SOL – Safety through Organizational Learning. A Computer assisted Event Analysis Methodology

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Abstract:
Accelerating technological development leads to an increased importance of safety aspects for organizations as well as for their environment. Therefore, especially in the case of high hazard organizations an expanded view of safety--system safety--is needed. These organizations need appropriate structures as well as rules for the treatment of safety relevant events to ensure their safety and reliability. These structures and rules are part of the safety management of an organization, here the feedback-control strategy. A core aspect of feedback control is the learning from operational experience. Organizational weaknesses and latent failures should be identified by permanent monitoring and systematic analyses of events and near-misses or organizational surprises to generate adequate measures for the prevention of comparable events. Results of event analyses should lead to the learning of the organization with the goal to obtain higher reliability and safety. The learning bases are analyzed events fed to a database. The systematic analysis of events can therefore be seen as the starting point for learning from operational experience, thus, valid methodologies for event analysis are important to gain a valid base for the subsequent processing of learning. The Research Center Systems Safety developed an event analysis methodology called SOL --Safety through Organizational Learning--which helps to overcome the above problems. The paper deals with a short description of SOL and the computer supported SOL-VE as well as with the experimental and practical evaluation, which proved that SOL is a valid methodology that gives sufficient support to analysts.

The Organizational Learning Metaphor

People learn from errors: It is by now a truism, of course: errors are constitutive of human nature ("errare humanum est"). And we know that errors are important for individual learning. However, even though also people in high hazard work systems learn, such individual learning does not necessarily imply safer systems. Apparently, more is needed than just individual learning in order to improve systems safety.

Organizations learn from events: In high hazard systems it is safety which must be considered as the most critical performance parameter. We have two basic analytic strategies to optimize this parameter: *feed-forward control and feed-back control* of safety. Feed-forward techniques are considered as state of the art and are commonly employed for improving probabilities of safe systems conduct ([1, 2]. These are such analytic methods as Probabilistic Risk Assessment (PRA), Probabilistic Safety Analysis (PSA) or Human Reliability Analysis (HRA), commonly used in the nuclear industry, in aviation and space industry.

However, conceptual notions and pragmatic tools of feedback control still remain in dire need of development [3]. In this context organization sciences with increasing frequency evoke the metaphor of organizational learning [4].. Although the metaphor may be liable to questionable anthropomorphic generalizations, casual observations and systematic studies demonstrate that organizations for better or worse do retain knowledge of past experience [5]. Events in an organization's history may thus be attributed to constitute promising material and triggers for organizational learning [6].

Events may be defined as

occurrences of unexpected, undesirable system states

either with negative consequences or without. Thus, event is seen as the general term including incidents, accidents and near-misses. Basically, events are organizational surprises [6]. The better we understand the factors and their interaction which led to events, the better are the chances to utilize such experience to improve safety. However, the veracity of this conjecture will depend on the organization's success to make valid and reliable inferences from analyzing history, especially small histories, single or infrequent cases which are typical for high hazard – low risk organizations.

The analysis of events is fundamental for organizational learning. An event analysis is the later reconstruction of the occurrence of an event as well as of its causes in the sense of a root-cause analysis, i.e. the identification of WHAT happened and Why it happened. The answer to the what-question requires a detailed description of the course of the event. The answer to the why-question calls for the identification of as many contributing factors as possible. The concept of contributing factors is somehow different from the concept of a rout-cause, even factors with a weak causal relation are seen as relevant for learning. For the identification of contributing factors the analyst has to go beyond the given information, i.e. make causal inferences. Therefore, we define **event analysis as the socially accepted reconstruction of an event or a surprise**. The task at hand poses both, an epistemological and an organizational, practical problem, [7] because any event analysis (EA) has to go beyond easily accessible information and inescapably has to conjecture causal relations between antecedents and consequences.

The *epistemological issue* refers to the need of an adequate **theoretical conceptualization** which reflects as closely as possible the dynamics of the contributing factors and defines the realm of their potential origin. This is where theories of accident genesis come in handy [8]. Various theoretical models for EA have been proposed such as the model of events sequence [9] the energy transfer model [10] or the accident causation model [8]. We favor the socio-technical systems model of event genesis [11] which subdivides the system components into five parts: the technical sub-system and the parts of the social subsystem: individual, team/work group, organization, and extra-organizational environment. Events are conceived as multi-causal and interconnected sequences of micro-events based on contributing factors which may emanate as directly or indirectly contributing from any of the five sub-systems.

The *practical issue* is contained in the task of a proper design and institutionalization of organizational learning, i.e. its **practicability** [12]. Practicability of organizational learning will be conditioned by at least two characteristics: **manageability** of event analyses

by organization members themselves and the **economy** of methods employed. Event analyses which are conducted by members of the respective organization offer the most direct opportunity to learn since feedback and distribution of relevant information gathered is inherent in the analytic process itself. The need for economic properties of the analytic procedures follows from the infrequency of events which suggests that as many events as possible, including near misses, should be analyzed.

Analysis of events is always a retrospective analytic process to identify all relevant contributing factors and to reconstruct their dynamic interaction in the production of the event. This requires **comprehensiveness** of the analytic framework. Comprehensiveness is called for simply because

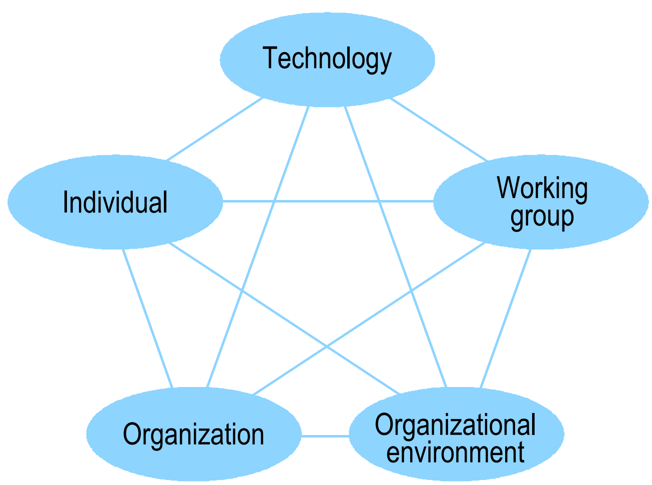

Figure 1 - Pentagon

of the general human nature to stop a causal analysis the very moment a "cause" is found which strikes the analyst(s) as reasonable explanation of the event. But such early stops of the analysis may entail that major contributing factors are omitted from the analysis and never discovered. In other words, event analysis is tantamount to **problem solving** by analysts whose competence and systems knowledge need to be exploited to maximal degrees while minimizing bias.
Thus, we may be able now to name the critical characteristics of adequate event analysis methods:
- Adequate theory
- Practicability/manageability
- Economy
- Comprehensiveness
- Problem Solving Nature of Event Analysis

<u>Individual and organizational learning:</u> As pointed out above: we note a growing body of literature on organizational learning [12]. But we must be aware that the term OL is used in a

metaphoric sense in analogy to individual learning. Learning is generally defined as **change of goal directed behavior based on experience.**

What then is required for individual learning?

-> an **organism** equipped with

- sensors
- a sensory afferent apparatus transporting information
- a center for storing experience (memory)
- a center for analyzing stored experience
- a center for formulating new behavioral goals
- an efferent apparatus transporting information
- operators implementing the new intended behavior
- afferent feedback to center

Now, what about Organizational Learning (OL)?
There are, of course, dangers in equalizing organizations to organisms such as an individual. Nevertheless, we may learn something from good analogies as heuristic devices. What then, in analogy to individual learning, is necessary for OL?

-> An **organizational system** equipped with

- apperceptive sensors taking in information about system states
- information channels transporting the relevant information to central units and relevant members
- a data bank for storing the reports
- a unit of analysis of the reported system states
- a unit of goals and policy formation
- information channels transporting new goals to relevant operators
- operators implementing new goals
- evaluative feedback again through information channels to central units

The different units and processes must be considered as forming part of a permanently ongoing learning cycle.

It seems that so far the metaphor of OL works. It breaks down, however, (and all metaphors must break down at some point otherwise the metaphor would be the reality of the entity it tries to emulate), it breaks down in terms of the multiple individual actors that are involved in OL: It is not one individual which learns, but many, and the knowledge (experience) gained is distributed knowledge, shared by many. We will see later how we in Berlin try to use OL under these conditions.

Error Producing Psychological Mechanisms in EA

Fahlbruch (2000, 2001) modeled the psychological process of event analysis on the base of a review of psychological literature on attribution theories and causal inferences and has pointed out that the quality of EA may be jeopardized and biased by various psychological factors which follow from characteristics of human information processing and general attribution processes. In consequence, learning potential is reduced. Such mechanisms are:

- Formation of premature hypotheses where the first plausible "cause" is taken to explain what happened [13]. The result is a truncated search for information and a restricted space of causal conjectures

- Difficulties to identify contributing factors which are remote in time and space from the actual event [13]. The result may be an over-estimation of directly contributing factors at the expense of indirectly contributing factors (e.g. past managerial decision)
- The general human tendency of reducing complexity leads to mono-causal thinking and satisfaction with only one contributing factor although there may have been many multiple factors involved [14]
- Situational elements which were not present in the context of the event and by their very absence may be difficult to identify as contributing factors (e.g. the omission of a procedural step) [13]
- Identification of contributing factors because of past accidents (mental availability of potentially contributing factors) [15]
- Methodological artifacts: contributing factors which are not written down in the method are not accounted for (e.g. a given checklist or fault-tree) ("out of sight – out of mind") [16]
- Concentration on contributions by human actors directly involved in the event (fundamental attribution error) [17]

An adequate EA needs to protect the analysts from such potentially bias producing tendencies.

Basic Characteristics of SOL

SOL operationalizes the concept of event analysis in a set of standardized process steps. A set of three specific instruments is aimed to aid the process of event analysis, to insure its standardized conduct while at the same time mobilizing expert knowledge and creativity of the analysis which can be compared to a backward oriented problem solving process:

Guideline for the description of the situation
Guideline for the identification of contributing factors
Guideline for the reporting of the event

Guideline for Description of the Situation: As soon as possible after an event occurred the whole event must be described, i.e. *what* happened. The description aims at separating the process of information gathering and interpreting this information. Similar to the STEP [18] method the event is broken down into a sequence of event-parts i.e. single actions of different actors (man or machine), event-building blocks. But SOL differs from STEP in that no contributing factors should be identified at this stage yet. The guideline serves as an aid for analyzing and describing the situation, in which the event occurred. An event is determined by a sequence of singular actions by different actors (maybe a person or a technical component) between a starting point and an end point. The starting point is defined as the first alarm or the first perceived deviation from a warranted course of action. The end point is defined as the recovering of a safe system state. The situational description should be conducted as soon as possible after the occurrence of the event and it should be separated from the event analysis per se by reviewing only observable facts (what happened, no hypothesis about causes or why it happened). The guideline contains information for breaking down the situation into single actions, i.e. decomposing the event into smaller parts, because of limited information processing capacity of analysts and for graphically charting the course of actions taken in the event by ordering the event building blocks in an time-actor-diagram, i.e. recomposing the event for an overview. The situational description thus serves as one information source for the subsequent event analysis.

Guideline for the Identification of Contributing Factors (CF): This guideline carries the analysts through the single steps of an event analysis in a certain sequence. It provides the standardization of the analysis process. Every single action (representing an "event building block") identified in the description of the situation should be analyzed by asking the question "why". Each event building block is located within an time-actor diagram. This graphic charting of the single building blocks of the event is completed by identifying contributing factors. Every contributing factor is complemented by adding further contributing factors. Thus, a graphic chart is developed which represents the event and all contributing factors in their whole complexity.

The CF-identification aid was developed by deriving contributing factors from a theoretical viewpoint and by gathering empirical data. SOL differentiates directly contributing factors from indirectly contributing ones. Six factors are deemed to be directly contributing in terms of their direct and immediate contribution to the genesis of an event:
A- Information
B- Communication
C- Working Conditions
D- Personal Performance
E- Violation
F-Technical Components

Indirectly CF are seen to be factors which are temporally and spatially somewhat more distant from the actual event evolution but nevertheless often crucial for the event. A list of 19 contributing factors was collated to assist the search for CF:

- Information
- Communication
- Working conditions
- Personal performance
- Operation scheduling
- Violation
- Responsibility
- Control and supervision
- Group influence
- Rules, procedures and documents
- Qualification
- Training
- Organization and management
- Feedback of experience
- Safety principles
- Quality management
- Maintenance
- Regulatory and consulting bodies
- Environmental influence

All identified contributing factors are grouped in line with the five subsystems. All possible contributing factors are transferred into general questions, e.g. the factor "working conditions" is transferred into the question "Could there have been an influence of the working conditions on the operator performance?" and examples like time pressure, noise, heat, lights or disturbances are given. Thus, the aid contains general questions related to possible contributing factors for each of the five subsystems and thus insures the comprehensiveness of the analysis. It also contains illustrative examples of the potential influence of contributing factors with the aim to stimulate the creative problem solving process of analysts.
This CF-identification aid facilitates the search for contributing factors, which is usually done by asking a series of "why"-questions. At a certain point it is assumed that the team members conducting the event-analysis will not find an adequate answer to these questions by themselves.

This is where the identification aid comes in. It helps to get a possible answer to the "why"-questions. The aid contains general questions related to theoretically derived and empirically gained contributing factors out of the five subsystems. Since it is assumed that the members of the team who conduct the event analysis may not be human factors specialists this aid provides examples for each of the general questions which assist in the identification of contributing factors. The general questions serve as a heuristic for the analysts' problem solving and the examples are concrete enough to cover the range of the potentially contributing factors but this is not meant to be exhaustive. This seems to be important if the analysis is conducted within the organization without external support. Thus, the identification aid serves as support of the problem solving process of the team by giving them an idea of how certain factors could have contributed to the occurrence of the event. To insure the comprehensiveness of the analysis all general questions are linked to others. If one of these questions is answered in the affirmative, the team is guided to answer another set of questions. The links are theoretically and empirically based. For instance for the factor personal performance an inadequate mental model of the worker could be responsible, thus, a link to training is given. By these links mono-causal thinking should be overcome. Thus, contributing factors from each subsystem are covered by this referral system. The analysis should not be stopped before more than one contributing factor is found.

<u>Guideline for Reporting the Event</u>: This guideline is an aid for the composition of the event description, the event report, and the allocation of descriptors. The event description is a comprehensive documentation of the process of analysis and provides the main basis for the Nuclear Power Plant's (NPP) internal organizational learning. The guideline contains information about the role, form and writing of the description as well as a description of how to include also analytic paths that were not further pursued. The event report is addressed to the regulatory bodies, if such reports are required and, if not, for reports that may be forwarded to other NPP or a data base of the national nuclear industry. The guideline insures the standardization of the reports in all NPP and it contains information about the role, form and writing of the event report. Further, it contains information about the classification of contributing factors for statistical analysis, later on.

Wide experience in using SOL in various industrial areas shows that the method effectively overcomes or reduces the effects of the various psychological bias producing mechanisms discussed above:

- The separation of the information search and the identification of contributing factors and the rule to identify factors for each event-building block separately prevent premature hypotheses formation and restricted information and truncated causal search.
- For the identification of factors remote in time and space from the actual event the guidelines offer pointers from directly to indirectly contributing factors as well as examples of how the gap could be bridged.
- As prevention against mono-causal thinking serves the procedure that for each event-building block should be conducted a separate analysis as well as the use of said pointers.
- A help for the identification of factors which contributed by their absence is given by questions and examples in the identification aid.
- Rules for information and causal search (for each event-building block separately) prevent the identification of contributing factors because of past accidents.
- In SOL the impression of completeness is avoided by making the incompleteness of examples explicit and by leaving out a refined presentation of very specific subcategories. Thus, the impression of incompleteness should support the analysts in identifying "out of sight"-factors.

- Pointers from human related contributing factors to the other subsystems serve as a prevention against the concentration on individual human contributions like operators' performance.
- The comprehensiveness of the investigation scope of SOL is guaranteed by the inclusion of organizational and extra-organizational factors.

Furthermore SOL is developed for a group analysis, i.e. for an analysis by a team of analysts comprising also staff directly involved in the event, which should help as well in minimizing biases and constraints.

Empirical Validation of SOL

A serious shortcoming of most available event analysis techniques is their patent lack of empirical validation. This may be due to the intrinsic theoretical problem of ascertaining a "correct" event analysis result. Only approximations to demonstrate the validity of an event analysis method seems possible. We have tried do evaluate SOL in two different ways: experimentally and practically.

Validation in practice settings

- It was tested whether it is possible to conduct an adequate SOL event analysis with the SOL instruments by students and union members (experienced NPP operators) analyzing an event. The results showed that both groups had no difficulties in using the instruments and aids in the analysis of real nuclear events.
- The SOL instruments were discussed with top level managers of German NPP. They found that the analysis is similar to their own method but that it is more comprehensive in its scope due to the inclusion of organizational and extra-organizational factors.
- The manageability and understandability of the questions and examples was discussed with representatives of a private consulting agency which is working in nuclear industry since the beginning of nuclear power operation in Germany. The representatives agreed that SOL, apart from being comprehensive and seemingly manageable and understandable, can be considered as a valid and useful approach to help improve the practice of consultation in NPP.

Experimental validation studies [19]

- In one experimental evaluation of SOL analyzed events were transferred into a SOL analysis. The results served as standard solution for the experiments. Subjects then analyzed the events with SOL on the base of a short description and standardized answers to questions they could ask. The experimental validation showed that it is possible to identify the a priori determined causes with SOL as well as to overcome the above mentioned biases which can be seen as a test of internal validity.
- We completed the re-analysis of civil aviation incidents which had been obtained and had already been analyzed by the Aviation Safety Reporting System (ASRS) of the US. We were able to show that our SOL-analysis identified significantly more contributing factors than had the experts from ASRS, the results were checked by an expert from the aviation field.

Summing up these results SOL seems to be a valid event analysis method which helps teams of event analysts to identify contributing factors from the whole range of the socio-technical subsystems: technology, individual, work group, organizational and extra-organizational. Conducting an event analysis with SOL enforces systemic thinking because the whole network of contributing factors and their interaction are taken into account. The results make aware of a broad range of organizational weaknesses and therefore offer a valid base for the learning from experience. The analysis by a team comprising analytic staff with various backgrounds as well as staff directly involved in the event forces an attitude of critical reflection of the whole system performance.

This is a summary of the paper version of SOL. It was already widely used in the German nuclear and chemical industry. However, soon it became evident that event analysts in plants would be considerably better served in their tasks if a computer assisted version was offered to them. This insight led to the development of SOL – Versio Electronica : SOL-VE .

SOL-VE Today

Various new features were added to SOL

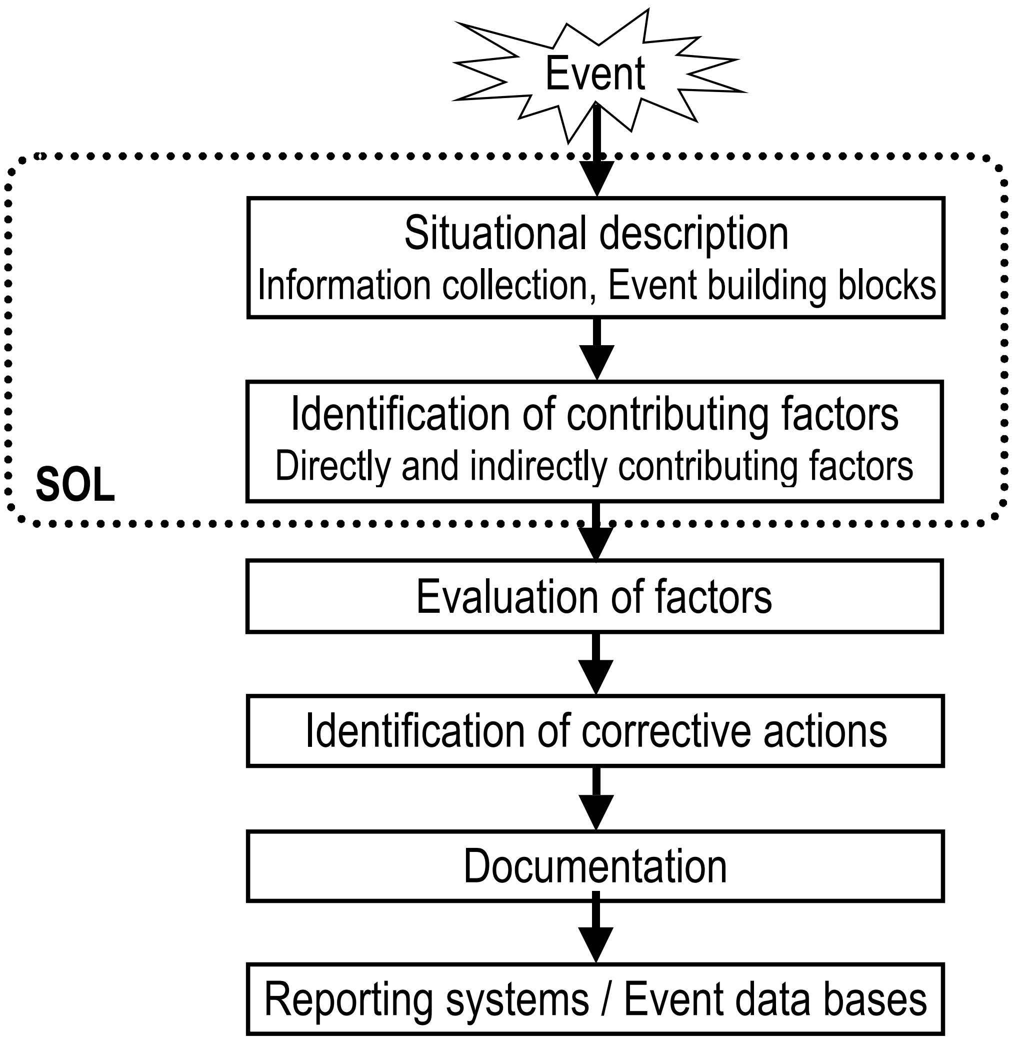

Figure 2 – SOL & SOL-VE Analysis Procedure

While the pencil and paper version of SOL had already been successfully used also in civil aviation and in chemical process industry, SOL-VE has meanwhile been adopted by the Swiss and German nuclear industry as the standing operating procedure for event analyses. Training workshops on the efficient use of SOL-VE have been conducted in all NPP for specially select staff members whose task it is to analyze events. A visiting scholar from the Chinese Academy of Science has during her six month visit to the Berlin Research Center Systems Safety thoroughly familiarized herself with the methodology, has translated all parts of the instrument and is presently back in China to discuss the use of SOL-VE in Chinese NPP. Further, a contract has been concluded with Spanish nuclear installations for the adaptation and adoption of SOL-VE. Operating theatres in large hospitals have demonstrated a lively interest in SOL-VE and the German railway company is presently discussing how SOL and SOL-VE procedures could be integrated into its safety programs.

Conclusion

Experimental and practical experience shows that SOL and SOL-VE represent an efficient, economical and valid event analysis methodology which is readily accepted as a standard operating procedure in various industrial contexts. The method helps to avoid generally known biasing tendencies in event analyses. Based on sound socio-technical systems theory it guarantees a comprehensive analytic scope leading to CF from the wide range of possible sub-systems of the focal organization and goes beyond several root-cause analysis methods which per definition see management as the root-cause. Thus SOL-VE enforces systemic thinking because the whole network of contributors and their interaction are taken into account in leading to an event. Since event analyses with SOL and SOL-VE are always carried out in teams of analysts, including staff involved in the event itself, it fosters an attitude of critical reflection of the whole system performance. The various modules of SOL-VE are aids to the establishment of a complete organizational learning cycle.

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