
Preparing 3: Is there a description of the operation that is: • Sufficiently mature; • Understood by the safety analysts and moderator; and • Frozen in agreement with the developers?	• Concerning maturity, see the remarks under Checklist Planning 2 in Section 5.2. Concerning understanding by the analysts: • At the beginning of the brainstorming session there will be an overview presentation of the operation. This can be used to solve small questions. More fundamental questions have to be addressed much earlier. It is important that the developers understand that for a good hazard identification or safety assessment, the operation under consideration cannot change in the mean time. The description of the operation for identification or assessment has therefore to be frozen in agreement with the developers.

Preparing 4: Have hazards and hazard categories for subtly steering brainstorm been prepared?	The moderator and/ or safety analysts should use • Scoping brainstorms; • Literature on related operations; • Hazard databases; and • Incident/ accident databases to get an overview of the potential hazards of the operation and use this, to make various categorizations according to • Operational aspects; • Conflict scenarios; and • Groups of hazards with the same effect or cause. The hazards and, more importantly, the categories can be used during the brainstorm to steer subtly for completeness.
Preparing 5: Have presentations for the brainstorming session been prepared?	It is suggested to give presentations about: • The background of the project; • The safety assessment method in which the hazard identification is embedded; • The operation to be brainstormed about; and • Hazard identification brainstorming rules. Except for the presentation about the operation, which may take a little longer (say ten slides, 20 minutes) all presentations should be very short (a few slides and minutes).
Preparing 6: Have the practical things about the brainstorm been arranged?	Quiet room with: • A round table configuration; • Drinks; • Notebook computer and beamer; and • Flipchart, ...

5.4 Quality criteria/ checklist for evaluating the output of hazard identification

The following questions yield indications of the quality of the output of hazard:

Checklist	Explanation
Evaluation 1: Have the hazards been understood correctly?	• The hazards identified in brainstorming sessions must have been carefully written down quickly after the session, and have been checked by the participants for correctness. • Of course, during the brainstorm the moderator monitors this issue. However, the step from flipchart hazard summaries and notes to extensive minutes needs to be verified.

Evaluation 2: Have sufficient hazards been identified for all prepared hazard categories?	• If there are hazard categories for which no or only a few hazards have been identified, why is that? In case several categories have not been covered in the brainstorming sessions due to a lack of time, additional brainstorming may be necessary. • To some extent this check can be done at the end of the session.
Evaluation 3: Have the brainstorms been sufficiently reproductive?	• Have most hazards prepared via preliminary brainstorms, literature, hazard database and accident/ incident database been (re-)identified in the brainstorm?
Evaluation 4: Have the brainstorms yielded sufficient creative hazards?	• If the operation is relatively new: have the brainstorms yielded surprising hazards? If all identified hazards were more or less foreseen by the moderator and safety analyst, the brainstorm may well have been too restrictive, and the full potential of creative air traffic controllers and pilots has probably not been exploited maximally. • If the operation is a modest adaptation of an operation for which hazard have extensively been identified before, brainstorms may yield only few new hazards, because there are only a few new ones.
Evaluation 5: What percentage of the identified hazards is human related?	Experience has shown that a significant part (at least half) of the hazards is related to human operators. If the percentage is much less, the brainstorm may have concentrated too much on technical systems, for instance.

If there are significant shortcomings related to one or more of the last four checklist items, it should be considered to perform additional brainstorms.

6 Conclusion

This report gives guidelines on how to perform hazard identification brainstorms. These brainstorms are intended as an approach complementary to the functional hazard identification performed in EUROCONTROL's well-known Edition 1.0 of FHA, see [3]. Edition 2.0 of the FHA [13] will incorporate both ways to identify hazards.

With respect to hazard identification, the functional approach to identify hazards proceeds along the following steps:

- Given an new or adapted ATM system/ operation, first its functions are identified;
- Next the possible ways in which these functions may fail are identified, i.e., the failure modes; and
- Then the operational consequences of these failure modes are investigated, and the effects they may have on the safety of the operation (the hazards).

There may be hazards not or not easily associated with functional failures. Hazard identification brainstorms attempt to identify in a direct way anything that might negatively influence the safety of the operation. The creativity and experience of air traffic controllers and pilots (the direct users of the operation) are very effective sources in hazard identification brainstorms.

It is believed that the functional and the brainstorming approached to hazard identification yield different kinds of subsets of hazards associated with the operation: the functional approach will be more complete in the region of hazards associated with functional failures, hazard identification brainstorms yield a more diverse subset. This is illustrated in the picture below:

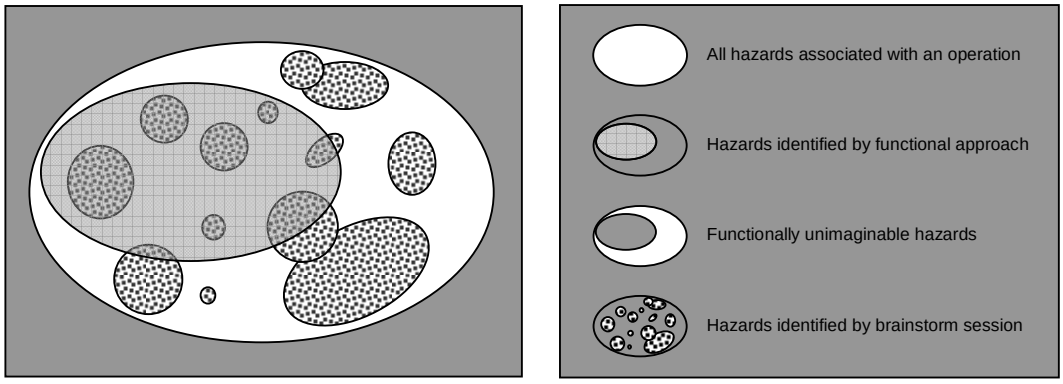

Figure 4: Functional and brainstorming approaches yield different hazard subsets

Extending the functional approach in the FHA with brainstorming approaches to hazard identification is therefore valuable.

When combining, it is strongly recommended to perform first the brainstorms and then the functional hazard identification sessions, as participants to brainstorms will be fixated on functional hazards if they have been involved in functional hazard identification sessions before. Another advantage of this order is that, based on a broad overview of various kinds of hazards, it may occur that there may be better ways to proceed than performing an in-depth analysis of the functional hazards.

It has turned out during literature search and talking to experts, that brainstorming science and techniques have developed far beyond what appears known in the world of ATM safety. It is expected that exploration and development of this knowledge can yield important further improvements in hazard identification for safety assessments in ATM.

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Appendix A A few example hazards for an active runway crossing operation

Several years ago, NLR was tasked by the air traffic service provider of a large airport to perform a safety assessment of the operation where taxiing aircraft cross an active runway. In this appendix we sketch the crossing operation, list a few instructive hazards and state some conclusions and observations of the safety assessment.

A.1 An active runway crossing operation

At the large airport under consideration, a new runway was being built far from the central area with the gates. In order to minimize taxiing times, it was considered to develop taxiways to the new runway that would be as short as possible. These taxiways would cross another runway that would often be used in combination with the new runway.

Since ICAO in principle advises not to cross active runways, the air traffic service provider sought ways how to develop a crossing operation such that it could be performed safely. The crossing operation that was developed, contained two main concepts:

- A new controller concept: the runway controller is responsible for and in direct contact with ALL traffic on or in the neighbourhood of the runway; and
- A runway incursion alerting system, which is aware (via radar and other surveillance systems) of traffic around the runway and which gives alerts when a runway incursion is impending. When an aircraft is approaching or departing from the runway, a number of guarding boxes around the runway are activated, and when a taxiing aircraft or vehicle enters one of these boxes an alert is given. See the picture below:

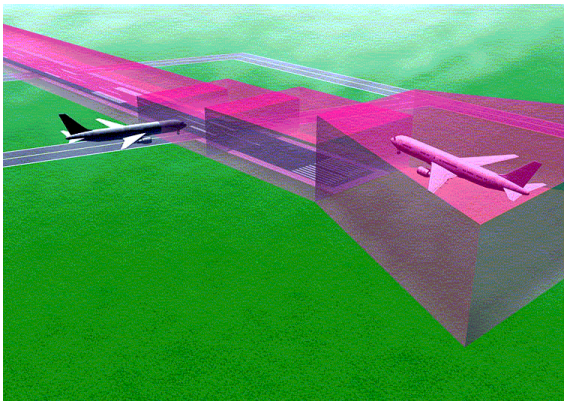

Figure 5: Impression of the logic of a runway incursion alerting system

A.2 Example hazards for the active runway crossing operation

Two hazard identification brainstorming sessions where performed for the operation, and these were supplemented by hazard and incident database searches. A total of about 100 hazard was obtained. Although the database searches yielded a significant portion of the hazards, they were in general more vague and overlapping and less applicable and risky.

A few example hazards:

h1: Runway incursion alerting system reacts too late or not at all;
h2: System gives nuisance alert (for instance triggered by bird control);
h3: Pilot misunderstands ATCo and takes off erroneously;
h4: System generates alert, but ATCo does not react appropriately;
h5: Pilot on the wrong frequency;
h6: ATCo abuses alerting system for efficiency reasons;
h7: Pilot is triggered by the elapsing of the prescribed wake vortex separation time with the previous take-off and takes off without clearance;
h8: Pilot on incorrect frequency and eventually takes off independently*; and
h9: Pilot is mistaken/confused/lost due to taxiway complexity and accidentally enters runway.

*: Hazard h8 was obtained from an incident database; it is not clear how it could occur that the pilot took off independently.

A.3 Some observations and conclusions

The above list of hazards has been ordered with respect to the degree in which they are related to the functioning of the ATM system: The first two hazards would undoubtedly have been identified in functional hazard identification sessions. The next three are less directly connected with the functioning of the ATM system, but they are still quite conceivable and could have been identified by safety analysts alone. Routine violations are increasingly taken account of in hazard identifications according to FHA. The last three are of a more surprising nature, easily identified by operational experts (air traffic controllers and pilots) but hard to identify from a systematically functional point of view. In the last two hazards, functionally independent issues (communication failures in combination with a pilot being lost or taking off erroneous) turn out to be conceivable or actually occurring operational events. Note that the last hazard is not even directly related to crossing aircraft: the aircraft is mistaken/ confused/ lost due to taxiway complexity may not have had the intention to cross.

In the risk assessment that followed, it turned out that the largest risks were related to hazards of the last kind. It was surprising to learn that the related risks were rather insensitive to performance of the alerting system and runway controller: even perfectly functioning alerting system and runway controller would not significantly decrease these risks! Or in more general

terms: it may well be that an operational safety risk cannot be decreased by better performance of technical systems.

Later, an operation was developed with less active runway crossings, a simpler taxiway structure, adapted crossing procedures, measures to decrease the probability of communication problems due to wrong frequency, and without the alerting system.
Hence it is important, especially in the first stages of the development of an operation to perform wide scope risk assessments, not restricted to ATM system functionality.

Appendix B Overview of hazard identification guidelines

B.1 The main activities, inputs and outputs

In these guidelines, the main activities and goals related to hazard identification brainstorming are grouped and order as follows:

Activity	Goal
Plan	• Tune operation definition and hazard identification • Involve controllers and pilots via companies
Prepare	• Arrange participants • Prepare participants and context to make brainstorm maximally productive
Brainstorm	• Obtain as many hazards as possible related to the operation
Evaluate	• Judge if “all” of the operation’s hazards have been identified

In the picture below the main activities are ordered in their context, and their inputs and outputs (products) are indicated:

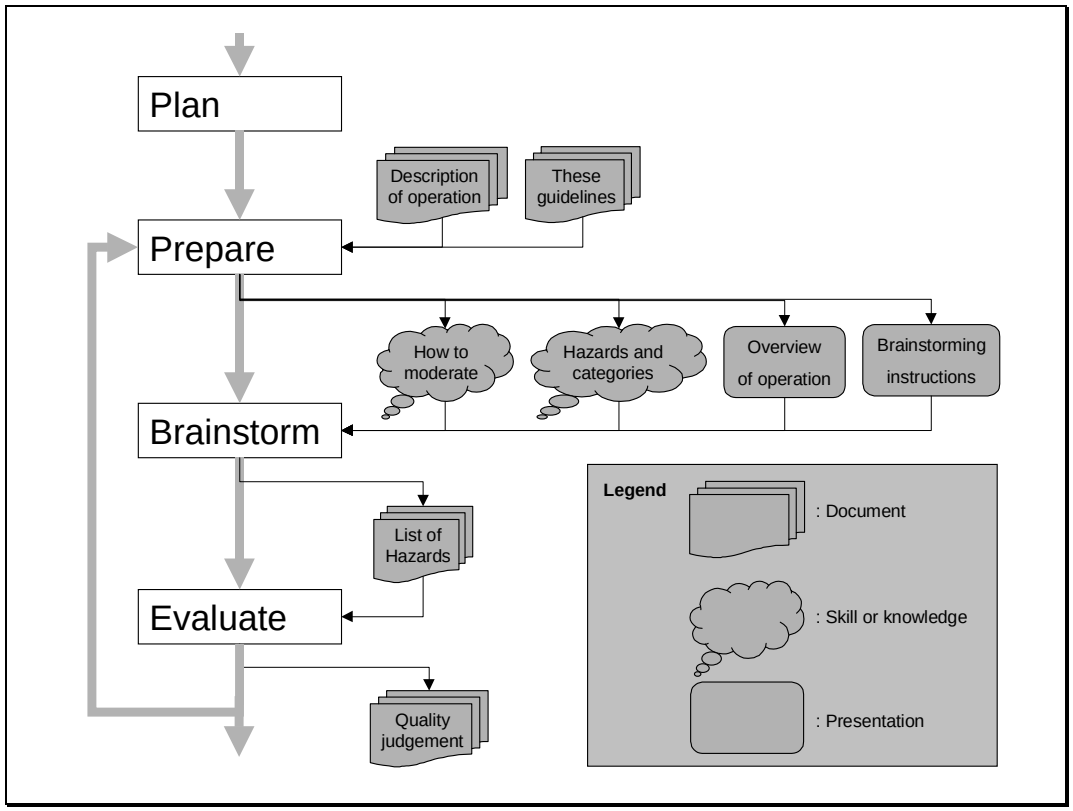

Figure 6: Main activities, their ordering and their in- and outputs

B.2 Detailed activities

Plan	• Tune plans of operation development and safety assessment • Involve ATC service provider and airline for participation ATCos and pilots

Prepare	• Arrange participants
	  • ATCo (NOT involved in development or functional hazard identification)
	  • pilot (NOT involved in development or functional hazard identification)
	  • moderator
	  • somebody taking notes
	  • expert on operation
	  • safety analyst
	• Prepare how to brainstorm
	• Make presentations of
	  • general background of the project
	  • operation
	  • what is a hazard
	  • how to brainstorm?
	• Prepare hazards and categorizations using
	  • preliminary scoping brainstorms
	  • literature, hazard and incident/ accident databases
	• Make a program for the brainstorming session
	• Arrange practical issues:
	  • quiet room
	  • flip-over
	  • beamer
	  • drinks

Brainstorm	• Introduce using prepared presentations
	• Brainstorm
	  • take care that basic rules are respected:
	  • as many hazards as possible
	  • no criticism and analysis
	  • make short notes of hazards on flipover
	  • steer subtly using prepared hazards and categories
	  • apply short breaks before productivity drops significantly
	• Close the session
	  • preliminary evaluation
	  • new appointment?
	  • Thanks!

Evaluate	• Distribute minutes of brainstorm with hazard list, ask corrections and process
	• Evaluate brainstorm:
	  • are all categories covered?
	  • are most prepared hazards re-identified?
	  • are there sufficient surprising hazards?
	  • are there sufficient hazards human related?
	• Decide about having another brainstorming session or not