

# HUMANS AS AN ASSET IN A SYSTEM CONSIDERATION ON THE CONTRIBUTION OF HUMANS TO SYSTEM PERFORMANCE AND SYSTEM SAFETY

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This paper presents an approach to incorporate human factors in systems engineering and safety management. This approach relies on the built up of a so called Concept of Use and is based on modern views on integral systems design. The Concept of Use is a description of more static parts of the system, together with distinguishable operation status, interface systems, environment and dynamic operational scenarios. The Concept of Use is useful in hazard identification, development of new system elements and in risk analysis with special interest in human reliability.

## **Introduction**

Nowadays human factors get high interest in safety. Mostly human factors is seen as human behaviour, which can be managed by creating awareness and by training. It is possible to calculate on safety performance of technical systems and to rationalize safety, but it is difficult to link human reliability to system safety. Just like for technical systems it is tempting to calculate on human error. But does this contribute to a higher safety performance?

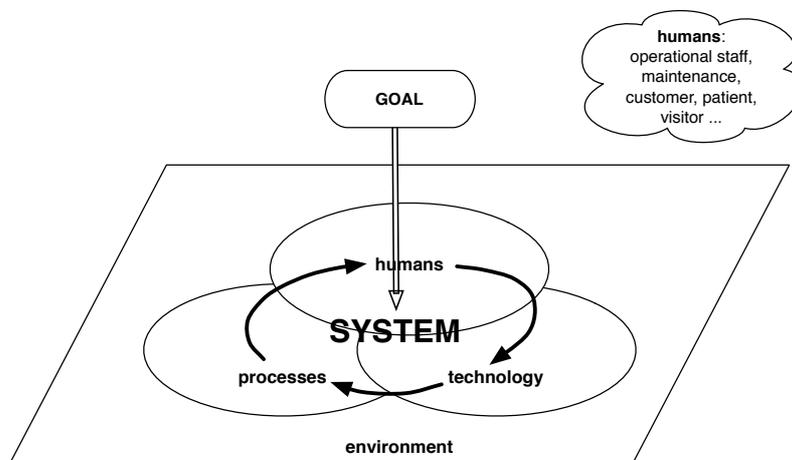
In this paper an approach is presented to reflect on human behaviour in a systematic way, where human reliability is related to the position and role of the human actor in the integral system. In this way the human factors approach presented fits principles of systems engineering and safety management.

## **Methods**

### *Humans in history of systems design*

Human factors is about humans being integral part of a process or system. Traditionally systems are considered and designed as a technical system. Based

on this technical system, processes are defined. Finally human tasks are the left overs of the design process. The focus on safe human behaviour, to be reached by training and supervision, is also based on this traditional approach. Modern consideration of human factors can be recognized in more recent views on systems design (Hollnagel, 2009), where humans, processes and technology are part of an integral system, which interacts with its environment. Humans can play different roles within the system (e.g. employee, passenger, patient, visitor etcetera), but can also be part of the environment (for example as citizen), see Figure 1.



**Figure 1: Modern approach in systems design**

### *Human factors in Systems Engineering in Rail*

In rail industry development of new systems takes place according to the principles of Systems Engineering and in conformity to international standards (EN-50126:1999 and related series) more and more. Safety is an important part of these standards and remarkable attention is paid to human factors. Below are some quotes out of chapter 4.4 of this standard. Especially the last quote is remarkable: humans are an asset in the system.

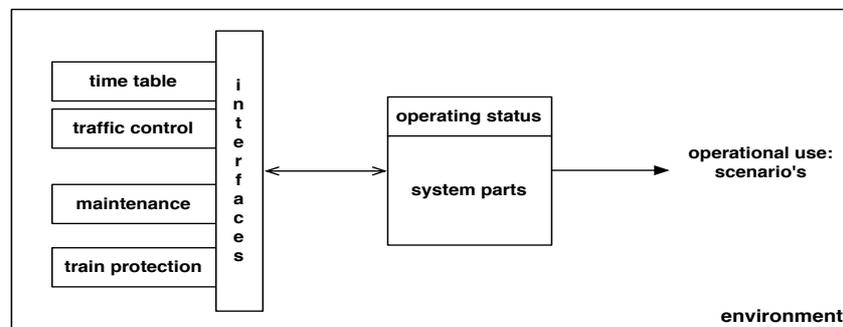
- An analysis of human factors, with respect to their effect on system RAMS (Reliability, Availability, Maintainability, Safety), is inherent within the 'systems approach' required by this standard.
- Railway applications typically involve a wide range of human groups, from passengers, operational staff and staff responsible for implementing systems to others affected by the railway operation, such as car drivers at railway crossings.
- Humans shall be considered as possessing the ability to positively contribute to the RAMS of the railway system.

### *Human factors in risk analysis in rail industry: Concept of Use*

In rail industry there are two important documents that describe how to perform risk analysis. The first one is the standard about systems engineering in rail (EN 50126-1: 1999), the other is the so-called Common Safety Method (CSM, 2009). According to both documents a risk analysis starts with a system definition. Both documents emphasize the description of the dynamical aspects or the operational use of the system. Particular operational use is very important for human factors risks. For example London Underground mentions the ‘operational concept’ in its Human Factors Integration Standard (LU, 2003). The total of system definition (more static elements: humans, technology, but also procedures), operational use (dynamic aspects based on operational status, goals and scenario’s) and environment is defined by Intergo as ‘Concept of Use’.

Of course the idea of the Concept of Use (CoU) without elaboration is quite abstract. An example about driving a train will clarify. The CoU consists of:

- parts of the system under analysis: signal positioning, signal aspects, rails, train driver, rolling stock etcetera ....
- .... which are in several operational status: normal operations, disturbed operations, degraded operations, calamity ....
- .... with interface-systems: time table, traffic control, maintenance, train protection ....
- .... operating in several scenarios: to and from a track yard, with or without partial routes across the track yard ....
- .... in a certain environment: time of day, light, wind, rain etcetera.



**Figure 2: Elements of the Concept of Use for driving a train**

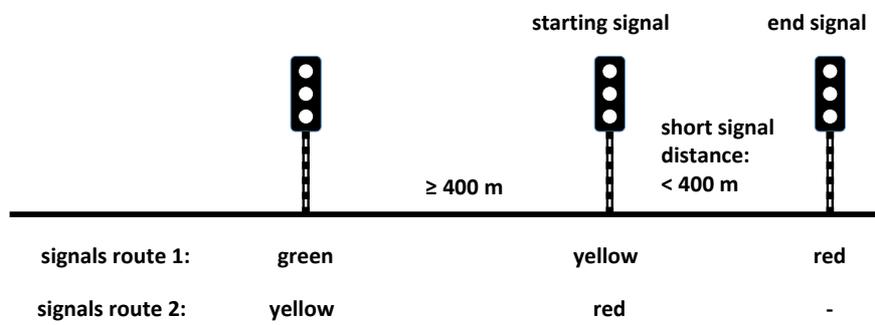
### **Case study: change of signal distances of signals on a track yard**

The idea of the CoU for driving a train is used for risk analysis with regard to change in signal distances and signal aspects shown to train drivers when entering a track yard (De Bruijn and Zeilstra, 2010). Change of signal distances

was desired because of the wish to increase capacity of track yards and therefore it was postulated that a change of signal aspects would be necessary. However signal distances are related to minimum braking distances for a train, so when signal distance is decreased, it has to be assured that required minimum braking distance is still available for a train.

Figure 3 illustrates the schematic lay-out of the rail infrastructure including signal distances and signal aspects for this situation with short signal distance. Two routes along the signals can be distinguished:

- Route 1: a route with a stop at the end signal with short signal distance.
- Route 2: a route with a stop at the starting signal with short signal distance.



**Figure 3: Schematic layout of a route with signals with short signal distance**

According to Common Safety Method CSM (CSM, 2009) the desired change of signal distances is evaluated as a change with safety impact, so risk analysis should be performed. Because of the lack of the so called 'code of practice' and the lack of a suitable so called 'reference system', risk analysis is performed as Explicit Risk Estimation as mentioned in the CSM.

#### *Hazards for the risk of SPAD on track yards in general*

As input for risk analysis on the desired implementation of signals with short signal distance on track yards, hazard identification is performed based on analysis of SPADs on track yards in general and subject matter experts opinion.

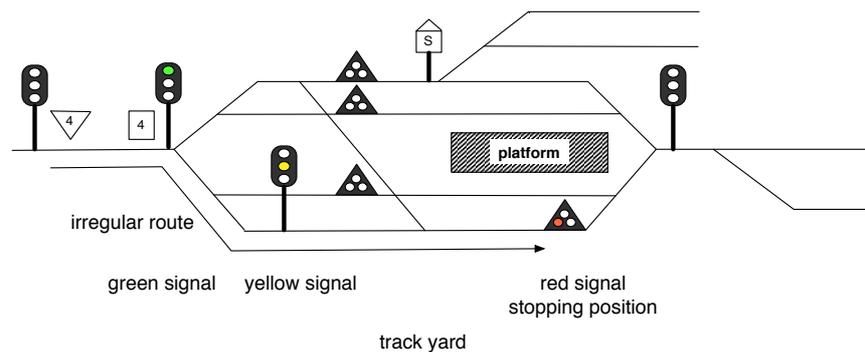
In incident registration of SPADs in Holland (IVW, 2007) there was a remarkable difference between passenger trains and cargo trains. SPADs occurred 2.6 times more with cargo trains compared to passenger trains. At first glance the task 'driving a train' is the same for both types of trains, so the differences in number of SPADs should be explained by differences in humans, e.g. train drivers. Further analysis (Van der Weide e.a., 2009) showed that processes and tasks in driving a cargo train differ from driving a passenger train. Also some characteristics of train drivers and train operating companies (TOC) were part of the clarification of the difference in number of SPADs.

Each element of the CoU (see Figure 2) is evaluated for potential hazards with a project team of subject matter experts (safety officers and train drivers of several train operation companies, members of the department of train protection of the Dutch rail infrastructure provider, human factors consultants). Of course the earlier study about SPADs (Van der Weide e.a., 2009) was very useful in this hazard identification together with subject matter experts. One major issue discussed is the difference between passenger trains and cargo trains. Cargo trains are much heavier than passenger trains, which means that accelerating is time and energy consuming, so a cargo train driver wishes to keep speed. Passenger trains have other brake technology with other characteristics than cargo trains. Weight of a cargo train combined with braking characteristics makes that cargo train drivers brake more carefully than passenger train drivers.

### *Resulting Concept of Use*

In order to limit the amount of variety in the CoU and in the number of scenarios to be analysed in risk analysis, most hazardous occurrences of elements of the CoU and the operating scenarios (as mentioned in Figure 2) to be evaluated were defined together with subject matter experts of the train operating companies:

- Scenario 1: entering a track yard, via irregular route but regular signal aspects to expected stop at regular stopping position. **Figure 4** gives more detail of this scenario.
- Scenario 2: entering a track yard via regular route with yellow signals to an expected stop at regular stopping position.
- Scenario 3: entering a track yard, with early unexpected stop.
- Scenario 4: entering a track yard, with unexpected late stop because of incomplete route through the track yard.
- Scenario 5: leave of a track yard, with unexpected stop.
- Scenario 6: other movements on a track yard, e.g. shunting.



**Figure 4: Visualisation of scenario 1**

Table 1 gives a shortened overview of the resulting CoU.

**Table 1: Chosen occurrence of elements of the CoU**

Elements of CoU	Chosen occurrence
Operational status	Disturbed. The train is several minutes late. Because of that a irregular route is being set to the irregular stop position.
Environment: Physical circumstances	
• Time of day	Daylight
• Weather conditions	Rain
• Temperature	Summer, more than 25 C
System parts	
• Rails	No special adhesion conditions
• Signal positioning	Height of signal dependent of position in track yard. Several signals following behind each other. Route along a bend, therefore limited view on next signals.
• Environment	No landmarks in surroundings of route (e.g. buildings)
• Signal aspects	Approaching red, no provisional improvement to yellow or green.
• Train driver	Fully qualified on track yard and fully qualified for the rolling stock, mediate experience as train driver.
• Rolling stock	Cargo train, braking in so called braking position G (no full brake)
Interfaces	
• Time table	High train frequency, mix of passenger trains and cargo trains
• Traffic control	Automatic route setting, driving according to signal aspects.
• Maintenance of infrastructure	No unplanned maintenance jobs.
• Train protection	Dutch train protection system ATB-EG

*Incidents related to short signal distances in current situation*

Currently in Holland there are some track yards where short signal distances are present. In rail unauthorized passage of red signals is called SPAD (Signals Passed at Danger). The risk for SPADs for situations with short signal distances is determined by statistical analysis of incidents in this typical situation during the period 1999-2010 (Dijk, e.a., 2012).

**Table 2: Number of SPADs at signals with short distance according to Figure 3 and at other signals, period 1999-2010 (\*  $p \leq 0.05$ )**

Type of signal	# Signals	# SPADs	# SPADs with train at point of danger	# SPADs with collision
End signal	457	344*	116*	7*
Other signals	4515	2688	618	30
Starting signal	524	232	204*	3
Other signals	4515	2668	618	30
End signal	457	344*	116	7
Starting signal	524	232	204*	3

Table 2 shows the following results for this period:

- SPADs, SPADs with train at point of danger, and SPADs with collision are more likely to occur at end signals with short signal distance than at other signals (signals without short signal distance).
- SPADs with train at point of danger are more likely to occur at starting signals with short signal distance than at other signals.
- SPADs are more likely to occur at end signals with short signal distance than at starting signals with short signal distance.

Several possible contributing factors for the risk of SPAD at a signal with short signal distance are assessed:

- Real occurring signal aspects in the route to the SPAD-signal.
- Kind of train movement along the SPAD-signal with short distance (arrival, passing through, leave, shunting).
- Location on a track yard of the SPAD-signal (near a platform or not).
- Occurrence of red signal aspect in both signals with short distance.

Unfortunately it appeared that data available was of insufficient quality to perform statistical analysis on possible contributing factors.

### *Risk analysis*

Identification of hazards related to route along signals with short distance is performed with a dedicated SPAD-analysis tool. Basis for this tool is work of the RSSB on SPADs (RSSB, 2012), analysis of SPADs by the Dutch Transport Safety Inspectorate (IVW, 2008), and Intergo's experience in analysing SPADs (SPAD analysis, without year). Signal aspects that are shown in a route should be in such a way that a train driver will give right meaning to each signal he

passes, and that anticipation and reaction of the train driver on each (next) signal aspect is correct. Of course it should be clear which signals belong to the route across the track yard. Finally the train driver should be able to stop at the red signal. Our SPAD-analysis tool follows this sequence:

1. Activation – alertness of the train driver.
2. Expectation – expectation about a route, signal positions, signal aspects.
3. Distraction – visual distraction or cognitive distraction.
4. Visibility – visibility of a signal.
5. Conspicuity – conspicuity of a signal in relation to its surroundings.
6. Identification – identification of the right signal within the route of the train.
7. Interpretation – clear meaning of the signal aspect shown related to other characteristics of the route of the train.

Hazard classification is performed by assessing the chance of making a mistake by a train driver at a specific signal position in defined scenarios by comparing two situations: with and without the use of short signal distances. Mistakes can be distinguished in type of mistakes, for example the well-known Skill-based, Rule-based en Knowledge-based mistakes (Rasmussen, in Reason, 1990). Each mistake has its own characteristics, even within the general types of mistakes as distinguished by Rasmussen. The chance of making a mistake will differ per signal position in the scenario. Therefore it is difficult, almost impossible, to perform a quantitative risk analysis on human tasks and human error, and a semi quantitative method was chosen according to the classification the Dutch Infrastructure manager ProRail uses in its safety management system.

In summary most hazardous factor is the fact that the train driver is not always timely aware of a short braking distance because of a short signal distance. Track curves and irregular routes and other irregularities can strengthen the surprising effect of this insufficient or not timely awareness. Possible positive side effects of short signal distances can be that a train driver has better sight on his complete route, but with the proviso that visibility and conspicuity of signals is optimal.

Several possible mitigating measures, which could be implemented in relatively short time, were defined:

- Specific signal aspect in the signal at the entrance of the track yard.
- Instruction to train drivers.
- Implementation of short distances for an entire track yard instead of some specific locations on a track yard.
- A specific visual sign at the entrance of the track yard.

Evaluation of these mitigating measures took place by assessing the relevance and expected effectiveness of these measures to mitigate the identified hazards related to the use of short signal distances. Additional mitigating measures for the hazards identified are suggested. Effectiveness and feasibility of these measures is under consideration.

## **Discussion**

Risk analysis with regard to changes in signal aspects is performed in a semi-quantitative way, not a full quantitative way. There are quantitative methods like HEART (Williams, 1986), but in general they are based on specific domains, in case of HEART nuclear industry in the mid eighties of last century. Human error in nuclear industry of course is not entirely comparable to human error in other domains, like health care or rail industry: different humans, different technology, different processes, different environment, so a different Concept of Use. Moreover composition of a Concept of Use makes clear whether a quantitative risk analysis can be performed in a valid way. If basis for a quantitative risk analysis comes from another, non-similar, Concept of Use, then all alarm bells should be jingling.

Mistakes, especially human errors, often occur because of a special concurrence of circumstances or interaction between several factors that makes human error more likely. The Concept of Use provides insight into these factors or circumstances. For the case of the Concept of Use for change of signal distances, the choice for a specific anticipating driving- and braking strategy within the scenarios evaluated, makes clear that humans are not only prone for error. When approach of the last red signal in a scenario is considered in isolation, this anticipating strategy can be seen as some kind of a mistake. But this strategy has major advantages. Especially cargo train drivers want to limit braking forces, because of the characteristics of the braking system. With maximum braking force, the braking system cannot easily be released in case of an improving signal aspect (from red to yellow) and the train driver has to allow coming to a full stop. When he doesn't allow himself to a full stop after maximum braking, and he wants to accelerate again early, large longitudinal forces will occur on the couplers of the train and the train can break because of that. Train drivers will avoid such hazardous forces when possible. In terms of the Concept of Use, nowadays the train driver is the only system element that can judge which braking strategy will be appropriate in circumstances of the moment. The desired change of signal aspects must allow this judgement in order to avoid undesired (safety) consequences. Besides that maximum braking also causes heavy wear of the braking system and high frequency noise and accelerating from stop to service speed again costs a lot of time and energy. Therefore a cargo train driver only uses maximum braking force when it is really necessary

## **Conclusion**

The case presented shows it is possible to incorporate human factors in systems engineering and safety management. But it requires thorough knowledge of psychological mechanisms behind human reliability, with desired human behaviour as result. And even more important, it requires thorough knowledge on the role and position of humans in the integral system under consideration. But when being done, humans no longer are reason for decrease in system performance, but can be considered as an asset within the system.

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