Nationaal Lucht- en Ruimtevaartlaboratorium

National Aerospace Laboratory NLR

NLR-TP-2006-687

Development of a structured database of safety methods

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This report contains a paper presented at 8th International Conference on Probabilistic Safety Assessment and management (PSAM8), at New Orleans, Louisiana, USA on 14-19 May 2006.

Customer:	National Aerospace Laboratory NLR
Working Plan number:	2005 AT.1.A
Owner:	National Aerospace Laboratory NLR
Division:	Air Transport
Distribution:	Unlimited
Classification title:	Unclassified
	September 2006

Approved by:

Author	Reviewer	Managing department
ME '06	Anonymous peer reviewers	22-12-6

DEVELOPMENT OF A STRUCTURED DATABASE OF SAFETY METHODS

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ABSTRACT

Many techniques and methods have been developed to support the safety assessment process of a particular operation, procedure, or technical system. Since there has been a tremendous growth of method developments in different domains, a complete picture is missing. Hence, for many organizations it is challenging to find the technique(s) or tool(s) that best fits one's purposes.

Through an extensive literature and internet search, complemented by interviews with experts from different domains, a collection has been instantiated of well over 600 safety methods. The list contains methods for hazard identification, for human behavior assessment and for software evaluation, as well as mathematical models, interview techniques, incident databases, and complete methodologies that combine various methods in an integrated way. The methods come from several domains of application, such as aviation, nuclear power industry, telecommunications, and chemical process industry. Subsequently, interviews with various safety experts have been conducted to develop a structured way of categorizing these safety methods and techniques. The paper first describes this categorization development and next gives examples of how this categorized structure works in finding one's way in tools and methods for practical questions.

Organizations may find this structural way of working very useful. It delivers a broad categorized view of techniques, methods or tools that are well in use in other communities, so that one can identify what is successful and fulfils one's own needs, and possibly further adapt it on details when necessary.

1. INTRODUCTION

Inherent to the key role of safety in various safety critical industries, there have been several previous surveys that have collected and evaluated many of these methods; examples of these surveys are:

- [1], which contains a directory of evaluated methods to assess the dependability of critical computer systems;
- [2], which contains a collection of methods for railway applications;
- [3], which includes a survey of hazard analysis and safety assessment methods for use in the air traffic management domain;
- [4], [5] and [6], which contain collections of evaluated (technical) system safety analysis methods;
- [7] and [8], which contain collections of evaluated methods dealing with identifying human errors in high risk complex systems;
- [9] and [10], which provide guides to methods and tools for airline flight safety analysis and for safety analysis in air traffic management.

These surveys illustrate that there has been a tremendous growth of method developments in different domains, and that a complete picture is missing. Hence, for many organizations it is challenging to find the method(s) or tool(s) that best fits one's purposes. This paper addresses this challenge. The aim of this paper is to outline a structured database of methods and techniques that have been developed in support of a safety assessment process of particular operations, procedures, or technical systems, as conducted in various domains.

The paper is outlined as follows: Chapter 2 outlines a generic safety assessment process. Chapter 3 explains how a database collection [11] has been instantiated of over 600 safety methods that each may support one or more stages in a safety assessment process. In this database, for each method, a brief description and references to more information is provided, but in addition there is classifying information like domains of application in which the method has already been used, whether the method focuses more on hardware or software, or more on human factors, to which stages in the generic safety assessment process the method may be of value, etc. Chapters 4, 5, 6 and 7 provide statistics on the number of methods in each of the resulting classes. Chapter 8 explains how this classification can be exploited to select from the database those methods that are of value to one's own purposes, and chapter 9 gives an example of how this has worked in one particular air traffic management application. Finally, chapter 10 gives concluding remarks.

2. GENERIC SAFETY ASSESSMENT PROCESS

Safety assessment is the process through which it is assessed whether increase of demand in an existing operation or new proposed changes do not sacrifice safety and preferably make things better[1]. This means that all possible impacts of a new operation or system should be assessed, and their combined safety effects determined. These potential impacts can be intended (e.g. reducing separation minima between aircraft, and therefore bringing aircraft closer together), or unintended (e.g. new technology may possibly introduce new errors). A safety assessment starts with considering the scope of the assessment (affecting how far the analysis is taken particularly in terms of interactions with other system elements), and then identifying all possible hazards and the severity of their consequences. The analyst then determines how probable these failures are, as well as how likely the operation is to recover from such failures. This culminates in an overall picture of the safety of the operation.

Typically, when such a safety assessment process is conducted, it is documented as a 'safety case', and is used to justify to the regulatory authorities that the new proposed operation or operation change will not adversely affect safety. However, because the safety case will often contain safety requirements and assumptions that are key to ensuring that the operation remains within its safe operational envelope, it should be seen as a living document, and be periodically updated. Ideally it contains information that is utilized initially by the operation designers and then by the operations people for the remainder of the operation's lifecycle.

Once the new design itself is operational, there becomes a need to continually monitor safety performance and archiving relevant data, so the responsibility for safety oversight then transfers to the management of the operational facility. When a trend that could compromise safety is determined to be operationally significant, an appropriate reaction should occur to ensure that the operation returns to its safe performance. Such information on the causes and contributors to incidents and accidents also needs to be fed back to safety assessment practitioners, enabling them to

[1] This section is based on the work done in FAA/Eurocontrol (and NASA, NLR, NATS, CENA) Action plan 15: ATM Safety Techniques and Toolbox, see reference [12].

reduce bias and uncertainty in their safety assessment. The challenge to proactive management of safety is discovering the precursors of the next accident, identifying their causal factors, and implementing the most effective interventions before an accident occurs.

Safety assessment of an operation can therefore be seen as a seven-stage process, as shown below, with two feedback loops. The first refers to 'Iteration', meaning that safety assessment is usually iterative in nature and safety assessments themselves are not always 'once-through' processes. The second feedback loop is safety communication and feedback leading to organizational learning. This communication should be part of all other stages; however, in this paper it is sometimes also referred to as an 'eighth' stage.

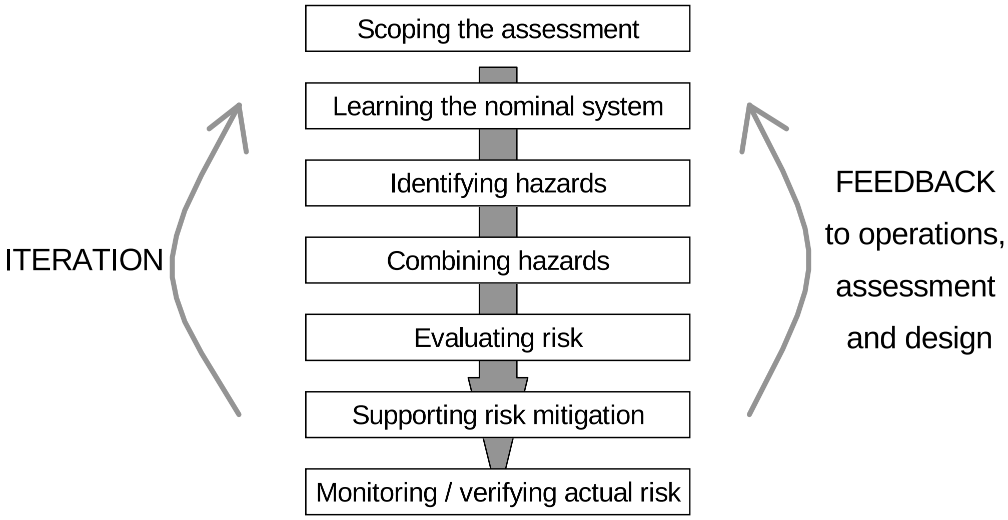

Figure 1: A generalized Seven-Stage Safety Assessment Process, with right-hand-side feedback loop as an 'eighth' stage that should be part of all other stages

The question that remains, however, is how to execute each of these stages during the safety assessment process of a particular operation. Over the last decades, many techniques or methods have been developed to provide support for this, often with emphasis on particular domains. Hence, for many organizations it is challenging to have a complete picture and to find the method(s) or tool(s) that best fits one's purposes. The aim of this paper is to developed a structured database of safety techniques and methods and to provide guidelines for its use.

3. IDENTIFICATION OF SAFETY METHODS

This section describes the development process of a database collection of over 600 techniques, methods, incident databases, models, and frameworks, that each can support one or more of the stages in a safety assessment process. This collection, referred to as "Safety Methods Database" [11] has been developed in two major phases:

The first phase took place in 2002, when a comprehensive survey was conducted by NLR for Eurocontrol, aimed at collecting and evaluating techniques and methods that can be used to support the EATMP (European Air Traffic Management Programme) Safety Assessment Methodology (SAM) [13]. This collection exercise resulted in a list of over 500 methods from various industries (e.g. nuclear power, telecommunications, chemical, aviation, etc.). For each method, various details were identified, like age, type, focus, domain of application, etc. The results are available in [14]. The main sources used for this survey were:

- Several available surveys on safety methods, such as [1–8], which provided numerous methods and descriptions.
- NLR and Eurocontrol experts were interviewed to identify names of additional methods and references.
- Internet searches on safety assessment methods provided many papers published on the Internet, or references for books or documents available in a library. Internet searches also provided details for methods already gathered, such as age, description, full name if only an abbreviation was provided,

domains of application. Usually, these searches led to many names and descriptions of new methods and to new references, and also to previous surveys mentioned above.

The second phase took place within project CAATS SKE II, conducted by a consortium of partners for the European Commission. The list of methods identified in [14] was extended with complementary methods identified in other recent surveys, e.g. [9] and [10], and some additional methods identified by organizations involved in the project. Also added for each method was an indication in which of the eight stages of the generic safety assessment methodology process (see chapter 2) the method can be used. The results are available in [15].

The resulting database currently contains over 600 methods, with many details provided, and is publicly available at [11]. The following four chapters will give some analysis results on the list of methods collected. For details on the individual methods, the reader is referred to the database itself [11].

4. COVERAGE OF DOMAINS OF APPLICATION

The Safety Methods Database includes methods from various domains of application, such as nuclear industry, chemical industry, aviation, telecommunications, health, rail, etc. For each method, the database indicates in which domains of application it has been used to date. The figure below shows for different domains how many of the 628 collected methods have been applied in that domain. Note that one method may cover several of these domains, so some methods are counted multiple times. Also, for some methods the domain of application is unclear (e.g. some methods are generic models, developed with no particular application in mind), hence these are not counted at all.

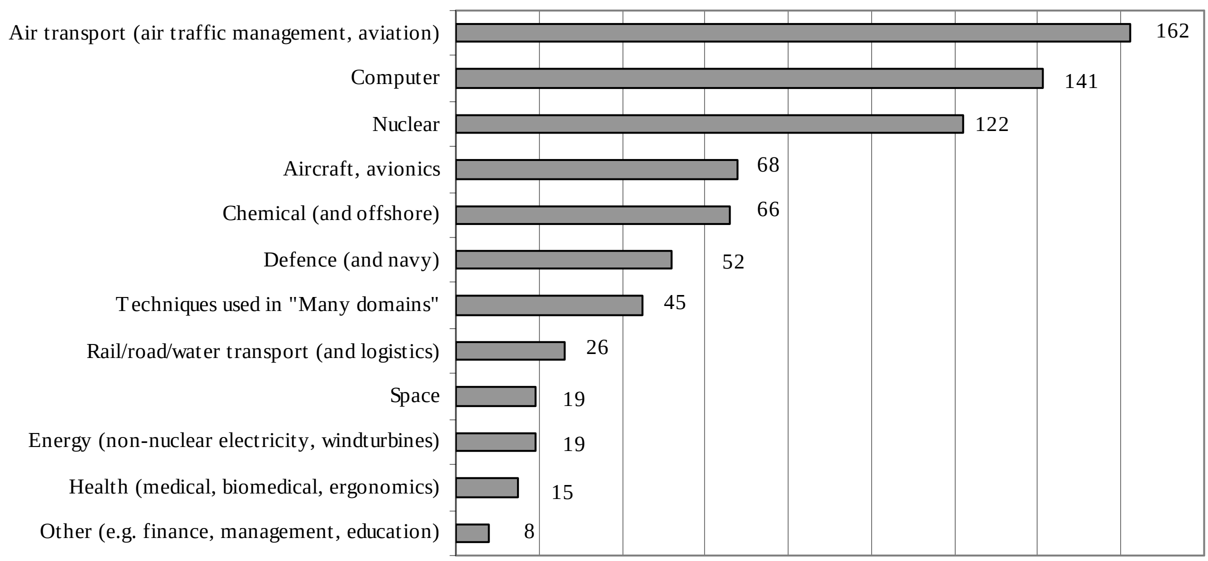

Figure 2: Number of collected methods that cover the different application domains

5. COVERAGE OF GENERIC SAFETY ASSESSMENT PROCESS STAGES

The Safety Methods Database also indicates in which stages of the generic safety assessment process (see chapter 2) the method can be of use. Some statistics are given below. For example, out of the 628 methods collected, 7 methods (i.e. about 1%) support stage 1 (Scope the assessment), 106 methods (i.e. about 17%) support stage 2 (Learning nominal operation), etc. Note that there are very few methods that cover Stage 1.

Also note that a high number of methods indicated does not necessarily mean that that stage is completely supported by methods. For example, all of these methods may focus on only one aspect of the stage, and forget another aspect. On the other hand, if only few methods are indicated to support the stage, the stage may be completely covered by these few methods.

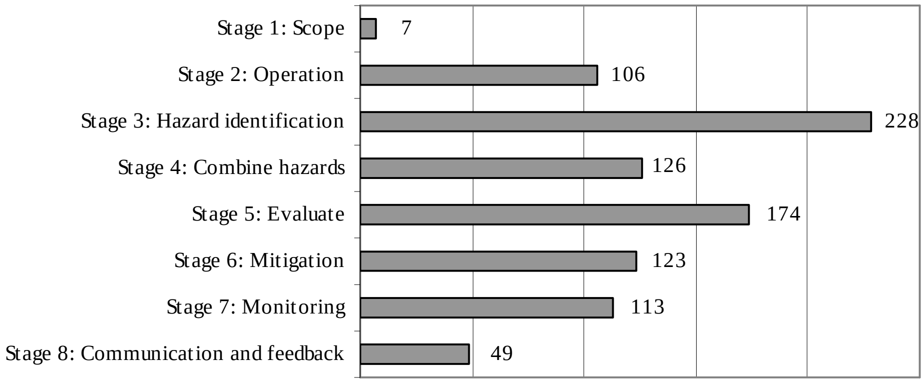

Figure 3: Number of methods that cover the seven + one safety assessment process stages

6. AGES OF METHODS

Another statistic presented in this paper is on the age of methods collected, in terms of year of introduction or development of the method. For 88 of the 628 methods collected, this information was not available. For some other methods, only an estimated year could be identified, and for others only a 'latest' year is available, i.e. the method existed in that year, but it is possible that it was developed earlier than that. The oldest method in the database appears to be dated as far back as 1777 (Monte Carlo Simulation).

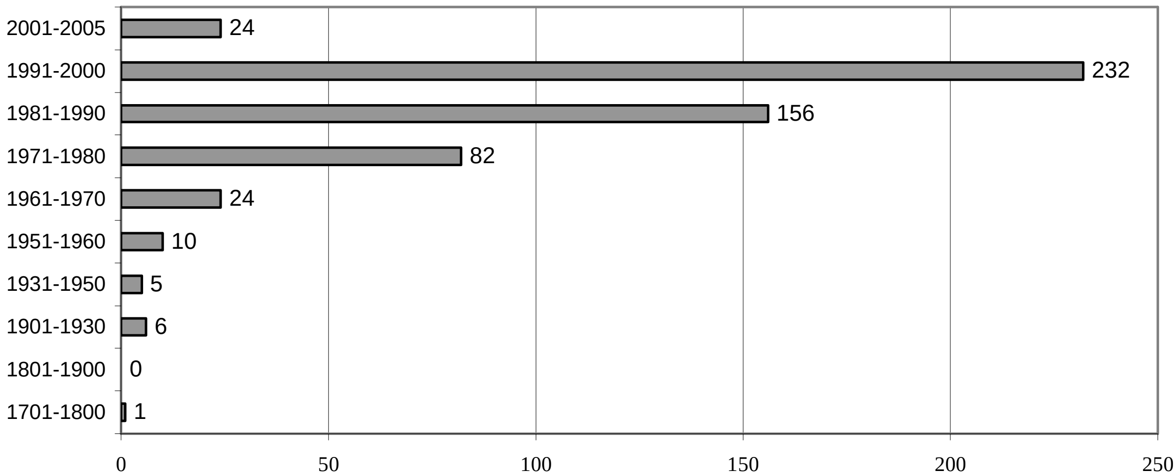

Figure 4: Number of methods per year of development (vertical axis has non-linear scale)

7. COVERAGE OF CONCEPT ASPECTS

Another detail provided for each method listed in Safety Methods Database is whether it is aimed at assessing Hardware aspects, Software aspects, Human aspects, Procedures, or Organization; together, these are referred to as Concept aspects. It appeared that out of the 628 methods collected, 311 methods (i.e. about 50%) can be used to assess hardware aspects; 230 methods (i.e. about 37%) can be used to assess software aspects, 301 methods (i.e. about 48%) can be used to assess human aspects and 171 methods (i.e. about 27%) can be used to assess procedures aspects. Organization is covered by the lowest percentage (68 methods or 11%).

Note that one method may cover several of these concept elements, so some methods are counted more than once. The following table shows how many methods cover which of these elements. For example, the first row of this table indicates that there are 27 methods in the database that cover all five types of concept elements. The second row indicates that there are 10 methods that cover the elements hardware, software, humans and procedures, but not organization, etc.

Table 1: Number of methods that cover the five types of concept elements

Hardware	Software	Human	Procedures	Organization	# methods in this class
x	x	x	x	x	27
x	x	x	x		10
x	x	x		x	0
x	x		x	x	0
x		x	x	x	10
	x	x	x	x	0
x	x	x			11
x	x		x		2
x	x			x	0
x		x	x		44
x		x		x	0
x			x	x	3
	x	x	x		0
	x	x		x	0
	x		x	x	0
		x	x	x	12
x	x				59
x		x			31
x			x		19
x				x	1
	x	x			2
	x		x		0
	x			x	0
		x	x		24
		x		x	4
			x	x	3
x					95
	x				120
		x			126
			x		17
				x	8
311	**230**	**301**	**171**	**68**	**628**
50%	**48%**	**37%**	**27%**	**11%**	**100%**

In total, 262 of the 628 methods (42%) cover more than one concept element (all except the last five rows). This shows that it is not trivial for methods to cover more than one concept aspect; most likely because this requires cross-discipline research.

8. "WHICH SAFETY METHODS ARE OF VALUE FOR MY APPLICATION?"

This paper has made clear that there are many safety methods available, and that these support a range of safety issues. Now suppose that one has a particular safety problem at hand, for example: "I need to know the probability of a collision between two aircraft when they are taking off from parallel runways", or "I need to know the level of workload for the operator when he is doing this complex task", or "I need to know what may possibly go wrong if I replace this procedure by this other one". The question is, which methods are of value to approach or solve such problem? The Safety Methods Database gives guidelines for this. In particular, it gives guidelines when one is asking one or more of the following questions:

- <u>What is the domain of my application?</u> The database contains methods from many different domains, e.g. Air transport, nuclear industry, chemical industry. If one is working in a particular domain, one might consider selecting a method that has been developed or already applied within that domain, since then it will be adapted to the particulars of the domain of application. However, sometimes, one may want to consider borrowing methods from other domains, e.g. if an appropriate method is not available within the own domain. The database indicates for each method in which domains of application they have already been used; see also chapter 4 of this paper.
- <u>Which stages of a generic safety assessment process need to be completed for the application?</u> For some applications, it may not be necessary to complete all stages of the generic safety assessment process. For example, if only a risk level is necessary, but no mitigating measures, then it may not be

necessary to complete stages 6 and 7. The Safety Methods Database indicates for each method in which stages it is applicable; see also chapter 5 of this paper.

- Does my application require a mature method, or are recent developments more appropriate? One may also want to have knowledge on the age of the methods available. Some applications may ask for methods that are well established and well used, while other applications are thus advanced, e.g. because they use new technology, that they require methods adapted to that. The Safety Methods Database indicates for each method in which year it was developed; see also chapter 6 of this paper.
- Does the application have more focus on hardware, software, human elements, procedures, or organization? Some applications have more focus on hardware elements, e.g. a purely technical system like an aircraft, while some applications have more focus on human elements, e.g. workload questions, yet other applications have more focus on procedures or organization. In addition, there are applications that focus on combinations of these elements. Each type of focus generally requires different methods, and the Safety Methods Database provides the classification; see also chapter 7 of this paper.

9. EXAMPLE APPLICATION

Below, we give an example of how a searching process for desired methods may work in practice. Reference [14] describes a comprehensive survey conducted in 2002, aimed at collecting and evaluating methods that can be used to support the EATMP Safety Assessment Methodology (SAM). The survey consisted of three major steps: 1) Identification of candidate methods; 2) Selection of a relevant subset of methods; 3) Detailed evaluation of this subset of methods. The first step resulted in the identification of over 500 methods (see also chapter 3), the third step is described in [14], the second step is described below.

For this second step, a 'Safety Methods Workshop' was organized with the aim to select from the complete list of over 500 candidate methods collected, about 20 methods that would be evaluated in more detail. These 20 methods, if after the detailed evaluation they would turn out to be still useful, could then be used to support safety assessment practitioners when they apply the EATMP SAM.

Before the workshop, the methods had been divided into nine groups as in the table below.

Table 2: Nine groups of methods used as input to safety methods workshop

Group	
1	Databases (e.g. of incidents, accidents)
2	Generic terms rather than methods
3	Mathematical models
4	Techniques and integrated methods for hardware and software dependability, or for hardware only
5	Techniques and integrated methods for software dependability
6	Risk assessment methods
7	Human performance methods
8	Hazard mitigation methods
9	Integrated methods, except for dependability

Within a group, the methods were ordered by age, the oldest methods first. Before the workshop, a few workshop participants had made a preliminary assessment of all methods by indicating which methods, in their view, would probably not pass the eventual selection. During the Safety Methods Workshop, these assessments were taken into account in the final selection. The workshop itself was organized in sessions, each session covering one or more groups as listed in the table above. In total, nine experts participated in the workshop, but the team differed per session, based on expertise required for the group of methods to be assessed. The initial criteria for not selecting a method were:

- Inappropriate or not suitable for ATM (e.g., specifically for nuclear or chemical process plants)
- Outdated; not used (anymore)
- Superseded by another method on the list
- Less suitable for SAM than another method on the list
- Proprietary to a particular organization (and hence unavailable in the public domain)
- Commercial tool (the client did not want to promote one commercial tool over another)

- Too general; more a generic term than a specific method
- Too specific, detailed or limited

The methods in Groups 1, 2, 3, 4, 8 and 9 were evaluated one by one, by assessing them on these de-selection criteria. For Groups 5, 6 and 7 (which were larger), a three-step approach was taken. First, all methods that did not pass the pre-workshop preliminary assessments were removed. Next, the remaining methods were grouped into clusters. Finally, each cluster was considered separately and one (or no) methods were selected from each cluster. For Group 5, the clusters were: Requirements, Design, Verification and testing, Integration, Hazard identification / link with System Safety Assessment, Maintenance. For Group 6, the clusters were: Identification, Make a model, Run the model, Interpretation and Feedback, Mitigation. For Group 7, the clusters were: Safety Culture, Task analysis and Sequencing, Cognitive modeling, Error of commission, Quantification, Performance measurement. During the workshop, the Safety Methods Database was electronically projected on a large screen, so that more details could be looked up in case no participant had proper knowledge on a particular method.

It appeared that, even though the total number of candidate methods to be considered for selection was quite large, the selection process worked well and provided interesting and useful results. The expert resources required were limited due to the fact that to each session only experts were invited that had dedicated knowledge on the group of methods discussed in that session. For example, human factors experts were invited for Group 7; software experts were invited for groups 4 and 5. Eventually, in total, 76 methods were selected, which are listed below. From these 76 methods, 19 were subsequently selected to investigate their immediate incorporation within EATMP SAM [13].

Air Safety Database; Air-MIDAS (Air- Man-Machine Integrated Design and Analysis System); ASCOT (Assessment of Safety Culture in Organisations Team); ASP (Accident Sequence Precursor); ASP (Accident Sequence Precursor); ASRS (Aviation Safety Reporting System); ATHEANA (A Technique for Human Error ANAlysis); BASIS (British Airways Safety Information System); Bias and Uncertainty assessment; Bow-Tie Analysis; CCA (Common Cause Analysis); CHASE (Complete Health And Safety Evaluation); CHIRP (Confidential Human Factor Incident Reporting Programme); Contingency Analysis; CORE-DATA (Computerised Human Error Database for Human Reliability Support); CREAM (Cognitive Reliability and Error Analysis Method); CSSM (Continuous Safety Sampling Methodology); CTA (Cognitive Task Analysis); Data Recording and Analysis; ECCAIRS (European Co-Ordination Centre for Aviation Incident Reporting Systems); Emergency Exercises; EOCA (Error of Commission Analysis); ESSAI (Enhanced Safety through Situation Awareness Integration in training); ETA (Event Tree Analysis); External Events Analysis; FACE (Framework for Analysing Commission Errors); Five Star System; FMECA (Failure Modes Effects and Criticality Analysis); FTA (Fault Tree Analysis); HATLEY; HAZOP (Hazard and Operability study); HCA (Human Centred Automation); HEART (Human Error Assessment and Reduction Technique); HITLINE (Human Interaction Timeline); HPED (Human Performance Events Database); HTA (Hierarchical Task Analysis); HTRR (Hazard Tracking and Risk Resolution); Human Error Data Collection; Human Factors Case; IDEF (Integrated Computer-Aided Manufacturing Definition); INTENT; IPME (Integrated Performance Modelling Environment); ISRS (International Safety Rating System); Job Safety Analysis; Library of Trusted, Verified Modules and Components; MANAGER (MANagement Assessment Guidelines in the Evaluation of Risk); Modelling / Simulation; MSC (Message Sequence Chart); Multiple Agent Based Modelling; NOMAC (Nuclear Organisation and Management Analysis Concept); OPL (Operational Procedure Language); ORR (Operational Readiness Review); PEAT (Procedural Event Analysis Tool); Plant walkdowns/ surveys; PRASM (Predictive Risk Assessment and Safety Management); PRISM (Professional Rating of Implemented Safety Management); RCM (Reliability Centred Maintenance); Real-time Yourdon; Re-try Fault Recovery; Return to Manual Operation; Rule violation techniques; SATORI (Systematic Air Traffic Operations Research Initiative); SCHAZOP (Safety Culture Hazard and Operability; SDL (Specification and Description Language); SFMEA (Software Failure Modes and Effects Analysis); SMHA (State Machine Hazard Analysis); SOCRATES (Socio-Organizational Contribution to Risk Assessment and the Technical Evaluation of Systems); SpecTRM (Specification Tools and Requirements Methodology); SRS-HRA (Savannah River Site Human Reliability Analysis); TOPAZ (Traffic Organisation and Perturbation AnalyZer); TOPAZ hazard database; TRACER-Lite (Predictive Technique for the Analysis of Cognitive Errors); TRIPOD; Usability Heuristic Evaluation; Use of Expert Judgement; WPAM (Work Process Analysis Model).

Since the Safety Methods Workshop described in [14], the Safety Methods Database has been extended with about 100 more methods. Reference [12] describes a selection of methods from this extended version of the database, and with a more generic safety assessment process in mind than considered for [14]. The 11 methods that were additionally selected by [12] are listed below.

Collision risk model (CRM) of ICAO obstacle clearance panel; Gas model; Generalised gas model; Absorbing boundary model; Reich collision risk model; Refined Reich collision risk model; Generalised Reich collision risk model; HERA (Human Error in ATM); PDARS (Performance Data Analysis and Reporting System); SADT (Structured Analysis and Design Technique; Simmod Pro.

10. CONCLUDING REMARKS

The aim of this paper was to present a collection of methods that may support the execution of a generic safety assessment process. The paper describes a methods categorization development and next gives examples of how this categorization structure works in finding one’s way in tools and methods for practical questions. Organizations may find this structural way of working very useful. It delivers a broad categorized view of techniques, methods or tools that are well in use in other communities, so that one can identify what is successful and fulfils one’s own needs, and possibly further adapt it on details when necessary.

ACKNOWLEDGEMENT

The authors wish to thank Patrick Mana (Eurocontrol) for his enthusiastic support to this research, and the following persons for providing input to the database: Michael Allocco (FAA), Mete Çeliktin (Eurocontrol), Oliver Sträter (Eurocontrol), Edwin Van der Sluis (NLR).

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