Human factors in the design of highly automated safety systems in railroad tunnels

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Abstract

Rail infrastructure in the Netherlands is being extended with dedicated new railways for goods transport and high speed passenger transport. Each of the railways encompasses several tunnels.
The safety systems in these tunnels are highly automated. They detect stopping trains, fires, high water level, gas levels etc. and subsequently take automated measures to combat the consequences. Nevertheless the role of the human operator is essential for effective functioning of the tunnel safety system as a whole. Different roles/operators have been defined: process operator, maintenance operator, calamity operator. For each of these operator roles adequate interactions and interfaces with the tunnel safety system had to be developed.

The paper focuses on two aspects in this design context:
(a) the rather tough going 'negotiations' to obtain a consistent set of methods of working for the different operators and parties,
(b) the development of user interactions and interfaces that support both, the different operators in their individual way of working as well as in their cooperation.

Obviously the different stakeholders in the project each put their own interests first. Therefore the start of the project was rather an uphill battle. However, after having developed good concepts, such as modes of the system, roles of the different users and fitting a clear basic structure of the interaction and interfaces to these concepts, the progress of the project went of well.

Keywords: Smart transport, human computer interaction, methods, safety communication

1. Introduction

1.1. Two new railways: freight and high speed

During the last decades transport is increasing exponentially. The same counts for transport by rail. By the pressure on the existing railways passenger trains are taking more and more precedence over freight trains. For that reason the government decided to build a railway dedicated to freight transport, spanning 160 km between the port of Rotterdam and the German border and going further into Europe. The line will be operational in 2007.

In that same year the country will get a connection to the European network of High Speed Lines, with ultra-fast trains up to a maximum speed of 300 kilometres an hour. The railway will take travellers directly from Amsterdam to the Belgian border (100 km) and further to Brussels and Paris.

For both new railways it is of utmost importance that trains can ride safely through, over and under the densely populated regions of the Netherlands. So both railways include a great number of new civil engineering structures, such as viaducts, fly-overs, bridges, dive-unders and tunnels. The latter two structures, especially the 13 tunnels require rather sophisticated systems to ensure effective operation, particularly because high standards concerning the safety systems in these tunnels are to be met.

For the preparation and construction of the new railways two separate, independent organisations are founded.

1.2. Stakeholders

Not only for the construction but also for the contracting out and exploitation of the railways new organisations are set up. Generally spoken parties involved in railway transport are:
(1) owners of the infrastructure,
(2) carriers,
(3) passengers,
(4) owners off goods being transported.
The latter two can be seen as customers, mostly represented by government, consumers' organisations and associations of interested parties. Because of recent denationalisation there is not *one* national railway company anymore. There are several parties in the category carriers (2). These are in fact owner of rolling stock who buy the right-of-use of infrastructure (at a given place and for a given time) from the owner, party (1). From an operational point of view party (1) consists of sub parties for: (a) selling the rights-of-use, (b) daily operations, i.e. train traffic control and (c) maintenance of the infrastructure.

With respect to the tunnels there is a fifth category, namely the governmental emergency services (police, fire brigade, ambulance). For a project as the design and building of (railway) tunnels the logical and technical challenges can be called problematic. However, the different interests of the parties mentioned, in the project acting as stakeholders, result in an enormous increase in the complexity of the project.

An extra problem in the development of the tunnel safety systems was that in both new railways the development of the supporting automation systems and Human Computer Interactions (HCI) were ahead of the (re-)structuring of the organisations which would monitor, maintain and, in case of an incident, operate the system. In other words the HCI had to be developed before its stakeholders, users and their organisations were defined.

2. Context of railway tunnels

2.1 Operational characteristics of the safety system

Briefly explained the operation of the Tunnel Safety System encompasses: detecting stopping trains, fires, high water level, gas levels etc. and subsequently takes automated measures to combat the consequences. If such an incident or calamity in a tunnel occurs, the operators of the different stakeholders do need information of the situation which is tailored to the tasks they have to fulfil. However, a substantial component of their task fulfilment consists of adequate communication with each other based on information given by the HCI in a consistent way. So, despite the differences, the HCI of the different operators also need to show similarities.

Because of the high safety standards to be met, the designers strived for a high degree of automation. This striving for automation runs the risk that it becomes difficult for operators to interact with the system when needed. All the more because events leading to severe calamities are rare. This puts high requirements on the HCI; it must only draw the attention of the operator in case of a process related event and then it must be self-explanatory.

2.2. Operational modes and operator roles

Initially stakeholders were quite holding back in taking their responsibilities. However, when the concepts of modes and roles and the basic structure of the HCI were clear this reticence disappeared. The system concept entails three basic modes of operation of a tunnel: operation, maintenance and calamity fighting. Different roles/operators have been defined: process operator, maintenance operator, calamity operator. In the HCI the three modes had to be tailored to the needs of the user in charge, but should not differ in such a way that multiple interpretations of information between the different modes would be the result. For each of these operator roles adequate interactions and interfaces needed to be developed.

3. Design

3.1 Introduction

As mentioned above, based on the operator roles and the three basic modes of operation of a railroad

tunnel, a HCI had to be developed which would accommodate the different needs for information and interaction of the operator roles within each operational state (mode) of the tunnel.
It also was required to maintain a top level overview of the state of all individual tunnels under all operational modes and independent of the information selected by the operator at any given point in time. Thus if an operator would require information or needs to interact with the system of a specific tunnel, the top level information of all other tunnels should still be presented.

Subsequently the presentation of events and interaction with the system should be consistent for all users in all different operational modes of a tunnel.
This led to a basic structure for all displays within the tunnel safety system HCI.

3.2 Basis display structure

The screen layout is fixed for all primary displays and distinguishes areas for:

1. special overall functionalities,
2. the basic overall status information of a tunnel,
3. information dependent on the navigation,
4. navigation, between objects such as tunnels and (sub-) systems.

A layout of the different areas is given in figure 1, in figure 2 an example screen is given. The example is taken from the Freight Project. In the High Speed Project the same HCI is being developed. (Which is necessary from an ergonomic point of view because the maintenance role is fulfilled by the same operator for both railways.)

Area 1 - System bar.
A small area of the screen used for computer system specific functions.

Area 2 - Status bar.
Overview of the status of all tunnels of the railway.
Shows the actual status of the 6 tunnels within the Freight Railway (BetuweRoute), i.e. the mode (operation, maintenance, calamity), the message class (alarm, pre-alarm, critical equipment failure, failure). See paragraph 3.3.

Selection of the tunnel name in the object will show the process view of the tunnel in Area 3. Selecting a message class will open the alarm image. In case of the process operator the alarm list will be shown in Area 3, in case of the maintenance and calamity operator the list is shown on a second monitor (Area 7).

It will also activate message class filtering in accordance with the message class selected.

Area 3. Display Zone.
This area is used to visualise the process information, such as values and their ranges, detailed technical information related to the installation selected (for the maintenance and calamity operator), or the alarm image (for the process operator).

Area 4. Process navigation bar.
This relatively small area contains buttons to select the process display for a specific segment
of the tunnel selected in area 2 (for maintenance and calamity operator).

Area 5. Process overview bar.
Area in which information is displayed with respect to:

- the meteorological conditions on both entrances of the tunnel (West en East),
- the position of the train within the tunnel,
- the temperature within the tunnel.

This zone is identical for all users.

Area 6. Tunnel navigation bar.
Area to navigate in the subsystems of a specific tunnel system. The buttons for subsystem navigation also indicate the active messages as well as the availability of the subsystem.

This strict lay-out offers the users, mainly due to the continuous presence of Area 2, status of all the tunnels, the possibility to be informed about the operational status of all tunnels at all times, even when no interaction with a specific tunnel system is required. This information is consistent for all users on all locations (at the tunnel systems as well as at the central control rooms).

3.3 Message classes

The HCI is designed to alert the operator in case of a change of state either in one of the tunnel (sub-) systems, or an event or emergency within the tunnel.

To distinguish the severity and nature of the

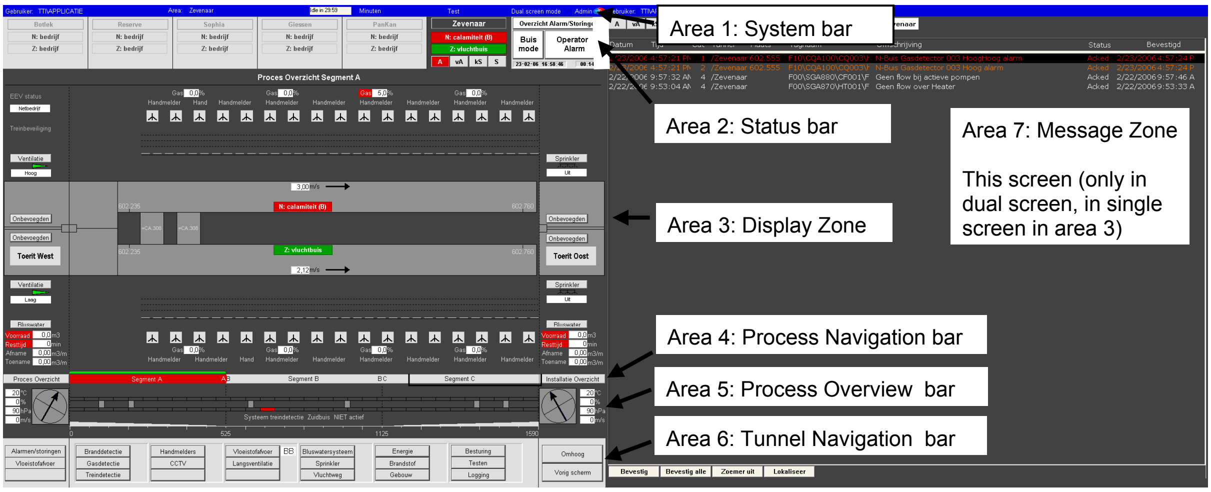

Fig. 1: Layout of the screens

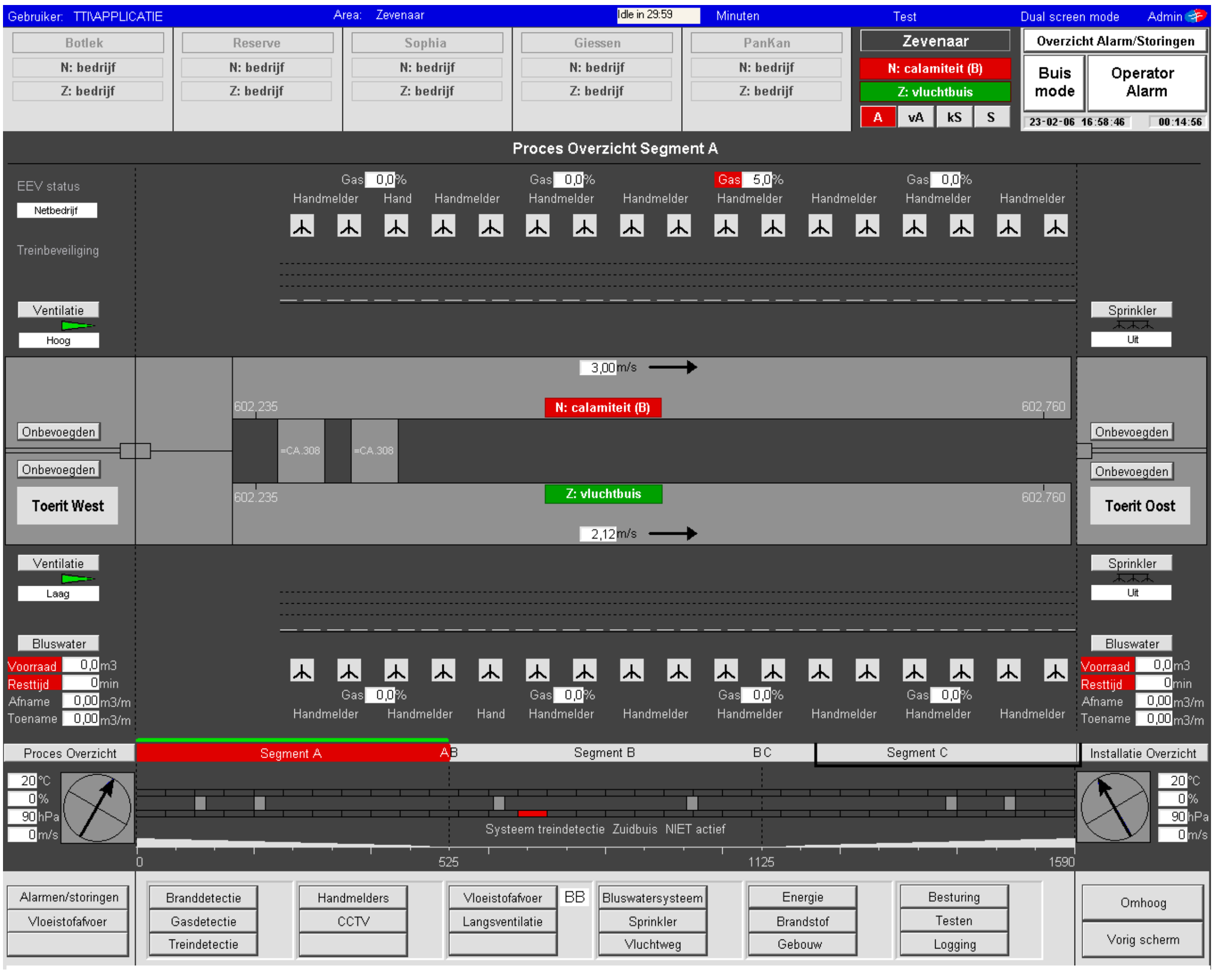

Fig. 2: Screen example

event, four message classes are defined:

- ‘Storing’ (Dutch)

  A (technical) failure of the tunnel safety system itself, without consequences for the availability of the (sub-) system.

- ‘Kritische Storing’ (Dutch)

  A critical (technical) failure which will influence the availability of the (sub-)system. Hence, the correct functioning of the tunnel safety system is no longer guaranteed. This can lead to reduction of trains driving through the tunnel or even a complete close down for train traffic.

- ‘VoorAlarm’ (Dutch)

  A low priority (process) alarm based on the detection of an event by the tunnel safety system. Based on this event the tunnel safety system will not take any automated actions.

- ‘Alarm’ (Dutch)

  A high priority (process) alarm based on the detection of an event by the tunnel safety system, on which an automated action is taken. Due to this event the operational state of the tunnel (tunnel mode) will change to “calamity”. All train traffic through the tunnel will be stopped.

All (major) process events and technical failures are classified in accordance with these four message classes. Depending on the operator role, an event class can be acknowledged and handled, or just been seen (view only). In this way the HCI can support the different operator roles with respect to the responsibility and authorization given to handle a specific event.

Failures, critical failures and low priority alarms will be handled by the maintenance operator. Alarms will be handled by the process operator, on transition from Operation to the Calamity Mode of the tunnel. When in Calamity Mode, all messages will be handled by the Calamity Operator.

3.4 System interaction

Under normal operational conditions of the railway system (train traffic) and the tunnel safety system, a tunnel will either be in the ‘operation’ or ‘maintenance’ mode. In ‘operation’ mode the process operator is in charge. He will take action and interact with the system in case of an event or hazardous condition in the tunnel which will influence the railway operation.

These events or conditions can be detected by the tunnel safety system itself (such as detection of gas or fire within the tunnel) or the process operator. The later gets information from his train traffic control system or he is informed by observation of a train driver or someone else who observed something strange. In all cases actions and measures are taken by the safety system based on the detected condition or can be initiated by the process operator himself. As a result the tunnel mode may change to ‘calamity’.

The maintenance operator will normally interact with the system in case of a technical failure. This may occur during ‘operation’ or ‘maintenance’ mode. If back-up equipment (like pumps or ventilators) is installed, automatic change-over secures the availability of the tunnel safety system during normal operation. Both failure modes and change-over actions are reported to the maintenance operator. The maintenance operator will also perform al actions necessary during the ‘maintenance’ mode of the tunnel. Maintenance can be performed on the tunnel, the tracks or any other technical system within the tunnel complex.

When the ‘calamity’ mode is initiated, all responsibility for actions taken within the tunnel are transferred to the local authorities and emergency services. The ‘calamity’ operator will then support the emergency services and act on behalf of the authorities.

4. Conclusion

The development of the HCI in both projects (Freight-Line and High-Speed Line) appeared to be a process which was difficult to start off. It took a lot of time to make clear how the responsibilities would be allocated to the different parties involved. During the workshops which were held with all major stakeholders this item required laborious discussions. However, once the role concept was introduced the discussions went on quite smoothly. The fact that this concept was independent of the organisational structure was of great help. Then the basic characteristics of the HCI could be developed and shown in the workshops. Step by step all parties involved got familiar with the new tasks ahead and the efforts of the participants were directed to getting an effective and ergonomically sound HCI. A remarkable change in the discussions was that it became a shared aim to strive for a HCI which was on the one hand tailored to the specific role and on the other hand showing such an overall unity that the mutual vocal communication (mostly by telephone) is maximally supported.

Recently the stakeholders management asked to include the monitoring and control of other – very different - technical systems within the HCI. Here again the concept of modes and roles as well as the basic structure of the HCI turned out to be a solid basis to offer the same key users the additional information to operate and maintain these systems.