Exposure and Accident Scenario's during Tunnel Construction

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Introduction

Drilling big tunnels in soft soil is a relatively new activity in The Netherlands. The western part of the country is below sea level, resulting is a very soggy soil. There is not much experience with tunnel drilling in these soil-conditions in the Netherlands.
Fire and water are two main hazards, which worry managers, designers and builders during tunnel drilling. This makes sense. Workers may be trapped by an underground fire, resulting from gas enclosures in the ground for instance, or from a short circuit in a tunnel-building machine. The escape routes of the workers are very limited, there is only one way out. A similar problem occurs with water: an unexpected pressure, or a failure of the tunnel lining can result in a sudden flooding of the tunnel. But during tunnel construction more hazards are at stake, and accident and exposure scenario's for this activity are largely unknown. The aim of the study is to develop a technique to foresee these scenario's for tunnel construction.

Methods

Scenario's

Figure 1 presents the simplest model in safety science. Risks arise from hazards. Within the field of safety science hazards are equivalent to energy and have a potential for harm. Unstable grounds, water, noise, moving machinery are examples of hazards. A scenario is defined as a combination of hazard and loss of control. A scenario shows the route of a hazard to a risk or to damage.
In occupational hygiene the term hazard is not familiar, instead 'source of exposure' is used. Also 'loss of control' is not a frequently used term in occupational hygiene. An equivalent term will be 'transmission' or 'exposure'. Loss of control makes sense, because in safety science the time laps between hazard and risk is generally a matter of seconds, or even shorter. In that respect it resembles exposure conditions of hazards with acute health effects.

Figure 1 Scenario's

Scenario's were specified during the various production functions of tunnel construction. These production functions are derived from a design analysis, which divides the activities of underground drilling into relevant process steps.

Apart from the production functions the worker-hazard distance is relevant for the identification of scenarios. During so-called direct driven production functions, the distance between worker and hazard is short. By these production functions the actual activity is input for the scenarios. By so-called indirect-driven production functions, like automated or remote controlled ones, the distance is long, and process disturbances become input for the scenario's. During these process disturbances a worker has to intervene in the process flow, which generally will reduce the distance to the hazard dramatically.

Hazard evaluation technique
Relevant scenario's are identified during interactive sessions with a small number of experts from within the company. The expertise required for these sessions derive from various fields, and include a worker, a foreman, a manager and a HSE officer. During the group session a matrix of guidewords and process parameters are applied to the production functions (table 1).

The process parameters actually are various forms of hazards and the guidewords can either be used to define process disturbances or to define alterations in work activities.

Not all the cells of the matrix contain useful combinations. For instance time x opposite does not make any sense. When useful combinations are detected, the consequences in terms of required activities of workers are discussed in the group, leading to various possible accident or exposure scenarios. After the session similar scenarios are grouped together, which can be ranked to frequency of occurrence or to potential damage. During the project conducted the frequency of occurrence was determined, using a three-point scale of high (daily/weekly), medium (monthly) and low (once during the building project)
Per production function the hazard evaluation technique was applied, focussing on relevant disturbances of the material

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Table 1 Guide words and process parameters

Process parameters (hazards)	Guide words (process disturbances)						
	no	more	less	opposite	as well as	reverse	other than
Pressure							
Movement							
Space							
Time							
Speed							

flow. The focus on process disturbances is highly relevant for accident scenarios in case of remote controlled or automated operations. Exposure scenarios do occur during process disturbances as well as during normal process conditions. The technique was adopted to include these conditions as well.

Results

During the tunnel construction the following production functions were specified:

1. Vertical transport of loads into the building excavation
2. Positioning of loads on wagons
3. Horizontal transport of loads and people
4. Positioning of lining elements
5. Extending of rails, supply pipes

Raw materials, like tunnel linings, supply of bentonite, and equipment are transported into the building excavation and placed on wagons. Inside the building excavation wooden stages are present and frequently these stages are damaged, suggesting this vertical transport is sometimes very bumpy. Scenario's like loads falling from vertical crane transport become very likely. The hazard of this scenario is 'falling objects', or potential energy, and the loss of control can be failing crane brakes, or a operating error of the crane driver.

After positioning loads on wagons raw materials are transported to the tunnel-boring machine by rail transport. The connection between the rail and the tunnel boring machine is a tricky one, because there is a difference in level of a few inches, and accident scenarios related to the entering of the tunnel boring machine are not that difficult to imagine. The hazard is difference in level of the rails and the loss of control might be a breaking rail connection or unstable wagonloads. The tunnel-boring machine is a highly sophisticated installation, but the start and end points of these installations are badly designed.

The lining elements are transported inside the tunnel-boring machine and just before the drilling head the elements are put into place. A pneumatic erector positions the elements. The noise levels at the drilling front are high, so a strange and peculiar form of communication occurs between the operator of the erector and the worker, which guides the actual placing of the linings. So the hazards at this workstation are the noise level, the pneumatic erector and the activity of positioning the elements. Also there are various possibilities for loss of control. Miscommunication between the two operators, and failure of the pneumatic system can lead to hands entrapped between lining elements or falling elements.

The hazard evaluation technique generated a list of accident and exposure scenario's during various production functions. The ranking technique provided a shortlist of the most dominant scenarios (table 2).

Table 2 Ranked scenario's

Production function and scenario	Ranking
Vertical transport of loads	
• Hit by loads during crane transport	Low
Positioning loads on wagons	
• Exposed to high levels of physical strain	High
Horizontal transport of loads	
• Exposed to diesel exhaust fumes	Low
• Hit by loads on train	Medium
• Hit by derailed train	Low
• Exposed to high levels of physical strain	High
Positioning of lining elements	
• Hit by cracking pipes	Low
• Hit by heavy objects	Low
• Panic reactions due to blocked TBM activities	Medium
• Hit by electricity	Medium
• Exposure to high noise levels	High

Conclusions

The application of techniques from the domain of safety science into the domain of occupational hygiene is promising and needs further development. The technique provides a ranked list of dominant scenario's that might be expected to occur. The ranked scenario's can become a relevant input during early stages of design of the tunnel drilling operations, an area of influence, which is hardly explored by occupational hygienists.

In conclusion:

1. The concept of scenarios is a very useful approach to acute hazards, both from an occupational hygiene as from a safety science point of view
2. Safety science uses terms and models that are not that fami-liar in the field of occupational hygiene but are very well applicable in that field
3. Production functions are useful in breaking up a complex project as tunnel construction
4. The group session and the matrix shown during this presentation can be applied both during projects under construction and during the first stages of the design of these projects, especially this last item – the design phase of a project – opens new opportunities for occupational hygienists