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The key point of every safety process is hazard identification and management. This is required by many related standards and shall be performed for every project. It's often a challenge to find all possible hazards in advance but it's possibly an even bigger challenge to manage all hazards over a wide range of products and projects. It is therefore necessary to combine the results of several safety assessment activities with field experience of already existing systems. This paper describes in brief the development and the current state of an organization wide hazard management and tracking system, which al1ows for efficient hazard handling. The main goal is to act well in advance instead of reacting to problems in operations, which is both a safety benefit and a commercial one, as we all know about the cost explosion of problem-solving over lifecycle time. The hazard process defines the 'lifecycle' of a hazard: the phases, tasks and responsibilities from its detection to its closing. The gained knowledge about hazards is directly transferred to new projects where they might apply and possibly contribute to accidents.

The key to system safety is the management of hazards. To effectively manage hazards, one must understand hazard theory and the identification of hazards. Hazard analysis provides the basic foundation for system safety. It is performed to identify hazards, their effects and causal factors. It is further used to determine system risk, the significance of hazards and to establish design measures that will eliminate or mitigate the identified hazards and their associated risk.

Hazard Definition: According to MIL-STD-882D (Department of Defense 2000), a Hazard is 'Any real or potential condition that can cause injury, illness, or death to personnel; damage to or loss of a system, equipment or property; or damage to the environment.' A less formal, but helpful definition might be: 'A Hazard is an accident, waiting to happen', for example oil on a staircase. A further, practical definition is: 'A Hazard is a physical condition at the system boundary of the regarded system which could lead to an accident'. Herein it's clearly stated that a hazard is defined at the system boundary. Figure 1 provides the connection between system functions, the possible failure modes and their causal factors within the considered system and several hazards at the system boundary, which then can lead to possible accidents.

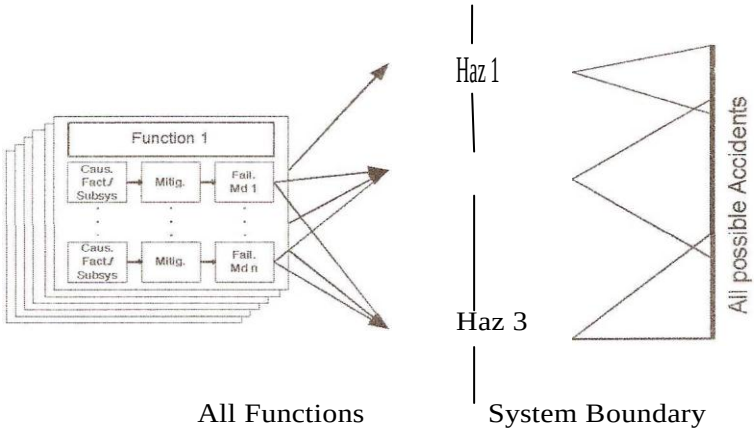

Figure 1: Definition of Hazard

Core System Safety Process: Several standards define different safety lifecycle models, whereas the core of them is always similar. As soon as hazards are identified, their risk has to be assessed and hazard mitigation methods have to be established to mitigate the risk as low as necessary. These mitigation methods are brought into the system design via safety requirements. Hazards are continually tracked until they can be closed.
The core system safety process can therefore be reduced to: Hazard Identification -> Hazard Risk Assessment -> Hazard Risk Control -> Hazard Risk Verification-> Hazard Identification ... (Ericson 2005). This is a closed-loop process where Hazards are identified and tracked until acceptable closure action is implemented and verified.
The relationship between the System Development Lifecycle and the Safety Achievement Process is illustrated in Figure 2. The first row represents a generic and simplified version of the development process. In the second row, the main phases of the safety process are shown, which start with the Safety Process Initialization and continue with the Functional Hazard Assessment (FHA), the Preliminary System Safety Assessment (PSSA) and the System Safety Assessment (SSA). Below each main phase, the primary question to be answered during this phase is shown.

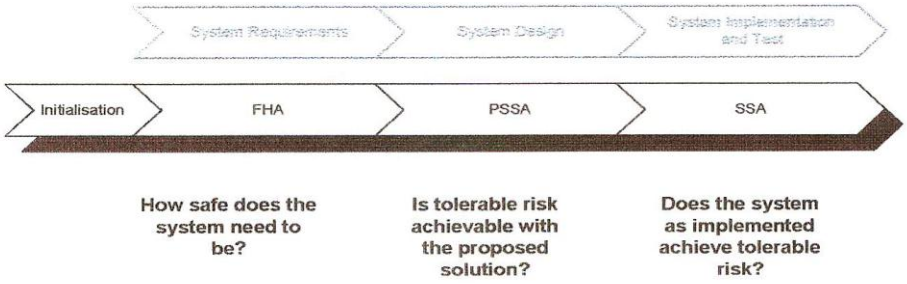

Figure 2: System Development Lifecycle and the Safety Process

The first step in the safety process comprises identification of safety relevant functions within the domain/environment in which the system will be operated.
These functions are the basis for the Functional Hazard Assessment (FHA), for the identification of possible hazards. In workshops with experts - to combine technical, domain and safety know-how - various techniques are applied. This includes brainstorming, use of historical data and functional failure modes and effects analysis to identify possible failure modes, their operational effects and the respective severity of the worst credible outcome. Based on the safety-relevant failure modes, potential hazards are determined and respective risks are allocated according to the risk matrix. The FHA leads to derivation of top level hazards.
Derived safety requirements are defined to reduce those risks which are not in the acceptable area of the matrix and to address safety issues emerging during discussions in the workshops. These safety requirements form a mandatory part of the system requirements and have to be fulfilled and verified accordingly.

Points of Challenge: It is often the case that a system safety program, and therefore hazard management, is required for a specific project.
A typical requirement is given in MIL-STD-882D: 'The contractor shall perform and document a system hazard analysis to identify hazards and assess the risk of the total system design, including software, and specifically of the subsystem interfaces.' But it would be very inefficient to perform such analyses purely on a project by project basis. If we consider each project as a stand-alone, we would miss many important results from former analyses and experience based data from similar projects.
Adequate fulfillment of such a safety process requirement is a crucial point for system safety. It is often a big challenge to find 'all' possible hazards. How can we be sure to have a complete hazard list as input for further activities? And how can we manage the different results of all performed safety analyses to have a set of hazards as an input for the next project? Detailed domain know-how is necessary to perform these tasks and to estimate the operational risk for each hazard.
A further problem is the management of hazards in already fielded systems, especially if new hazards arise after handover of the system from the supplier to the user. It is definitely a challenge to manage

hazards over the whole lifecycle.

Principles of the Organization-Wide Hazard Management

To deal with these problems we implemented a companywide hazard process in our organization, which is the most important safety tool that was developed in the last few years. This process is part of the company's internal mandatory processes, and defines the 'lifecycle' of a hazard: all the steps, responsibilities and time frames from its detection to its complete elimination. The state of each hazard is published in the organization's intranet and can be viewed by every employee, which makes the processing of hazards a transparent activity where everyone has to participate actively or passively.

Hazard Log: The Hazard Log is a database containing all our systems (independent from the life cycle phase) and all known hazards. 'Known Hazard' in this case means that this problem has already occurred, either during development or operation. We call these hazards 'Technical Hazards' to distinguish between such already emerged safety relevant technical problems and theoretical hazards, derived from safety analyses. After contract award, new projects are entered immediately into this database. Every hazard, once defined, stays in the hazard log, even if it is closed companywide, just as a project remains in it over its whole lifecycle.

Main Goal: The main goal is to act well in advance instead of reacting to problems in operation, which is both a safety benefit and a commercial one, as we all know about the cost explosion of problem solving over lifecycle time. Hazards are therefore assigned to all projects or systems where they might possibly contribute to accidents. As soon as a new project is acquired, all known hazards of the corresponding product family are checked for applicability. All open hazards of the same product are automatically assigned.
The Hazard Log Database provides the central record of the company-wide Hazard Tracking process. It provides a means by which the resolution of safety issues is monitored. The company-wide hazard process is a continuous assessment of all projects (and respectively their delivered systems) and products, which enable the identification of potential hazards, the classification according to their severity and probability, the assessment of their tolerability and the initiation and tracking of corresponding risk resolution activities.
Defined hazards have to be taken into account at development as soon as possible to assure elimination at the next product release.

Main Input: The most important Safety input is information!
All employees are responsible for passing on any safety-related information to the safety management department. A company-wide error database, called ERRSYS, is used for error handling and as a basis for safety data. Every entry can be classified in four severity levels and as company-wide, system-specific or project-specific. The ERRSYS database is regularly checked by the safety team for any potential new hazard.

Main Output: The most important output is the hazard checklist. The purpose of this checklist is to prevent hazards in a new project that are similar to hazards already known in other systems. Checklist questions are derived from existing hazards, asking for the root cause mechanisms of those hazards. For every product family the applicability of the checklist questions is decided. All applicable questions have to be answered prior to a product release to increase the awareness of the developers of the possible problems and to avoid their implementation.

Management Responsibilities: The unique hazard performance figures, which we use as a part of a management information system, give all departmental managers quick and concise information about the safety status of our systems.
There are three main hazard performance figures:

- Performance figure 1 is related to project management and gives the number of hazards in a project not eliminated one year after finding a technical solution, divided by the total number of projects.
- Performance figure 2 is related to the development and gives the number of hazards without released technical solution.
- Finally, performance figure 3 is a combined measure for project management and development to

cover the number of hazards where actions for all affected projects are not decided within three months after finding a technical solution.

Every head of a project management group signs in his annual business contract the firm intention to reach a hazard free state of his projects according to hazard performance figure 1 as well as the heads of the development departments sign the same for performance figure 2. In addition the hazard status and all activities associated with hazards are reviewed by the Quality Manager and the Safety Manager as a condition for every delivery release. To give managers a personal incentive to keep the number of open hazards down, their bonuses depend partly on these figures.
To emphasize the importance of hazard management, a quarterly report is produced, in which the current status of the hazard log and the defined actions are reported to the executive board and the top management of the company.

Hazard Process

Figure 3 provides an overview of the Hazard Process according to the internal process management. In general, the main process tasks for safety are gathering and editing information, make decisions, distribute the information and administrate this.

Figure 3: Simplified Hazard Process

Everybody, including the customer, is responsible for considering safety implications and identifying possible hazards. The main activities during this phase are the following:

System Hazard Cross Reference Matrix: For each new hazard, a system/hazard cross reference analysis is carried out. With this task, the applicability of a new hazard is investigated for each system under the supervision of the hazard log. This analysis results in the adaptations of the primary hazard entries, and initiates the respective project specific actions.

Hazard Reporting: Newly identified hazards are distributed after their definition as hazards according to the hazard process to the management boards and to all possible affected employees. The current status of the Hazard Log Database is presented in the company intranet. All hazards can be found in ERRSYS in the internal hazard project. There, every hazard number and every project specific hazard is administered. ERRSYS is the error change request, open item description and administration tool (FRACAS tool), which is used throughout the company. ERRSYS features the tracing and documentation of all errors - hardware, software or other errors - that occur within product development or project lifecycle, from the integration phase onward. It is accessible by every employee via the company wide intranet.
Once an error has been detected, it is permanently stored. Its status can be retrieved at any time.

Hazard Classification: We have defined an appropriate risk matrix, shown in Table 3. The categories are defined in Table 1, derived and adapted from MIL-STD-882D, extended with specific definitions for our application. The severity definitions differ according to the domain-specific needs. Table 2 shows the probability definitions.
The combination of the hazard severity and the hazard probability defines the hazard risk classes. These classes are listed in Table 4 with different levels of tolerability: Class A forms the intolerable area of the risk matrix, Class B and C the tolerable area and class D means acceptable risk.

Category Definition

Catastrophic

General: A failure which may cause death, system loss, or severe property or environmental damage.
Specific ATC: The mission of the system is unavailable for an unacceptable period of time. There are no back-up facilities to compensate the absence of the mission.
Examples ATC Applications: Total loss of the Core Switch for more than one minute.
Specific Voice Recording: The mission of the system is unavailable for an unacceptable period of time. There are no back-up facilities to compensate the absence of the mission.
Specific Maritime: The mission of the system is unavailable for an unacceptable period of time. There are no backup facilities to compensate the absence of the mission.
Specific Public Safety: The mission of the system is unavailable for an unacceptable period of time. There are no back-up facilities to compensate the absence of the mission.
Examples:
1) If an emergency call IS no group call and is lost without notification, then the mission of the system is not fulfilled.
Specific Public Transport: The mission of the system is unavailable for more than three minutes. There are no backup facilities to compensate the absence of the mission.
Examples: Total loss of the Ground Switching Centre (GSC), detraction of the GSC in a way that no operational service is possible for more than three minutes.

Critical

General: A failure, which may cause severe injury, major system, property or environmental damage.
Specific:1be mission can be re-established within an acceptable period of time, either by reconfiguratiol1 of the system or by use of back-up facilities. The use of these alternatives leads to physical distress or higher workload such that the personnel operating the system cannot be relied on to perform their tasks accurately or completely.
Examples A TC Applications: Loss of a specific number of controller positions, loss of roles, total loss of the Core Switch for less than one minute.
Specific Voice Recording: The mission can be re-established within an acceptable period of time, either by reconfiguration of the system or by use of back-up facilities (e.g.: 50% of channels lost, no replay possible, loss of data, etc.).
Specific Maritime: The mission can he re-established within an acceptable period of time, either by reconfiguration of the system or by use of back-up facilities. The use of these alternatives leads to physical distress or higher workload such that the personnel operating the system cannot be relied on to perform their tasks accurately or completely.
Specific Public Safety: The mission can be re-established within an acceptable period of time. either by reconfiguration of the system or by use of back-up facilities. The use of these alternatives leads to physical distress or higher workload such that the personnel operating the system cannot be relied on to perform their tasks accurately or completely.
Examples PS:
1) If an emergency call is a group call and is lost or not noticeable on an Operator Position (OP), but can be handled by another OP.
Specific Public Transport: The mission can be re-established within three minutes, either by reconfiguration of the system or by use of back-up facilities. The use of these alternatives leads to physical distress or higher workload such that the personnel operating the system cannot be relied on to perform their tasks accurately or completely.
Examples: Decrease of important functions of the GSC and/or deactivation or reduction of important functions of the GSM-R Application Server e.g. breakdown of the routing server (fallback to default routing)

Category Definition

Marginal

General: A failure, which may cause marginal injury, marginal system, property or environmental damage.
Specific: The failure will result in reduction of system capability/performance or mission degradation. The users can maintain the mission of the system by other means.
Examples ATC Applications: Loss of a communication path, e.g.: loss of one radio interface or one controller working position.
Specific Voice Recording: The failure will result in reduction of system capability/performance or mission degradation up to a defined critical level (e.g.: loss of single IF, monitoring system, housekeeping jobs, archiving, instant replay, etc.).
Specific Maritime: The failure will result in reduction of system capability/performance or mission degradation. The users can maintain the mission of the system by other means.
Specific Public Safety: The failure will result in reduction of system capability/performance or mission degradation. The users can maintain the mission of the system by other means.
Specific Public Transport: The failure will result in reduction of system capability/performance or mission degradation. The users can maintain the mission of the system by other means.
Examples: Deactivation or reduction of medium or lower level system functions, faulty GSM-R Dispatcher. General: A failure, which does not cause injury, system, property or environmental damage.

Negligible

Specific: The failure will result in unscheduled maintenance or repair. The failure has no effect to a required operational or mission function.
Examples ATC Applications: Loss of redundant system components.
Specific Voice Recording: The failure will result in unscheduled maintenance or repair. The failure has no effect to a required operational or mission function. (e.g. loss of redundant system component)
Specific Maritime: The failure will result in unscheduled maintenance or repair. The failure has no effect to a required operational or mission function.
Specific Public Safety: The failure will result in unscheduled maintenance or repair. -The failure has no effect to a required operational or mission function_
Specific Public Transport: The failure will result in unscheduled maintenance or repair. The failure has no effect to a required operational or mission function.
Examples: Loss of redundant system components.

Table 2: Hazard Probability Levels

Level	Id.	Probability per h	Definition
Frequent	a	$P \geq 10^{-3}$	may occur several times a month or more often
Probable	b	$10^{-3} > P \geq 10^{-4}$	likely to occur once a year
Occasional	c	$10^{-4} > P \geq 10^{-5}$	likely to occur once in the life of the system
Remote	d	$10^{-5} > P \geq 10^{-6}$	unlikely but possible to occur in the life of the system
Improbable	e	$10^{-6} > P \geq 10^{-7}$	very unlikely to occur
Incredible	f	$10^{-7} > P$	extremely unlikely, if not inconceivable to occur

Decide an Initial Hazard Probability: The hazard probability always refers to a system. If a project has more sites, each site is considered as a system. The hazard probability for a project is given by the site with the highest hazard occurrence probability. Often bigger sites have a higher hazard probability than smaller sites.
In the classification in the hazard description and in the Hazardlog Database, the worst case probability of all affected projects is defined. Therefore, each system shall be individually analyzed, in order to estimate the correct probability.

Table 3: Risk Matrix

	Hazard Severity			
Hazard Probability	CATASTROPHIC	CRITICAL	MARGINAL	NEGLIGIBLE
Frequent	A	A	B	B
Probable	A	B	B	C
Occasional	B	B	C	C
Remote	B	C	C	D
Improbable	C	C	D	D
Incredible	C	D	D	D

Table 4: Risk Class Interpretation

Risk Class	Interpretation
A	Intolerable
B	Undesirable and shall only be accepted when risk reduction is impracticable
C	Tolerable with the endorsement of either the Project Manager together with the internal ordering party or the Safety Director
D	Acceptable with the endorsement of the normal project reviews

Hazard Decision: A problem is decided to become a Technical Hazard within the companywide hazard tracking system if the following criteria are fulfilled:

- The problem is safety relevant.
- The problem is present in more than one project.
- The problem risk class is A, B or C. Class D is considered as acceptable.
-

Then the data collection starts to complete the corresponding problem reports:

- Original cause
- Complete failure description 'with technical effect
- All affected systems (products) and affected range of known file versions
- All identified affected fielded projects using these affected systems

Original cause, complete failure description and affected systems are often provided by the hazard owner. This is usually a member of the development team, who has the technical knowledge for the specific problem.
In order to improve the efficiency and transparency of the hazard processing, changes in the handling of hazards have been introduced to enable hazard processing for a high number of fielded systems. All hazards open in the Hazard Log will be tracked through ERRSYS.

There are some advantages for Project Managers from using the ERRSYS records for hazard tracking:

- A hazard can be treated like an error, which means that the handling, update and closing can be done in a familiar environment.
- It is possible to get an overview of which projects have a certain hazard assigned or closed, in order to check how the problem was solved by other projects.
- The due dates of the hazards in the projects can be easily extracted.

- Through filtering, it is possible to extract a list of all hazards that fulfill certain criteria, e.g. all hazards, which are assigned to a certain Project Manager.
- If a Project Manager changes project, he can transfer the hazard to the new Project Manager and Safety will be notified.
- By the transfer of a project to the maintenance department, the ERRSYS number could be used as a hazard identifier, with its complete event history. This means no information loss.
- Easy access to hazard status information and which actions can be taken, in order to close the hazard.

But there are also some advantages for the Safety Management Department:

- The hazard history, actions taken and the current status are preserved in ERRSYS, which makes the tracking easier even after several years.
- No hazards arc forgotten, because the due dates help safety management to monitor the hazards of the projects and to focus on projects with past due dates.
- If the hazard transfer between Project Managers is made correctly, the project lists can easily be kept up to date and the correct Project Manager is contacted regarding hazard issues.

Basic ERRSYS Structure: For each hazard number, a superior ERRSYS entry will be opened. This record contains the current hazard status and shows where to get detailed information about the hazard and its subordinated ERRSYS records in projects. This ERRSYS ticket is called the parent record for a hazard.
For each open hazard in any project, a child record is opened and linked to the parent record. This project specific record will be assigned to the responsible Project Manager. The due date of the record will be defined by the Project Manager or be set to the default value (see below). The child record contains information about how to close the hazard, its status and history.

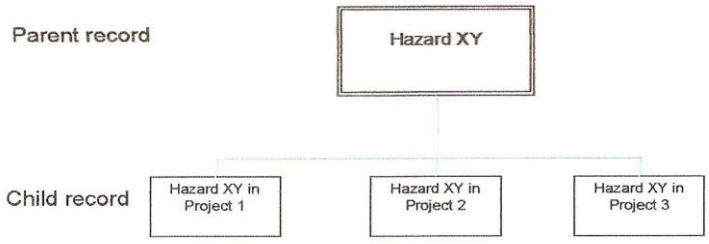

Figure 4: The connection between parent (hazard number) and child (project) hazards

Project Structure in the Hazard Log: Projects are also categorized in parent projects and child projects. A parent project is an active or closed project, which is representing one or more real systems at certain locations. A product may also be a parent project, as it represents a complete system. A child project is a project derived from a parent project. This can be either if the project does not represent a whole standalone system (e.g. repair, expansions) or if a project is obsolete and replaced by a newer one (e.g. projects, which are transferred to maintenance).
In order to manage over 1,000 projects by Frequentis, projects are grouped under a parent project. The responsible Project Manager for the parent project is responsible for its child projects, too. If a hazard is opened in a child project, it is shown in the parent project as well.
Procedure for Projects: After definition of a new hazard all affected projects have to be opened in the Hazardlog Database, in order to open a project specific hazard in ERRSYS as the ERRSYS record is linked with the ERRSYS record in the Hazardlog Database. A parent record is created and the project specific ERRSYS record is opened by Safety. Detailed information, such as due date, operator, references, and related tickets, is added. In addition the Hazards Checklist is sent to the projects, and the respective project managers are responsible for delivering the related information in detail. All open items from the previous release or project are listed. Then the project team has to answer if the open it= has been closed or not.
After finishing the action items for the project, the Project Manager reports the solution in the solution field of the ERRSYS record. It shall be detailed why the hazard is no longer opened or why the hazard can be waived (e.g. customer accepts the risk). The Project Manager sets the hazard status to 'close' and the Safety Engineer has to

confirm that the solution is implemented and the argumentation is sufficient. Only the Safety Engineer is allowed to set the status of the child record to 'closed'.
The hazard is closed in the Hazard Log Database referring to the solution in the ERRSYS record.
Solutions: A Hazard is solved if there are defined actions available for all affected projects. This could be

- A technical solution
- Letters to the customer for risk mitigation on site
- An escalation to one of the management boards, if the hazard has risk class A or B
- Or the decision to do nothing, if the analysis results in risk class D

Communication of Hazards: Internally, the company uses the Hazard Log to communicate hazards to all affected persons or groups.
In case hazards or necessary controls are identified which are outside the scope of the system, these will be communicated to the customer immediately via the regular project progress reports. All identified hazards, assumptions, and necessary controls will also be explicitly listed in the Equipment Safety Case.

The last major phase is the Closing one. The hazard analysis is closed if the following criteria are met:

- The problem report is completed
- All affected projects are assigned in the Hazardlog Database
- All technical solutions have been defined and released

After the hazard analysis is finished, a question based on the hazard root cause failure mechanism is created and added to the hazard checklist. The Independent Verification and Validation Group (IV & V) generates a respective test case. These test cases are collected in a Hazard Test Procedure Book.
All hazards in the projects are monitored in the Hazardlog Database and in ERRSYS until the hazards are solved, waived or the system is taken out of operation.
Finally, only if all open project specific hazards are closed, the hazard itself can be closed in the database.
Missing/unclear/inconsistent information: It's probable to have missing or unclear information of the problem if the various information sources have different opinions about the specific problems. A problem could be a single event which could not be reproducible. It's often not easy to estimate the probability of occurrence or to identify all possible effects of an error.
Actions to be taken in time: Another problem is that actions have to be taken in time to avoid delivery with possible problems within the system and to enable combination of planned customer visits with hazard updates. This means that there is sometimes not enough time to analyze a hazard in detail. Suitable solutions have to be defined together with the end-user.
No general entry point for management of root causes: This should be established in a company to prevent loss of knowledge about technical problems for future projects. A sufficient knowledge management is the key for future success.

Apart from these points we have already some further improvements in progress:

General Safety Requirements: We defined a set of general safety requirements, which are adaptable for all products. The requirements are based on past field experience (and therefore based on the root causes of the technical hazards) and/or based on safety analyses of previous products or projects.
All products have to go through the various phases of the safety process shown in Figure 2. One outcome of the FHA-phase is the definition of system safety functions and related failure modes. The failure modes are categorized according to the severity of their worst case end-effect. Hazards are then identified based on each safety related failure mode and assigned the worst of the related failure mode severities. Any mitigation means defined by the development team, composed of experts of all relevant groups at the company, form the basis for the definition of safety requirements imposed on the product and its development.
These requirements can possibly replace the Hazard Checklist in future, which leads to easier usage and to the possibility of combining theoretical and already occurred problems.

Hazard costs: And finally an improvement regarding financial issues. We defined a method for cost estimation for each hazard type, which helps for project risk planning and to enable company-wide hazard cost estimation.

Conclusion

It has been a long way of process development to reach our current state of hazard management and there are still enough possibilities for improvement. Hazard management as well as safety management in general are qualities that cannot be implemented in a company within a few days. They have to be built up with care, with commitment from the very top of the company and with much enthusiasm and especially endurance of the involved departments. We are convinced, though, that it is worth the effort!

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Biography

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