

Accident Analysis and Barrier Function (AEB) Method

Manual for Incident Analysis

Ola Svenson

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Ola Svenson

Stockholm University, Department of Psychology, SE-106 91 Stockholm,
Sweden

and

Netherlands Institute for Advanced Study in the Humanities and Social
Sciences, NL-2242 Wassenaar, The Netherlands

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Summary

The Accident Analysis and Barrier Function (AEB) Method models an accident or incident as a series of interactions between human and technical systems. In the sequence of human and technical errors leading to an accident there is, in principle, a possibility to arrest the development between each two successive errors. This can be done by a **barrier function** who, for example, can stop an operator from making an error. A barrier function can be performed by one or several **barrier function systems**. To illustrate, a mechanical system, a computer system or another operator can all perform a given barrier function to stop an operator from making an error. The **barrier function analysis** consists of analysis of suggested improvements, the effectiveness of the improvements, the costs of implementation, probability of implementation, the cost of maintaining the barrier function, the probability that maintenance will be kept up to standards and the generalizability of the suggested improvement.

The AEB method is similar to the US method called HPES, but differs from that method in different ways. To exemplify, the AEB method has more emphasis on technical errors than HPES. In contrast to HPES that describes a series of events, the AEB method models only errors. This gives a more focused analysis making it well suited for checking other HPES-type accident analyses. However, the AEB method is a generic and stand-alone method that has been applied in other fields than nuclear power, such as, in traffic accident analyses.

Sammanfattning [Summary in Swedish]

AEB metoden beskriver en olycka eller olyckstillbud som en serie av interaktioner mellan de mänskliga och tekniska system som är inblandade. En olycka beskrivs i en serie av mänskliga och tekniska fel som följer på varandra där det mellan varje fel i princip finns en möjlighet att genom en barriärfunktion stoppa utvecklingen. Efter upprättandet av en olycksmodell utförs **barriärfunktionsanalys**. En **barriärfunktion** kan t ex hindra en operatör att göra fel i en viss situation. Barriärfunktionen kan exekveras av ett eller flera **barriärfunktionssystem**. Så kan t ex ett mekanisk system, ett datorsystem eller en annan operatör utföra en given barriärfunktion som förhindrar ett och samma felaktiga beteende.

Barriärfunktionsanalysen omfattar förslag av förbättringar, analys av effektiviteten i föreslagna förbättringar, kostnader för implementering av barriärfunktionen, sannolikhet för implementering, kostnader för att vidmakthålla barriärfunktionen, sannolikheten att underhållet av barriärfunktionen kommer att ha tillräcklig kvalitet och generaliserbarheten till andra felsekvenser.

AEB metoden har likheter med den inom kärnkraften använda HPES, men skiljer sig från denna i olika avseenden t ex genom en större vikt på tekniska systemfel i analysen. Till skillnad från HPES baserade modeller beskriver AEB endast fel och inte hela händelsesekvensen, vilket ger en mer kondenserad analys. Därför kan AEB användas som ett kompletterande analysredskap vid granskningen av HPES baserade analyser. AEB metoden är emellertid ett generellt analysinstrument som har använts på t ex vägtrafikolyckor.

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1. Introduction

The Accident Evolution and Barrier Function AEB model provides a method for analysis of incidents and accidents that models the evolution towards an incident/accident as a series of interactions between human and technical systems (Svenson, 1991). The interaction consists of failures, malfunctions or errors that could lead to or have resulted in an accident. The method forces analysts to integrate human and technical systems simultaneously when performing an accident analysis starting with the simple flow chart technique of the method.

The flow chart initially consists of empty boxes in two parallel columns - one for the human systems and one for the technical systems. Figure 1 provides an illustration of this diagram. During the analysis these error boxes are identified as the failures, malfunctions or errors that constitute the accident evolution. In general, the sequence of error boxes in the diagram follows the time order of events. Between each pair of successive error boxes there is a possibility to arrest the evolution towards an incident/accident. *Barrier function systems* (e.g.,

computer programs) that are activated can arrest the evolution through effective *barrier functions* (e.g., the computer making an incorrect human intervention modeled in the next error box impossible through blocking a control).

An AEB analysis consists of two main phases. The first phase is the modeling of the accident evolution in a flow diagram based on a preprinted or computer based flow chart. The second phase consists of the barrier function analysis. In this phase, barrier functions are identified (ineffective and/or non existent), which could have arrested the unwanted evolution. The reasons for why there were no barrier functions or why the existing ones failed are analyzed and improvements are suggested. The AEB method provides a common theoretical framework that is useful for communication and improvements of complex systems. It is important to stress that it presupposes a simultaneous analysis of both human factors and technical systems by experts from both fields interacting when performing the analysis.

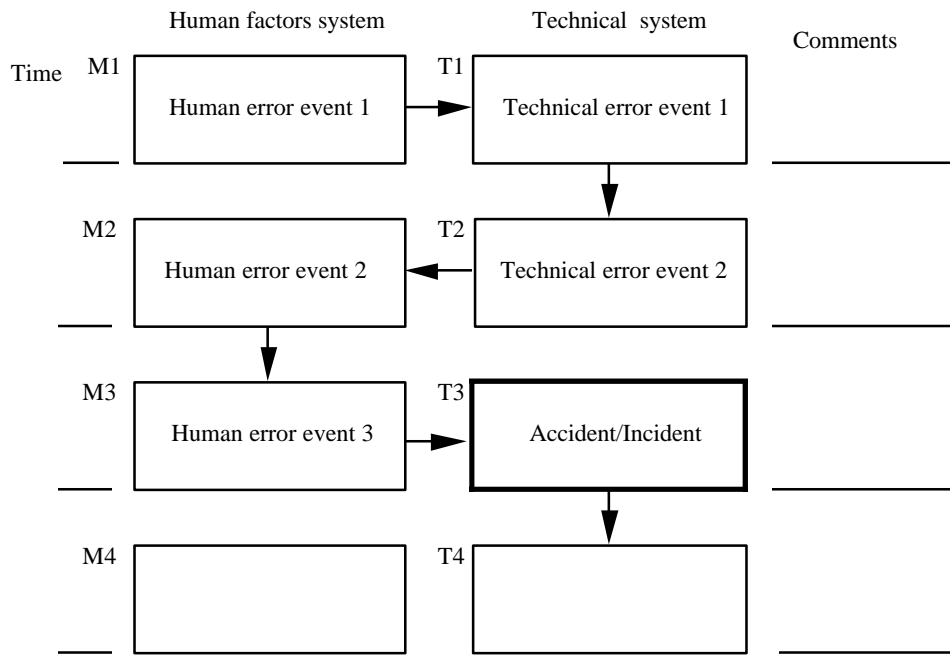


Figure 1. Graphical representation of the AEB-model. Failures, malfunctions and errors are located as error events in the boxes.

2. The AEB Model

2. 1 Graphical Representation of the AEB Model

As mentioned above, an incident/accident that is analyzed using the AEB method describes the accident evolution in a flow diagram. Sometimes, the flow diagram can be only approximately chronological because a sequential model is used to approximate the interaction of complex systems much of which goes on simultaneously. As illustrated by Figure 1, the AEB model makes use of a decomposition of the sequence of errors into human and a technical systems categories. It is establishment of this sequence of error events that is the first main focus of an AEB analysis.

2. 2 Systems and Components in the AEB Model

2. 2. 1 The Human Factors Systems

Humans always play a role in an accident either as actors in the accident evolution or as designers of failing or inadequate technology or organizations that contribute to the accident evolution. Therefore, one of the main components in an AEB analysis is the human systems component modeled in the left column of boxes in the flow diagram describing an accident. To exemplify, an operator initiating an action at the wrong time would be modeled in an error box in the human systems part of the diagram. In the right column of the flow diagram the technological errors are located. The erroneous technological system state or process resulting from the inappropriate operator action mentioned above, should be modeled in the next box of the technology systems part of the diagram.

Factors that have an influence on human performance have been called performance shaping factors (Swain & Guttman, 1983) or performance moderating factors. Examples of such factors are alcohol, drugs, lack of sleep and stress. In applications of the AEB model those factors are included in the flow diagram only as *PSFs* and they are analyzed after the diagram

has been completed. Performance shaping factors are included in the flow diagram in cases where it is possible that the factor could have contributed to one or more human error events.

Factors such as alcohol and age, are modeled as performance shaping factors, PSFs, but never as human error events or failing barrier functions. To exemplify, a driver who drives through red lights under the influence of alcohol would be analyzed as an error event of "the driver driving through red traffic signals" with alcohol (under the influence of alcohol), that is, one of several possible PSFs.

Note, however, that AEB does not analyze organizational factors as PSFs, which contrasts with Swain and Guttman's (1983) approach. Instead, organization can be integrated as a barrier function system with failing or inadequate barrier functions. Organizational factors should always be treated in a special way in AEB analyses because they include both human and technical systems.

2. 2. 2 Technical Systems

As mentioned earlier the right side column of an AEB flow diagram describes technical errors. Such errors can relate to construction, maintenance, processes and other aspects of technical systems. An example of technical errors in the road traffic area is insufficient or failing brakes. Also latent errors, earlier dormant in the system but revealed during the accident sequence have to be modeled. In this case, the location of the error box can be very early in the accident sequence or it can be located when the needed technology fails. Sometimes, it is appropriate to repeat the latent error box in a sequence. For example, if the dormant error could have been detected and eliminated at different points in the accident evolution there should be error boxes at those locations. For example, a valve that is erroneously left open and that was inspected without error detection, and finally allowed mass to pass can be modeled as open both before inspection and before the box representing the consequence of the erroneous flow of mass.

2. 2. 3 Error Event Boxes and Accident Evolution Analysis

Failures malfunctions and errors that contribute to the development of an accident/incident are described in the error event boxes. It is very important to stress that AEB only models errors and that it is not an event sequence method (as, e.g., HPES, INPO, 1987). The most common error made by novice analysts starting to use AEB is that they model also correct events. Error event boxes are numbered and marked H for human error events, and T for technical error events.

Arrows link the error event boxes together in order to show the evolution of the accident/incident. It is not allowed to let more than one arrow lead to an error box. An error box cannot have more than one arrow going from it. Because, systems interactions are modeled, it may be tempting to try to model multiple influences or energy flows but this is not allowed. The barrier function analysis phase can be used for modeling of subsystems interactions that cannot be represented sequentially in AEB.

The course of events is described in an approximate chronological order. At what point in time a certain error event occurred, is written (if such information is available) in the time column to the left of the flow diagram. It should be pointed out that the description of the course of events in the AEB analysis, is primarily approximately chronological, and that each link is not always (but in a great majority of the cases) causal. Thus, the analysis presupposes that a time order is assigned, even if this assignment can be only approximate in some respects.

The choice of a starting point for an AEB analysis is to some extent depending on the analysts and their knowledge and motivations. Svenson (1991) has commented on this in relation to AEB and we shall return to this later in this manual. In addition, the definition of accident is also partly depending on the analysts. To exemplify, a road traffic accident may provide the definition of an accident in one analysis, while the injuries caused by the accident can be the accident in another analysis.

Therefore, it is important to observe that the chain of errors in an AEB analysis is not necessarily complete with the box describing the accident. The AEB model can also be applied to analysis of courses of events following the accident event. An example of such an error event is the above mentioned human injuries following a road accident. The purpose of including also post accident errors is to stimulate identification of as many as possible barrier

functions. For example, one may ask if there are any actions that could have prevented human injury although the accident in itself could not have been prevented. An AEB analysis can also be used to describe hypothetical evolutions of events after the accident. In some cases, fault event trees can be appended to the AEB analysis, when possible post accident failures and errors are analyzed.

2. 2. 4 Barrier Function Systems and Barrier Functions

A *barrier function* represents a function that can arrest the accident/incident evolution so that the next event in the chain will not be realized. A barrier function is always identified in relation to the system(s) it protects, protected or could have protected. *Barrier function systems* are the systems performing the barrier functions . Barrier function systems can be an operator, an instruction, a physical separation, an emergency control system, other safety-related systems etc.

The same barrier function can be performed by different barrier function systems. An example of this is the blocking of a robot moving into a prohibited area, a function that can be performed by an operator or a computer. Correspondingly, a barrier function system can perform different barrier functions. An example of this is an operator who can perform a number of different barrier functions directed towards protecting different subsystems.

An important purpose of conducting an AEB analysis is to identify broken barrier functions and suggest how they can be improved and or supported by other yet non existing barrier functions - often executed by other barrier function systems. Thus, in the course of events described in an AEB analysis, barrier functions are identified that can arrest the unwanted evolution of an accident/incident. Barrier functions belong to one of three main categories.

- ***Ineffective barrier functions*** - barrier functions that were ineffective in the sense that they did not prevent the development toward an accident/incident.
- ***Non-existing barrier functions*** - barrier functions who, if they had been present, would have stopped the accident/incident evolution.

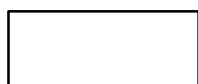
- **Effective barrier functions** - barrier functions that actually prevented the progress toward an accident/incident. Effective barrier functions are normally not included in an AEB analysis except at the very end of the chain since the AEB model is based on errors.

If a particular accident/incident should happen, it is necessary that all barrier functions in the sequence are broken and ineffective. Thus, the specific chain of malfunctions, errors, and barrier function failures appearing in an accident evolution are sufficient for the accident/incident to occur. The objective of an AEB analysis is to understand why a number of barrier functions failed, and how they could be reinforced or supported by other barrier functions. From this perspective, identification of a root-cause of an accident/incident is meaningless. The starting point of the analysis cannot be regarded as the root cause because the removal of any of all the other errors in the accident evolution would also eliminate the accident.

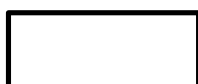
When performing an accident analysis it is sometimes difficult to know if an error should be modeled as an error or as a failing barrier function. This is because a barrier function failure can sometimes be seen as an error and be modeled in a box of the diagram. To exemplify, an error consisting of an act or function that was not performed can be modeled either as a barrier function failure or as an error in a box. When the error is modeled in a box, this straight away permits more detailed analyses of the two links connecting the box in the accident evolution chain. As a rule of thumb, when uncertain the analysts should choose a box and not a barrier function representation in the initial AEB analysis.

2. 2. 5 Graphical Representations Used in an AEB Analysis

This section first describes different graphical representations used in an AEB analysis and then gives a schematic representation of an AEB analysis diagram.



Error event box



Accident/incident

————— Arrows describe the development of the accident evolution in an approximately chronological order

//
————— Represents possible barrier functions, which could have arrested the accident and barrier function that were ineffective. Failing and possible barrier functions described in the margin for later barrier function analysis.

——//——
/—— Represent a barrier function that arrested the accident evolution. Effective barrier functions are normally not included in an AEB analysis except at the very end of the evolution.

PSF Represents a performance shaping factor (PSF). PSFs are marked in the flow diagram above relevant human error event boxes, described in the margin and later analyzed. PSFs represent conditions, such as, tiredness and time pressure that affect human performance. AEB does not analyze organizational factors as PSFs, but recommends detailed analyses of the organization as a context to the accident.

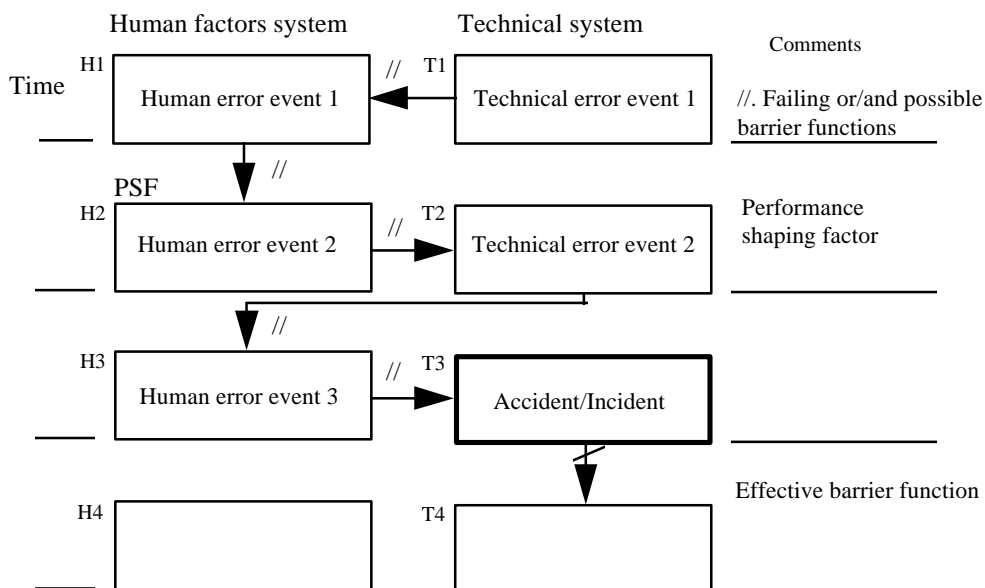


Figure 2. Graphical representation of an AEB analysis. The meanings of the symbols were described in the previous paragraph.

3. The Analysis

3.1 Performing an AEB analysis

At least two analysts should cooperate when performing an analysis. One of them should be a human factors specialist and the other a systems expert familiar with the (technical) system that had the accident. The following describes the different steps in an AEB analysis.

1. A general but detailed description of the accident/incident, the narrative, is first secured and studied. The narrative can be based on data of different kinds obtained from interviews, computer logs, written reports and other sources. The goal when establishing the narrative is to get a very comprehensive and yet general view of what has occurred.
2. Next the first error event is located in an error box. One way of doing this is to select an important error or failure in the middle of the diagram. Another way is to locate the accident in the error box. Starting from the top with an early error seems less practical than starting elsewhere.
3. Starting with the error box first marked, the analysts then identify earlier failures preceding the first located failure and indicate them in the flow diagram. In this process several iterations are usually needed to arrive at a accident sequence model that is satisfactory. Failures further down the evolution toward the accident/incident are also identified if the analysis did not start with the final accident. The description of the course of error events includes identification of *barrier functions that failed* to arrest the sequence towards an accident/incident.
4. As a fourth step, the flow diagram is completed with *barrier functions that could have arrested* the accident evolution chain. The goal is to identify sequences where barrier functions could have been present to prevent the same or a similar accident evolution. A recommendation is to go through the evolution chain starting from the top and to analyze every link between consecutive error event boxes and try to find out if some possible barrier function could have arrested the development. This can be done several times by experts

with different backgrounds. For some of these barrier functions, there are existing technical, human factors or organizational solutions, but for others those solutions have to be invented by the analysts.

5. Each *existing* barrier function is analyzed according to the guidelines provided later in this manual in the section about barrier function analysis.
6. Characteristics of the technical, human factors and organizational systems which may change the strength of each existing barrier function are identified.
7. This step includes a presentation of proposals for *new* barrier functions and what is needed for their maintenance.
8. Finally, an AEB analysis concludes with a written document giving the account of the accident and recommendations concerning how to improve safety of the systems analyzed.

3.2 When not to Search Any Earlier Errors Upstream the Accident Evolution ?

There are four informal criteria that often seem to be used to stop an accident analysis from going further back. Thus, an analysis can be stopped when:

- the chain of events cannot be traced further backwards in time because necessary information is missing.
- a well known abnormal event has been found and accepted as a valid explanation. Here, there is, a risk of routine errors or errors that fit the fashion of the time as initiating errors in an accident evolution sequence.
- a barrier function is encountered that can be easily fixed perhaps as a result of earlier experience. There is the obvious risk of accepting just one effective barrier function as the most prominent even though defense in depth requires several effective barrier functions.
- there is input to a system from another less well known system. This stop rule depends on the analyst's background. To exemplify, if an electrician makes the analysis and finds out that an incident was caused by a human error, his analysis is likely not to go further back beyond a human error. In contrast, an analysis performed by a human factors expert would go further back in order to discover the evolution beyond the human error.

4. Barrier Function Analysis and Protected Systems Analysis

A broken or non-existing barrier function signals that there is something wrong. There is a *protected system* and there are *barrier function systems*. In order to avoid further errors the barrier function systems can be changed or the protected system can be changed. A failing barrier function system can be substituted or reinforced. But the protected system can also be changed to eliminate failures in the future. In addition, the context of the systems can be changed to improve safety. For example, organizational routines or technical solutions can be altered to avoid future risks of malfunction and error.

4.1 Barrier Function Systems

Before the first error box and between all pairs of consecutive errors there are opportunities for barrier functions to arrest the accident evolution. In the barrier function analysis all these possibilities are considered. Therefore, the analysis starts from the top of the AEB diagram and proceeds down towards the accident.

As mentioned earlier, barrier functions are defined by the system(s) they protect and the system(s) that execute the barrier function. The essential point is to find barrier functions protecting the system, and other conditions being equal, it does not matter which barrier function system executes a particular barrier function as long as it is effective.

In the first round of analysis all existing barrier functions are identified including the last barrier function(s) that, hopefully, arrested the incident. When this has been done, the diagram is again processed, this time with the purpose of finding means to strengthen existing barrier functions and/or alternative barrier systems to execute the functions that failed. To give an example of the former, improved training could strengthen an operator as a barrier function system. An example of the latter is that when an operator makes a commission error (the operator did something that the technology was not prepared for as input) this could have been blocked by a computer safety system. Then the barrier functions would be performed by that system.

4.1.1 In Depth Analysis

Some barrier functions are candidates for systematic in depth analysis. Such analyses can be performed using different techniques. One such technique is to apply AEB once more, but now in a level 2 analysis., The error following the failing barrier function that one wants to analyze is modeled as the accident in the level 2 analysis. The failing barrier function is modeled as an AEB series of error boxes, when the detailed story behind a failing barrier function is analyzed. Another technique is the causal tree technique with "and" nodes, in which the failing barrier function is given the top position and the different conditions that could be derived behind the failure are interconnected in the tree. After another level of AEB or other kinds of analysis follow, namely general organizational, technical and human factors systems analyses.

Figure level 2 AEB analysis

However, for practical reasons, most barrier functions are analyzed directly using engineering and human factors expertise. When this is done it is important both to follow some kind of scheme and to document the sources to the evidence that the analysts use.

4.1.2 Steps in Barrier Function Analysis

For each *existing* and *possible* barrier function position, the analysts should first indicate the system(s) executing the function.

First, improvements concerning *existing barrier functions*.

- (1) Suggested improvements.
- (2) The effectiveness of the suggested improvements if implemented, e.g., the probability that the improvements will arrest another accident.
- (3) The costs of implementation - manpower, economy and other aspects.
- (4) Probability of implementation
- (5) The costs of maintaining the barrier function - manpower, human attention resources, economy etc.
- (6) The probability that maintenance will be kept up to standards
- (7) The generalizability (to other accident sequences) of the suggested improvement.

Second, following this analysis (or in parallel), *possible barrier functions* (other than those who failed) are listed. The above sequence, from (1) to (7) is then followed in the analysis of the suggested barrier functions and barrier function systems.

4.2 Protected Systems Analysis

Subsystems that should be protected by barrier functions in complex technological systems are integrated in those complex systems. In addition to questions concerning barrier function systems, there are issues related to the protected subsystems. If protected subsystems that are likely to fail are substituted with less failure prone systems, a risk has been decreased or eliminated. The two most important questions concerning protected subsystems are.

- (1) Can the protected subsystem be substituted by another and safer subsystem?
- (2) Can the protected subsystem be eliminated?

If the answer is yes to any of these questions, the new situation has to be assessed in a risk analysis.

4.3 Systems Context Analysis: Organization and Technical Systems

All barrier function failures, incidents and accidents take place in man - technology - organization contexts. Therefore, an AEB analysis also includes issues about the context in which the incident or accident took place. The organizational and technological context provides the framework for an accident. Therefore, the following questions have to be answered.

- (1) To increase safety, how is it possible to *change the organization*, in which the failure, incident or accident took place?
- (2) To increase safety, how is it possible to *change the technical systems* context , in which the failure, incident or accident took place?

It is very important to stress that when changes are made at in the organizational and technical systems at the context level far reaching effects can be attained. In general, the higher in the organizational context a change is made, the more general and wide spread are the effects. To exemplify, improving the organization for maintenance and or changing the safety culture in a plant influences not only the sequence in which the accident occurred, but also other sequences that can be safer in the future. Theory and application of organizations and of technical process systems are the tools for understanding fundamental problems at the organizational and technical systems levels identified in an AEB analysis.

4.4 Reporting the Results

Just as in all accident analysis methods a well structured results and recommendation section should follow the analysis. It is recommended that forms for collecting the data are prepared in advance and that the structure of the forms are used when summarizing the results. Examples of flow diagram charts are given last and the forms used in the analyses according to 4.1 - 4.3 can easily be prepared by the analysts themselves.

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Acknowledgements

This manual is based on the paper by Svenson (1991), in which the AEB model was presented in a fully developed form. After the publication of that paper, applications followed of which Svenson et al. (1999) is the most recent. Among the persons who have worked with applications of the AEB method, I want to mention Lars Andemo, Irene Blom, Anne Edland, Pia Jacobsson, Lena Jacobsson Kecklund, Gunnar Johansson, Anders Johansson Hammarberg, Christer Karlsson, Anna Lekberg, Nils Malmsten and Petra Sjöstedt. I learned a lot from you all. In particular, I want to thank Anne Edland and Nils Malmsten who co-authored an early Swedish manual. Thank you all.

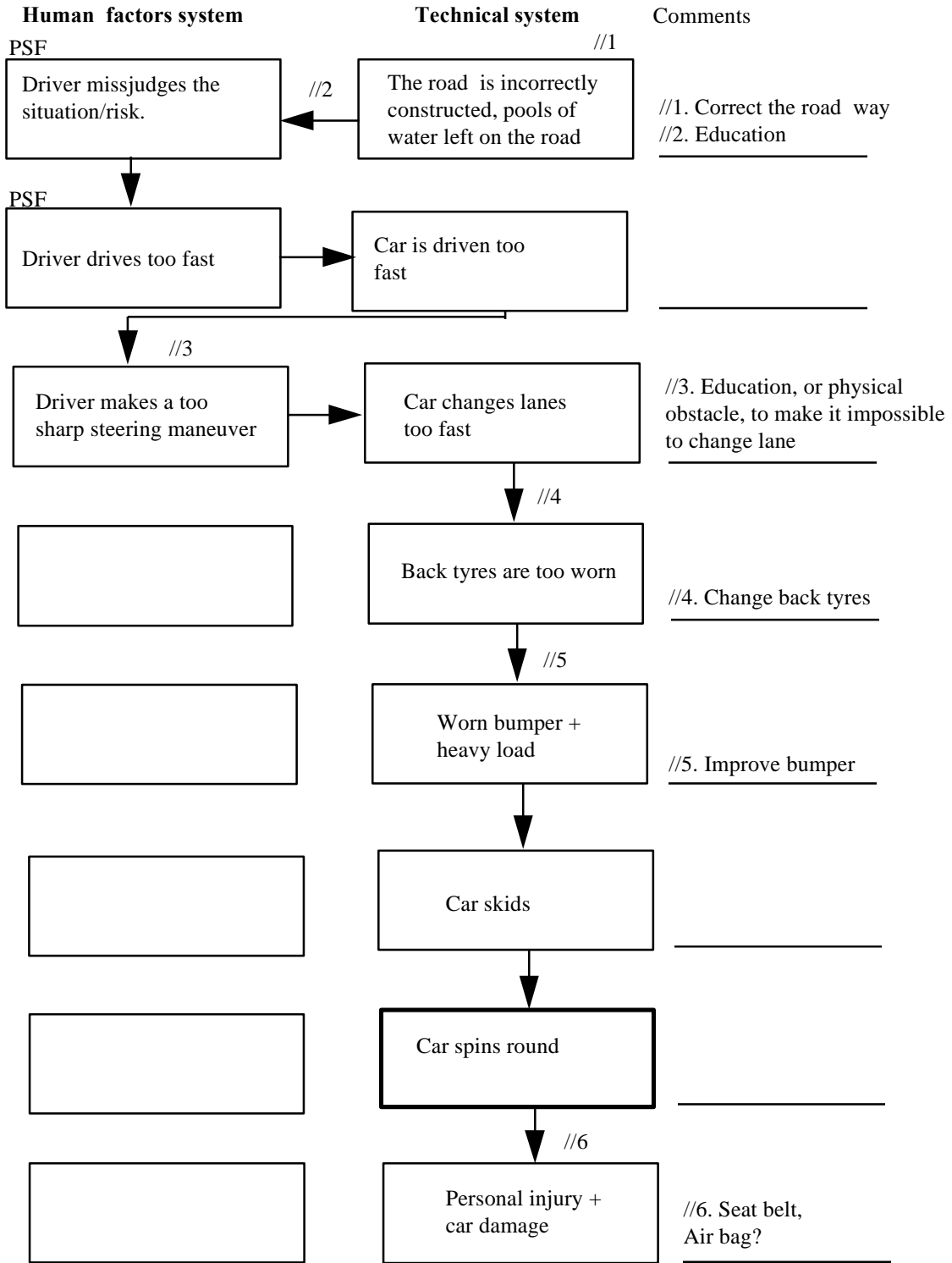
5. Examples

All examples in this section are based on real accidents.

5.1 Example 1 - A Road Traffic Accident

General description of the accident

A car is driven northwards on a highway in daylight. The surface of the road is wet from a strong shower of rain with pools of water. The driver is in the left lane after having passed car. While the road curves to the right, the driver intends to bring the vehicle back into the right lane. During the maneuver the car skids and the driver loses control. The car spins around and goes backwards off the road ending up on the roof.



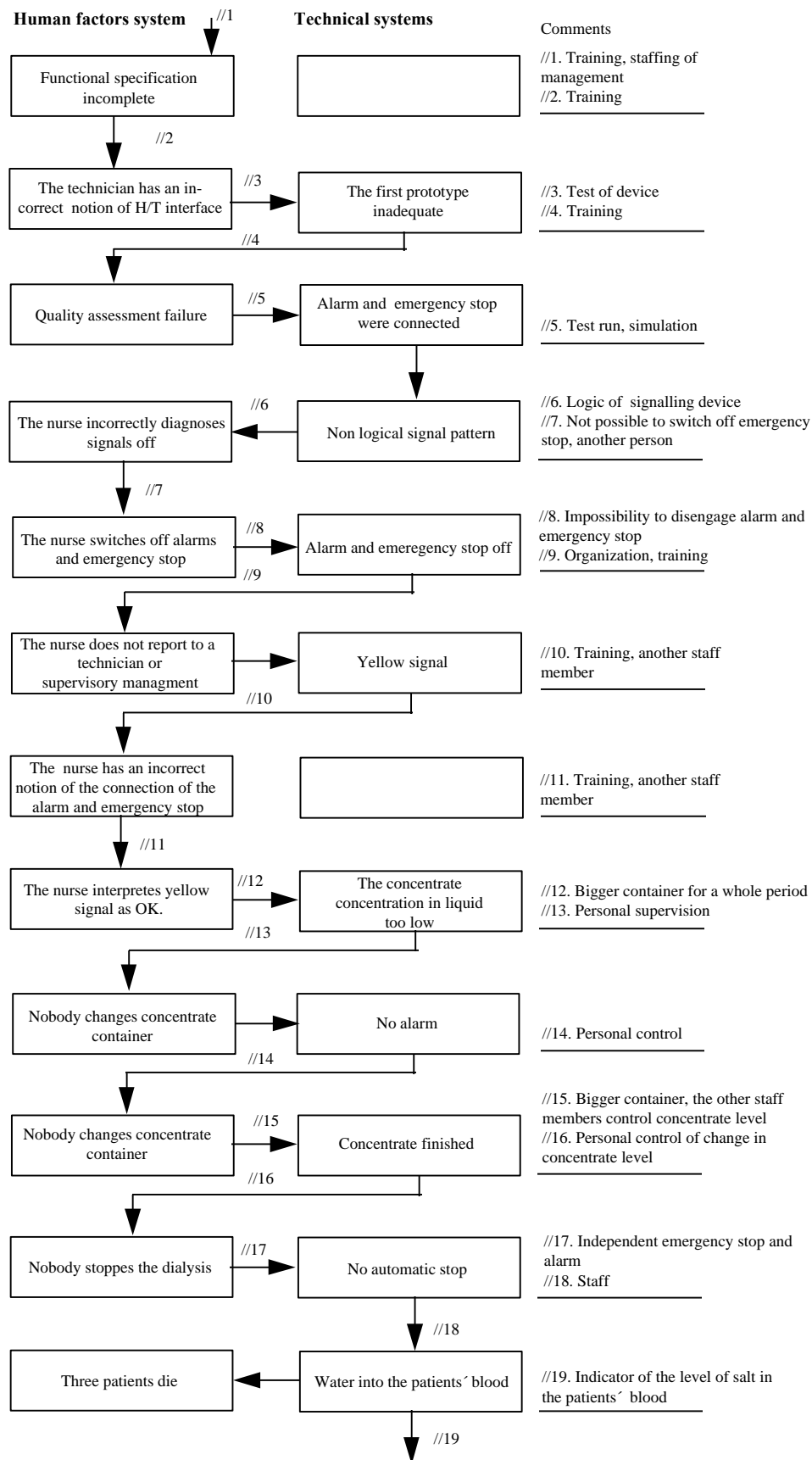
5. 2 Example 2 - The Dialysis Accident

General description of the accident

Dialysis is a treatment given to kidney patients. The treatment cleanses the blood from slag particles. This is accomplished using a dialysis liquid. It is important that the dialysis liquid has the correct salt percentage and temperature, since incorrect values could harm the patient.

In November 1983, there was an accident at the dialysis ward at a hospital in Linköping, Sweden. At the time of the accident a nurse unintentionally switched off all the alarms that signal when something is wrong. The salt percentage of the dialysis liquid decreased drastically until the dialysis liquid consisted of almost clean water - a deathly liquid in this context. The outcome of the accident was that 3 patients died of the 15 treated at the moment. In the analysis below H/T stands for human technology interaction.

Analysis with the AEB model



4. 3 Example 3 - A nuclear power plant example

The following example is taken from a nuclear power plant. The course of events that is described below is taken from an incident that took place in Sweden..

General description of the incident

At the regular load test of DG220 the DG220-S was supposed to be synchronized into DHC22. Instead, the operator choose to synchronize DT220-0, 5-S (he thought that he was synchronizing DG220-S). When the synchronizing was not successful the operator thought that there was an error in the indication device, so he switched off the DT220-0, 5-S. Consequently, the DHC22 lost power. The train of subsystems was correctly powered according to an automatic system and loaded according to the start sequence (automatic system)), by switching on the DG220-S. The operator was still focusing on an indication device error and was not prepared for the behavior of the diesel (that was running very uneven caused by the automatic start sequence). The operator decided that the diesel could get damaged and therefore switched of DG220-S. At this point he realized that the DT switch was off which explained why the diesel train was out of power. After repeating the sequence the operator managed to accomplish a stable feeding to the diesel train and the plant returned to the normal state.

Analysis with the AEB model

