Aanbevelingen tunnel operator

De navolgende tekst is een door het Projectteam Leidraad VBS vertaalde en aangepaste verkorte versie van het Engelstalige rapport. Het originele rapport is na de samenvatting toegevoegd.

HET UPTUN-PROJECT

Mede naar aanleiding van de tunnelongevallen in de afgelopen jaren is het Europese project UPTUN opgestart. Dit project richt zich op de verbetering van bestaande tunnels in het Europese wegennet, specifiek met betrekking tot branden.
De belangrijkste doelen van UPTUN zijn:

- Ontwikkeling van innovatieve technieken en beoordeling van bestaande technieken op hun geschiktheid voor tunnels. Resultaat moet zijn een verzameling innovatieve en kosteneffectieve technieken, bruikbaar voor bestaande tunnels.
- Ontwikkeling, demonstratie en promotie van procedures voor het evalueren van het veiligheidsniveau op een rationele wijze, inclusief beslissingsmodellen en kennisoverdracht. Resultaat moet zijn een op risico's gebaseerd model voor evaluatie en verbetering van bestaande tunnels.

RWS Bouwdienst participeert in dit project, waarbij zowel overheidsorganisaties als bedrijven uit Europese landen zijn betrokken.

ONDERZOEK NAAR DE TAAK VAN DE TUNNEL OPERATOR

In het kader van dit project is onder meer gekeken naar de taken van de tunnel operator, de knelpunten die daarbij kunnen optreden en mogelijke oplossingen daarvoor. Hiertoe zijn verschillende bronnen geraadpleegd en zijn in verschillende landen tunnel operators en tunnelbeheerders geïnterviewd om praktijkervaringen te verzamelen. Daarnaast is gebruik gemaakt van verschillende theoretische modellen.
Allereerst zijn de taken van de tunnel operator bij de incidentafhandeling geïnventariseerd aan de hand van de verschillende fases van een incident. Deze taken kunnen aan de hand van bepaalde karakteristieken worden onderverdeeld naar minder, of meer belastende taken. Op basis van de taken enerzijds, en praktijkervaringen anderzijds, zijn vervolgens knelpunten in beeld gebracht die een zo gunstig mogelijke afloop in de weg zouden kunnen staan. Vervolgens wordt ingegaan op de mogelijkheden die bestaan om ervoor te zorgen, dat tunnel operators optimaal functioneren. Aan de hand van deze algemene methoden wordt voor een aantal mogelijke knelpunten geschetst, hoe deze knelpunten opgelost zouden kunnen worden.
Het rapport wordt afgesloten met aanbevelingen voor het verbeteren van het prestatieniveau van tunnel operators. Die strategie is hierna weergegeven.

AANBEVOLEN STRATEGIE

Stap 1: Inventariseer de taken van de operator.
Taken in de processen verkeersmanagement en incidentafhandeling kunnen bijvoorbeeld in beeld worden gebracht aan de hand van incidentfasering. Andere taken (bijvoorbeeld in onderhoud) mogen echter niet uit het oog worden verloren.
In de tabel hieronder is een gegeneraliseerd overzicht opgenomen van de taken van de tunnel operator, gekoppeld aan incidentfases.

Incidentfase		Taken tunnel operator
Preventie	Activiteiten voor het wegnemen of reduceren van de kans op incidenten. Tevens wordt hieronder begrepen de preparatie voor de hulpverlening (opleidingen, oefeningen).	• Verkeer en tunnel monitoren. Op de hoogte blijven van de status van tunnelinstallaties (verminderde beschikbaarheid). Voortdurende waakzaamheid is geboden. • Indien sprake is van storingen in de installaties op basis van de vigerende procedures (urgentiecriteria) verdere handelwijze bepalen. • Opleidingen volgen, meedoen aan oefeningen.
Incident	Zodra er een afwijking optreedt van de normale verkeerssituatie, is sprake van een incident. Op basis van detectie worden maatregelen genomen, voorzover van toepassing.	• Snelle en correcte detectie van het incident. • Incidenten afhandelen met verkeersmaatregelen zodanig dat escalatie wordt voorkómen en zo snel mogelijk wordt teruggekeerd naar de normale situatie.
De meeste scenario's eindigen hier. Normaal gesproken handelt de operator deze incidenten af voordat zij tot grotere ongevallen escaleren.		
Escalatie	Als er toch escalatie optreedt, kunnen er maatregelen worden genomen om verdere escalatie te voorkómen en gevolgen te beperken.	• Calamiteitenbedrijf in de tunnel instellen (calamiteitenknop): ventilatie, tunnel afsluiten, vluchtroute gereed maken et cetera. • Alert blijven op de mogelijkheid van vervolgincidenten of verdere escalatie.
Alarmering	Hulpdiensten worden ingeschakeld, weggebruikers zonodig opgeroepen tot vluchten.	• Hulpdiensten informeren en de juiste informatie aan hen doorgeven. • Weggebruikers alarmeren via omroepsysteem. • Zonodig opschaling binnen de beheerorganisatie. • Verkeersmaatregelen nemen om de hulpverlening toegang tot de tunnel te verschaffen.
Zelfredding	Weggebruikers verlaten hun voertuig, vluchten, proberen mogelijk een eventuele beginnende brand te blussen en/of anderen te helpen bij het vluchten.	• Communiceren met de weggebruikers om het vluchtproces op gang te brengen en zonodig instructies te geven. • De rol van de operator is in deze fase van grote invloed op het goed verlopen van het vluchtproces.
Hulpverlening	Activiteiten, uitgevoerd door de hulpdiensten, gericht op het beperken van de gevolgen van een	• Hulpdiensten assisteren bij de hulpverlening vanuit de verkeerscentrale. • Fungeren als de "ogen en oren" in de tunnel zolang

Incidentfase		Taken tunnel operator
	incident en het bestrijden van de oorzaak: reddingswerkzaamheden, brand blussen, obstakels verwijderen. Deze fase eindigt met het opnieuw vrijgeven van de tunnel voor het verkeer.	de hulpdiensten nog niet aanwezig zijn en in gedeeltes, waar de hulpdiensten (nog) niet kunnen komen. • Omleidingsroute instellen voor nog toestromend verkeer. • Via de IM-procedure zonodig een bergingsbedrijf inschakelen. Ervoor zorgen dat tunnel en installaties (weer) gebruiksgereed gemaakt worden en (laten) toetsen of dit is gelukt. • Tunnel openstellen voor verkeer na het doorlopen van de hiervoor bestemde procedure.
Nazorg	Evaluatie en eventueel langer durende opvang van slachtoffers.	• Registreren van het incident. • Meewerken aan een evaluatie indien dit van toepassing is.

Stap 2: Identificeer (mogelijke) knelpunten.
Maak hierbij gebruik van de takeninventaris. Het type taak en het geheel aan taken op een willekeurig moment bij de incidentafhandeling kunnen aanknopingspunten bieden voor het identificeren van knelpunten.

In dit kader worden twee typen taken onderscheiden:

- Situation assessment: de situatie in de tunnel in de gaten houden: niet alleen het verkeer, maar ook de status van de installaties. Op basis van het geheel aan gepresenteerde gegevens wordt de situatie voortdurend beoordeeld. Veel voorkomende verstoringen (denk aan files) worden routinematig afgehandeld. Hiervoor is het niet nodig bewust beslissingen te nemen over de noodzakelijke handelingen.
- Decision making and control: Zodra sprake is van een minder gebruikelijk incident zal de operator beslissingen moeten nemen over de te volgen handelwijze. Mogelijk moet hij hulpdiensten en/of weggebruikers informeren danwel instrueren.

Het tweede taaktype is meer belastend dan het eerste.
Beschouwt men de taken in de tabel van stap 1 vanuit deze optiek, dan valt op, dat vanaf het optreden van een incident tot het arriveren van de hulpverlening binnen een kort tijdsbestek veel van dit type taken moet worden uitgevoerd door de operator. Hier dreigt het gevaar van mentale overbelasting, die kan leiden tot het maken van fouten bij de incidentafhandeling. Daarentegen moet ook worden opgepast voor mentale onderbelasting: een operator die in zijn eentje in de nachtdienst alleen monitoringsactiviteiten heeft, wordt mogelijk minder alert dan nodig, waardoor een beginnend incident aan de aandacht zou kunnen ontsnappen.

Het gedetailleerd uitwerken van de takenlijst, gespecificeerd voor de tunnel, kan meer specifieke knelpunten aan het licht brengen, of juist inzichtelijk maken dat een bepaald proces goed geregeld is. Een binnen Nederland wel gehanteerde methode voor het analyseren van veiligheid in tunnels en het opstellen van incidentafhandelingsprocedures (calamiteitenplan) is het uitvoeren van een scenarioanalyse.

Stap 3: Ondervraag betrokkenen om de knelpuntenlijst aan te vullen en te prioriteren.
Tunnel operators, een hoofd van een verkeerscentrale, collega's in andere regio's en hulpverleners beschikken over de nodige expertise om de knelpuntenlijst te corrigeren en aan te vullen. Bovendien zal bepaald moeten worden, welke knelpunten het grootste risico opleveren en daarmee de hoogste prioriteit moeten krijgen bij het zoeken naar oplossingen.

Stap 4: Inventariseer mogelijke oplossingen voor de belangrijkste knelpunten en bepaal een strategie.
Er bestaan verschillende methoden om het functioneren van de tunnel operator te verbeteren. De volgende vijf worden hier onderscheiden:

- Werving en selectie (criteria hiervoor opstellen);
- opleiding en oefeningen (niet alleen nuttig voor het verbeteren van de vaardigheden van het personeel, maar ook voor het toetsen van procedures op hun effectiviteit);
- personeel en organisatie (aantallen aanwezig personeel, werkwijze met roosters, maar ook organisatiecultuur);
- taakondersteuning (procedures en handboeken);
- technische hulpmiddelen (calamiteitenknop: vele handelingen in één actie; goede besturingsinterface; goede voorzieningen voor het instrueren van weggebruikers).

Met behulp van de geprioriteerde knelpuntenlijst en deze methoden kan worden bepaald wat een effectieve maar ook efficiënte aanpak is. Dit zal altijd specifiek voor een bepaalde tunnel, immers: er zijn meerdere wegen die naar Rome leiden, en wat voor de één een goede oplossing is, is voor de ander niet effectief. Bovendien kunnen in sommige situaties twee vliegen in één klap worden geslagen als de juiste keuze wordt gemaakt.
Een effectieve strategie, toegesneden op de eigen organisatie, zal dan ook bestaan uit een uitgebalanceerde mix van maatregelen. Hoe die is samengesteld, hangt onder meer af van:

- omgevingsfactoren;
- aanwezigheid van andere problemen die opgelost moeten worden (bijvoorbeeld problemen die niet specifiek met de tunnel operator te maken hebben, of niets te maken hebben met tunnelveiligheid);
- organisatiekarakteristieken.

Stap 5: Implementeer de strategie.
Op basis van de strategie wordt een plan gemaakt en uitgevoerd. In zo'n plan zal ook een toets opgenomen moeten worden: wanneer en hoe wordt beoordeeld, of de gekozen oplossingen de doelen bereiken.

Stap 6: Beoordeel het effect.
Hierbij kan onder meer gebruik worden gemaakt van het ondervragen van betrokkenen. Blijkt de gekozen strategie niet te voldoen, dan moet worden besloten tot aanvullende of alternatieve maatregelen.

Na deze pagina volgt de tekst van het oorspronkelijke rapport, waarop de samenvatting hiervoor is gebaseerd.

Ministerie van Verkeer en Waterstaat Rijkswaterstaat

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Tunnel operator

Task 3-3

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1 Introduction

1.1 The UPTUN project

The European economy relies upon a sustainable transportation system. In this transportation system, tunnels are a key element. The safety systems in a significant part of the existing tunnels were designed on the basis of traffic and its estimated growth of two or more decades ago. It appears however that traffic has grown more significantly and also changed in composition (more combustible and flammable goods). Consequently the safety level in existing tunnels has decreased in cases where no intermediate measures were taken to cope with the changed supply of rolling stock. This holds throughout Europe, for road, rail and mass-transit tunnels.

In addition to this, the accidents in recent years[1] have drawn widespread attention to the risks of fires in tunnels. This has two consequences. First, the fires themselves have resulted in fatalities, casualties and / or economic damage. They have also resulted in lengthy shutdowns of the tunnels themselves. Secondly, the perceived risk of fire is also likely to have discouraged tunnel usage in some cases (tunnels might become an unwanted impediment for trade). Both of these consequences will have added to congestion and hence noise, particulate and airborne pollution with negative environmental and health consequences. As a result of the accidents, and the media attention they have caught, the public acceptance level of fires causing major losses has also decreased.

The main problem statement is now listed as follows. Unsafe, or supposedly unsafe, tunnels hamper the use and the development of sustainable transportation systems, needed in a healthy European economy. Upgrading the safety level in tunnels is, with existing technology and within the legislation and guidelines frameworks of the member states, in most cases, however either nearly impossible or too costly.
Secondary problem is that fire safety is based on a conventional rather than a rational approach. Moreover, fire safety is seldom looked upon in an integral fashion, comprising all aspects (probability of incidents, consequences of fires, human response, structural response, emergency response teams, tunnel operators) in a similar manner. This may result in adverse interaction between preventive mitigating measures or non-optimal safety investments.

The UPTUN project main objects are therefore:

- Development of innovative technologies where appropriate and where relevant comparing to and the assessment of existing technologies for tunnel application. Focus is on technologies in the areas of detection and monitoring, mitigating measures, influencing human response, and protection against structural damage. The main output is a set of innovative cost-effective technologies.
- Development, demonstration and promotion of procedures for rational safety level evaluation, including decision support models; and knowledge transfer. The main output is a risk based evaluating and upgrading model.

[1] Besides the fatal accidents referred to by the December 2001 European Council, widespread publicity also resulted from the fire in the Channel Tunnel, which fortunately involved no fatalities.

1.2 Task 3-3: The tunnel operator

This report is produced in the framework of UPTUN work package 3 (Human Response) with the main objective to find, develop, evaluate and promote new methods and means to remove, neutralise, or correctly assess all factors, which contribute to a negative human response in incidents. A review of human behaviour, regarding all possible roles in a tunnel incident; as a road user, as an operator, or as a member of a rescue team, can be found in Deliverable 3.2 [1] of the UPTUN project.

The objectives of UPTUN task 3-3 are:

a) To analyse the task of the operator, including the interactions with tunnel users and rescue teams; and then

b) To collect and / or generate means of support for the operator, based on this analysis.

The main participants in this task are RWS (NL, task leader), TNO (NL), Maribor (SL), Ineris (FR), CERTH-HIT (GR) and COWI (DK).

2 Method

2.1 Task 3-3: approach

This report deals with tasks and behaviour of the tunnel operator and, more specifically, with possible methods for improving the operator's performance during incidents. These methods should be focussed on bottlenecks that threaten adequate tunnel operator performance.

The first step towards improving operator performance is to list the operator's tasks during normal operation and incidents. In Chapter 3, operator tasks as listed for a number of existing tunnels in Europe are described.
Bottlenecks are systematically identified in Chapter 4, based on operator tasks, actual incidents in the past and operator's experience.
The results are used to propose possibilities for improvement in operator performance. In Chapter 5, five general methods to influence operator behaviour are translated into specific ways to improve operator performance.
Chapter 6 proposes a strategy using the techniques from this report.

2.2 Sources

The analysis of operator tasks and bottlenecks is in part based on information from deliverable 3.2 [1], from several reports by the University of Maribor on tunnel operation in Slovenia, from Dutch data including a current safety review of tunnels in the Netherlands and from some TNO reports on operator behaviour.
In several cases, operators were interviewed using the questionnaire in Appendix A.1 or a similar questionnaire. The questionnaire was also used as a tool to analyse abovementioned reports and literature sources.

2.3 Definitions

Bottleneck	Anything that hinders a tunnel operator in performing his tasks in preventing and handling incidents. **à** 4
Incident	Any disturbance of the normal traffic situation, from traffic jam or an animal on the road up to large fires and explosions.
Cognitive task load model	A model for cognitive task load, used to describe the tasks and the mental load of operators in process control environments. This model was used in this task to identify problems that can occur within the work of tunnel operators and define solutions for these problems. **à** 3.1.1, 4.1.1, A.1.
Situation assessment; Decision making and control	Task type sets based on the cognitive task load model. Situation assessment includes situation awareness and disturbance assessment tasks. Decision making and control includes decision making tasks and direction & control tasks. **à** 3.1.1

3 Operator tasks

3.1 Approach

Tunnel operator tasks vary from country to country. Tasks may include:

- securing safety for users both in normal conditions (prevention) and in the event of an incident;
- monitoring the efficient performance of all technical installations during normal operation and adjusting them as required during incidents;
- properly maintaining structural and electromechanical installations.

In this report, only the tasks of operators directly relevant for prevention and incident management are mentioned.

Two approaches are combined to analyse the operator tasks: generic task types and scenario analysis.
In 3.1.1, four generic task types for operators are mentioned. These task types relate mainly to the cognitive level at which tasks are performed.
Since the UPTUN project is aimed at the reduction of probability and consequences of incidents, operator tasks during the course of an incident are reviewed in this chapter, using a general scenario approach (0).

Sources from different European partners reveal a wide range of operator tasks in incident management on a more detailed level. In paragraph 0, an attempt is made to summarize these tasks, using both approaches from this chapter.

3.1.1 Cognitive task load model

The cognitive task load model [1, 2] is a model, used to describe the tasks and the mental load of operators in process control environments. In this model, tasks are categorized in four generic task types:

1. Situation awareness
   Continuous monitoring of traffic and critical parameters that represent the state of the tunnel. This means not only monitoring the state of the tunnel, but also the state of the installed equipment to detect any technical failures.
   The operator needs the right information to get insight in the actual situation and the situation as it will be in the near future.

2. Disturbance assessment
   The situation awareness information is used to assess incidents in the tunnel. In some cases, disturbances are directly solved by standard or rule-based procedures.

3. Decision making
   When no standard procedure is available, the operator (together with others) might have to make decisions to prevent escalation of incidents.

4. Direction and control
   Intervention in the tunnel and participation in rescue operations if necessary. The operator is crucial in incidents, especially in the first stages, prior to the arrival of rescue services.

In practice, the distinction between situation awareness and disturbance assessment may be difficult to make. The same goes for decision making and direction and control. Therefore, the four task types are clustered into two sets:

Situation assessment:	Decision making and control:
1. Situation awareness 2. Disturbance assessment	3. Decision making 4. Direction and control
Especially relevant in normal tunnel operations.	Especially relevant in incident situations.

3.1.2 Incident scenario

In different stages of the incident process, different strategies can be used to return to the normal operation of the tunnel. There are several ways to define the stages of an incident scenario. For the purpose of reviewing operator tasks, incident stages derived from the incident scenario in Table 3-1 are used. Note that these stages may (partially) overlap.

Table 3-1: Generic incident scenario

Incident stage	Includes
Prevention	Activities to reduce possible incident causes: prevention, pro-action. Preparation for effect reduction (such as education or developing procedures).
Incident	When a disturbance occurs, detection equipment sends a signal to the control room. The operator handles the disturbance in order to avoid escalation.
Most scenarios end here. Usually, the operator handles the disturbance in time to avoid escalation of the incident.	
Escalation	If the incident does escalate, the operator takes action to minimize undesired consequences, and prevent further escalation: • he closes the tunnel for oncoming traffic; • he switches the tunnel equipment to the emergency operation status.
Alert	The operator alerts: • rescue services; • other operators, where applicable; • tunnel users, instructs them to escape if necessary.
Self rescue	Tunnel users • leave the car; • may try to help others evacuate; • may try to correct the situation; • flee to safe place.
Rescue by rescue services	All activities performed by fire rescue, medical rescue, police and towing service, to limit consequences to tunnel users and tunnel, and to prevent further escalation. The operator assists the rescue services. • Rescue of remaining tunnel users; • putting out fire; • removing vehicles and obstacles (towing service); • switching tunnel equipment to normal status (and check); • re-opening tunnel by proper authority.
Follow-up	After situation has been returned to normal: evaluation and aftercare.

3.2 Operator tasks

In Table 3-2, the operator tasks are listed following the incident scenario from 0. The tasks are categorized into the two task type sets as mentioned in 3.1.1.

Table 3-2: Operator tasks

Incident stage	Situation assessment task	Decision making and control task
Prevention	Monitoring the traffic flow and situation in the tunnel (and vicinity) using cameras, sensor readings and communication equipment. Note: constant vigilance is required.	
	Monitoring the installed equipment.	Making a decision about urgency when tunnel equipment fails: repair now or later? To call maintenance staff to repair the failure.
		Preparation for effect reduction: education, training, exercises.
Incident	Fast and correct detection of incidents.	Handling disturbances in order to return to the normal situation and avoid escalation: for example, flat tyre: close lane, help driver (phone), return to normal.
Escalation	Keeping alert, monitoring for additional disturbances or possible further escalation.	Closing the tunnel; switching equipment to 'emergency mode' (lights, ventilation, speed limits, escape doors, et cetera).
Alert		Alerting other operators (where applicable), rescue services and tunnel users (instructing them for escape if necessary).
		Alerting other authorities.
		Taking traffic measures to clear the road for the rescue services.
Self rescue		Communicating with tunnel users to help them escape and to help them help others or correct the situation (for example: putting out a small fire).
Rescue by rescue services	Being the 'eyes and ears' inside the tunnel for the rescue services.	From the control room, assisting the rescue services in their rescue operation.
		Implementing detours for oncoming traffic if necessary.
		Arranging to remove vehicles and obstacles. Arrange to restore tunnel and tunnel equipment to normal, and check.
		Re-opening the tunnel after authorization.
Follow-up		Evaluating and registering the incident for the purpose of improvement.

From this table it is apparent, that, the moment an incident occurs, many time-critical "Decision making and control" tasks have to be executed in the incident process. This phenomenon will be explored further in the next chapter.

4 Bottlenecks

4.1 Approach

In theory, the tasks listed in 0 are sufficient to minimize injuries and damages and quickly return to 'business as usual'. But: in reality, things can go wrong due to several causes.

Two approaches were used to identify bottlenecks:

1. Starting from the operator's tasks, factors can be identified that influence the probability of the operator making errors (cognitive task load model, see 4.1.1).
2. Incident reports identify several (possible) bottlenecks that, directly or indirectly, negatively influenced the situation (4.1.2).

4.1.1 Cognitive task load model

The cognitive load model [1, 2] distinguishes three load factors that have a substantial effect on task performance and mental effort:

1. Percentage time occupied: the percentage of available time that the operator is occupied with his or her tasks. The higher this percentage is, the higher the cognitive load.
2. Level of information processing: relates to the complexity of tasks. This factor is based on the Skill-Rule-Knowledge framework of Rasmussen [3], in which skill-based tasks demand the least cognitive effort and knowledge-based tasks the most.
3. Number of task-set switches: refers to the number of switches the operator has to make between different task-sets. The more switches, the higher the cognitive load.

Combination of these factors yields an indication of the operator's cognitive load:

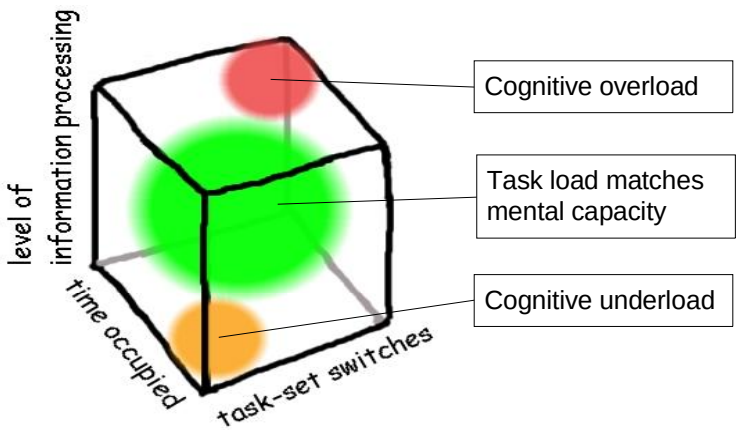

Figure 4-1: Schematic representation of the task load model

Cognitive *overload* (red area) can occur when one or a combination of the following situations is present:

1. The operator does not have enough time to finish the tasks.
2. The operator tasks are too complicated.
3. The operator has to perform too many tasks at the same time.

On the other hand, if all three factors can be characterized as "low", cognitive *underload* can occur (orange area). Cognitive underload, just as overload, may lead to sub-optimal performance. For example, it may have a negative effect on vigilance.
Ideally, all three factors are in between these two: in that case the task load matches the operator's mental capacity in a certain task setting (green area).

4.1.2 Error types

(Possible) bottlenecks identified from past incidents may cause different types of errors. Figure 4-2 is a schematic representation of a model described in [1].

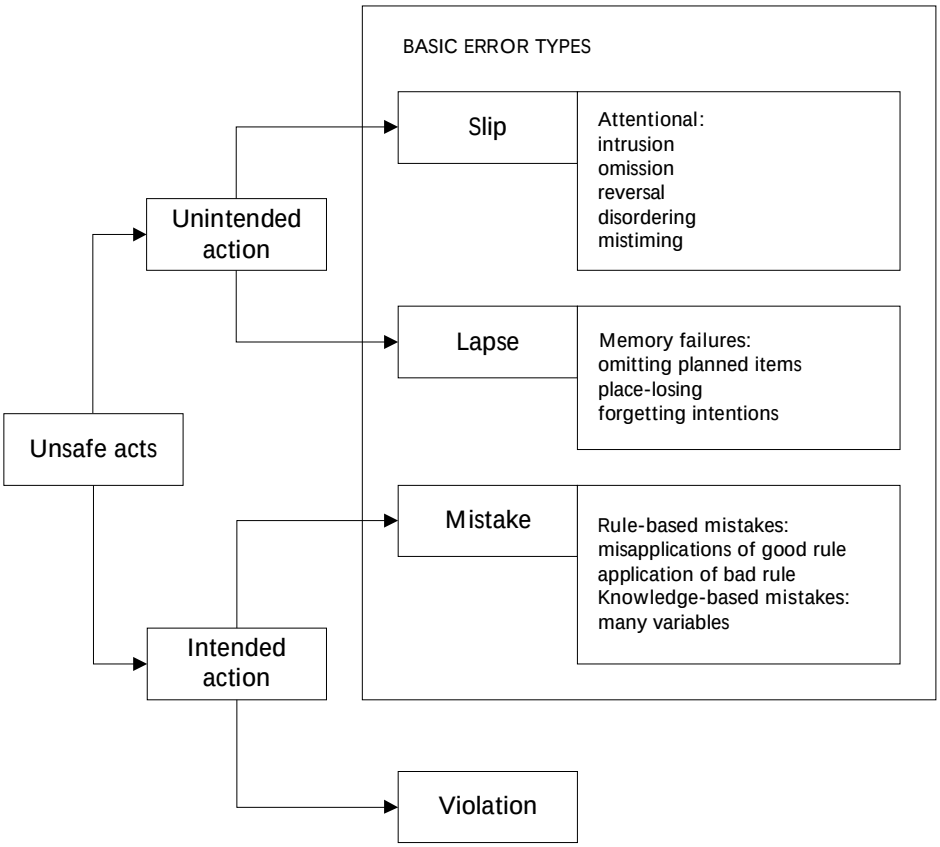

Figure 4-2: Error types

In 4.2, an attempt is made to identify error types connected with each of the bottlenecks. This is done to help direct the search for possible solutions. For example, for 'application of bad rule' (rule-based mistake), the solution most likely to be succesful is 'change the rule'.

4.2 Bottlenecks

Table 4-1 is a list of bottlenecks from the sources mentioned in paragraph 4.1. Table 3-2 was used to link operator tasks and bottlenecks.

It should be noted that a number of bottlenecks may occur in various incident stages. This is mainly due to the fact that lack of adequate preparation causes bottlenecks during an actual incident. In the table, bottlenecks with consequences throughout the incident process are listed under the heading ‘Prevention'.

In the previous chapter it was already mentioned that many tasks during the incident handling process can be categorized as ‘Decision making and Control’ tasks. Also, these actions have to be completed in as short a time as possible. This may cause cognitive overload as described in the Cognitive Task Load model (see Bottleneck 7 in the table).

This phenomenon is partly related to the fact that in many cases, there is a lack of adequate incident handling procedures, insufficient coordination and communication with rescue services as well as a lack of exercises.

Table 4-1: Operator tasks (from Table 3-2) and bottlenecks[2]

Incident stage	Situation assessment task	Decision making and control task	#	Bottleneck	Bottleneck type
Prevention	Monitoring the traffic flow and situation in the tunnel (and vicinity) using cameras, sensor readings and communication equipment. Note: constant vigilance is required.		01	During long periods of normal operation, vigilance may be threatened. This is especially critical during the night (3-6 a.m.), when tunnel users are also less alert.	Cognitive underload risk
		Preparation for effect reduction: education, training, exercises.	02	Bad or absent incident handling procedures; especially unclear allocation of responsibilities and authority to personnel.	Rule-based mistake: no rule or bad rule
			03	Insufficient skills due to lack of practice exercises, especially with the rescue services.	Knowledge-based mistake
Incident	Fast and correct detection of any event or disturbance likely to escalate into an incident.		04	Overdue, incorrect or incomplete detection of incident due to combination of suboptimal cognitive load and suboptimal detection of risk factors in tunnel.	Suboptimal cognitive load
			05	Overdue, incorrect or incomplete detection of incident due to combination of suboptimal cognitive load and suboptimal detection of risk factors in tunnel.	No error but lack of tools or wrong tools
			06	Operator is panic-stricken and does not respond (adequately) to incident.	Unintended action
Escalation		Closing the tunnel; switching equipment to 'emergency mode' (lights, ventilation, speed limits, escape doors, et cetera).	07	Starting from the escalation stage, many different decisions and actions are required in a short time.	Cognitive overload risk
			08	Too many incoming signals, not all of which are relevant	Cognitive overload risk

[2] Some bottlenecks are listed twice in the table. Under "Bottleneck type", bottlenecks are categorized according to the cognitive task load model and the error type model. Some bottlenecks may fit into one of two categories, depending on the actual cause in a specific case. In this table, these bottlenecks are listed with both relevant categories. In the next chapter, both categories will be necessary when a link-up of bottleneck types and generic solutions is used to help the search for solutions.

Incident stage	Situation assessment task	Decision making and control task	#	Bottleneck	Bottleneck type
				at this time.	
Alert		Alerting other operators (where applicable), rescue services and tunnel users (instructing them for escape if necessary).	09	Insufficient means to communicate with other operators, rescue services or tunnel users.	No error but lack of tools or wrong tools
			10	Insufficient skills and / or knowledge to communicate with other operators, rescue services or tunnel users.	Knowledge-based mistake
Self rescue		Communicating with tunnel users to help them escape and to help them help others or correct the situation (for example: putting out a small fire).	11	Operator does not succeed in convincing tunnel users to escape.	Rule-based mistake: misapplication
			12	Operator does not indicate right way for fleeing or does this too late.	Knowledge-based mistake
Rescue by rescue services		From the control room, assisting the rescue services in their rescue operation.	13	Absence of or insufficient coordinated procedures between operators and rescue services.	Rule-based mistake: no rule or bad rule
Follow-up		Evaluating and registering the incident for the purpose of improvement.	14	Absence of adequate incident evaluating and registration procedures.	Rule-based mistake: no rule or bad rule
			15	Mistake in incident is not evaluated or registered due to fear for career consequences.	Violation
			16	Incident is not evaluated or registered although adequate procedure is available and known.	Violation

5 Possible solutions

5.1 Approach

Improving operator performance can be achieved through a number of improvement methods:

1. Recruitment
2. Training and exercise
3. Personnel and organisation
4. Task support (such as procedures and guidelines)
5. Control room and interface design

Paragraph 5.2 discusses possibilities to prevent cognitive underload or overload by applying the improvement methods mentioned above. Paragraph 5.3 lists recommendations for each of the improvement methods, based on the bottlenecks identified in Chapter 4.

The first table in Appendix A.2 contains the bottlenecks identified in 4.2 along with possible solutions. No attempt has been made to list *all* possible solutions, but for each bottleneck, some solutions are mentioned. Appendix A.3 provides some background information on available tools and techniques mentioned in this report and supporting the solutions.

5.2 Optimizing cognitive task load

5.2.1 Solutions for cognitive underload

The earlier and the more correctly a disturbance or an incident is detected, the bigger the chance that it is handled quickly and adequately. This requires constant vigilance on the operator's part. Cognitive underload is a serious threat to the operator's vigilance.

SOLUTIONS FOR COGNITIVE UNDERLOAD

a) Limit operator's duties to a few hours at a time.
A practical solution is to have (at least) two staff members on duty, both qualified to perform operator's tasks, switching roles every few hours. One of the two may be performing other activities, while the other one is monitoring the tunnel.

b) Force the operator to employ activities from time to time.
Some tunnel owners choose an operating system that generates alarms if nothing has happened in the last, say, ten minutes. When this happens, the operator is required to take certain actions in order to disable the alarm, for example check on some part of the tunnel equipment.

Of course, a prerequirement for solution "a" is the availability of enough operators. If there can only be one operator on duty, activities besides actual operator tasks may not be possible.

5.2.2 Solutions for cognitive overload

The five improvement methods can all be used to lower cognitive task load. To be able to choose the most effective combination of measures, it is necessary to know the causes of cognitive overload (see also 4.1.1):

1. The operator does not have enough time to finish the tasks. The solution might be to reduce the number of tasks or the time required for individual tasks.
2. The operator tasks are too complicated (level of information processing: skill < rule < knowledge). Improvement by reducing the level of information processing.
3. The operator has to perform too many different tasks at the same time, including the interpretation of incoming signals irrelevant to the incident. Improvement by reducing the number of tasks and incoming signals.

Also, it is necessary to establish at what point in the incident process cognitive overload is likely to occur. Common times in the incident process where overload may be a threat are:

1. Detection: if the operator is too busy performing other tasks than monitoring, he may not notice an incident in the tunnel. The more other tasks and the more complex these other tasks, the greater the chance of this occurring;
2. After detection of a (serious) incident, many additional signals come in while at the same time the operator has to perform many different tasks in a short time;
3. Decision to evacuate: based on the assessment of the situation in the tunnel, the operator has to make the difficult decision whether or not evacuation is necessary. In a fire, lives may depend on this decision and especially on its timing.

SOLUTIONS FOR COGNITIVE OVERLOAD

c) Reduce the time required for a task and the number of different tasks required.
The operator's work station (hardware and software) should be designed in such a way, that all controls, switches, phones et cetera can be reached in an instant. Also, the number of actions that the operator needs to take during an incident should be limited to a minimum.

d) Reduce the level of information processing required for a task by providing adequate procedures for incident management and regular training and exercise based on these procedures. This way, tasks will move from knowledge-based to rule-based to skill-based.

e) During an incident, reduce the number of incoming signals to only those important for handling the incident.

Figure 5-1 shows a (very) crude representation of an analysis of cognitive overload threat. Both the incident scenario and the cognitive task load parameters were used to gain an insight into the overload danger. Scenario analysis (See A.3.1) can assist in specifying the tasks and actions required and the time needed to complete them.

When choosing improvement methods, attention should especially be given to tasks occurring in those stages, where cognitive overload is most likely to occur. In the example presented in Figure 5-1, this would be the incident, escalation, alert and self rescue stages.

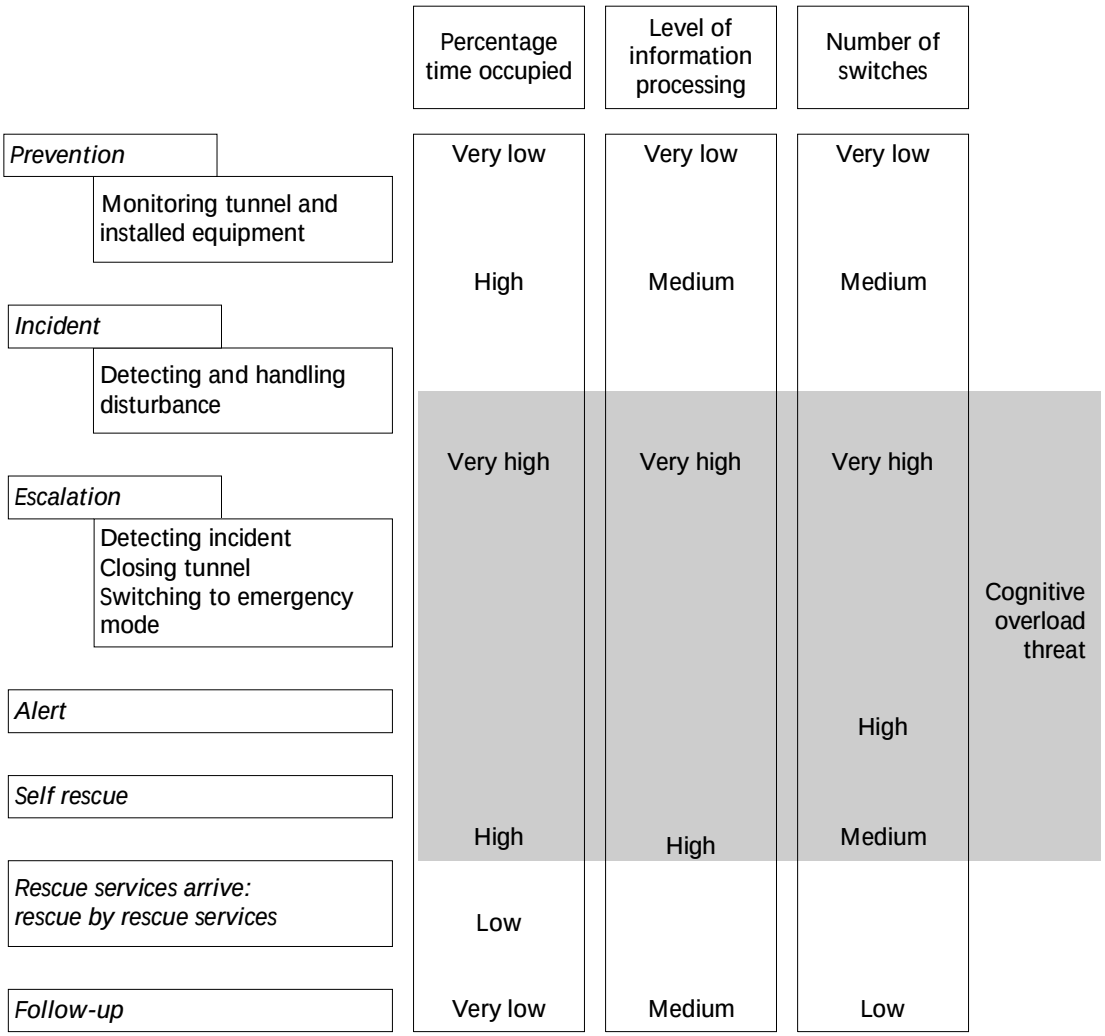

Figure 5-1: Example of an analysis of cognitive overload threat

5.3 Possible solutions to bottlenecks

Depending on the type(s) of error connected with a bottleneck, a generic match for bottleneck types and solutions was used to assist the search for possible solutions.
For example, education is often the answer to knowledge-based mistakes, and if, for a certain task, tools are unavailable or inadequate, the obvious solution is to change them or provide the right tools. This provides an indication for the improvement methods likely to be effective. Appendix A.2 contains two tables. The first one lists the bottlenecks from beginning to end of the incident scenario. The second one lists the same bottlenecks, rearranged into the five improvement methods. These tables were used to write the recommendations in this paragraph.

5.3.1 Recruitment

Certain personal characteristics are of the utmost importance when recruiting personnel for tunnel control centres, more important than knowledge or technical skills.

In a PIARC (AIPCR) working group, a 'Good practice' for the operation and maintenance of road tunnels was produced [4]. Part of this is an extensive set of recommendations for recruitment, training and exercises for tunnel operating staff. The PIARC report mentions prerequisites for recruitment and requirements for personal qualities and training levels for traffic control and incident response staff.

This report, therefore, merely suggest some specific staff selection criteria, based on the identified bottlenecks.

SOLUTIONS: RECRUITMENT

Apply staff selection criteria:

1) candidate should be able to handle stress, especially during incidents when tunnel users may be in danger;
2) candidate should possess excellent communication skills; should be able to communicate with tunnel users in such a way, that:
    - o tunnel users are aware of his authority;
    - o tunnel users are immediately aware of the urgency of the situation and, where applicable, the need to flee;
    - o he does not convey any feelings of panic onto the tunnel users;
3) candidate should be able to evaluate his own work, in order to effectively evaluate incidents; should be able to make improvements based on this evaluation (attitude / self-learning).

5.3.2 Training and exercise

Education provides a basis for the required skills and knowledge for managing an incident. Due to the fact that large-scale incidents – luckily – do not happen very often, experience cannot be relied upon to reach and keep the desired level of knowledge and skills. Additionally, the operator needs to know the existing procedures and specific characteristics of the tunnel he is monitoring.
Therefore, it is essential to keep the operator's knowledge and skills up-to-date in other ways, for example by regular training and exercises.
Exercises with the emergency services, in addition, will influence the quality of communication between the operator and emergency services.

Also, the PIARC document [4] provides a large number of recommendations for basic training, ongoing training and exercises (with or without emergency services).

Training and exercise (no matter what the subject is) can be used to increase cognitive load: keeping the operator alert by performing exercises at certain times. On the other hand, training and exercise can also be used to lower cognitive load by lowering the level of information processing. See also paragraph 5.2. In A.3.3, some training techniques are discussed.

SOLUTIONS: TRAINING AND EXERCISE

4) Include incident management procedures in both basic and ongoing training. Not only to enhance the skills of the operators and others involved, but also to evaluate the procedures themselves.
5) Include tunnel lay-out, location and operation of all safety measures, including communication devices in basic training.
6) Train communication skills.
7) In addition to the actual training and exercise programme, require operators to take periodical tests to make sure the training programme is carried out as it should be.

5.3.3 Personnel and organisation

The number of people or allocation of tasks should be optimally suited to the number and nature of control room tasks. However, if these personnel matters would only be based upon an efficient distribution of tasks, the result could be that only one operator on duty should suffice. In that case the tunnel owner should use caution: practical complications may occur. In this case it may be recommendable to search for alternatives such as having two operators present at all times (see also 5.2.1).

The effect of characteristics of the tunnel management organisation should not be underestimated when analyzing operator performance.
For example, every tunnel management organisation should have an excellent communication network with the emergency services to ensure that the duties of rescuers and tunnel operators are smoothly coordinated.

Another example: in some organisations, mistakes or errors are not evaluated or registered due to fear of punishment (adverse effects on career). As a consequence, the organisation misses out on the opportunity to learn from mistakes made by its employees.

SOLUTIONS: PERSONNEL AND ORGANISATION

8) Make sure there are enough operators on duty (and spares) to switch roles from time to time and to assist during incidents.
9) Stimulate communication on a regular basis with the emergency services to coordinate and facilitate incident handling procedures.
10) Make sure the company culture provides an environment that supports the company goals (including the learning process).

5.3.4 Task support

During an accident or calamity, the operator must – as much as possible – be protected from making mistakes and from making the wrong decisions under great stress (due to cognitive overload, see 5.2.2).
The number of decisions to be made by the operator must therefore be limited to a minimum. This can be achieved by standardization, which includes both procedures (exactly how to act in an incident) and tunnel safety equipment.

Procedures and plans may deal with:

- Preventive measures (e.g. maintenance schedules for technical installations)
- Adequate management of disturbances.
- Adequate incident management:
  - Communication: who gives what information how and to whom?
  - Who is authorized to do what at which moment?
  - In A.3.2, an example of a standard calamity plan is described.
- Incident evaluation and registration aimed at improvement by learning from mistakes.

Some kind of manual or procedure book is usually the carrier of this information. The existence of such a manual is, of course, not enough: the manual and its contents have to be available and known to all parties. Moreover, a manual has to be easily understandable to the persons who have to use them. Tools such as summarizing flow charts and reference cards may help.

Also, using procedures only *starts* by writing them. In order to successfully use procedures as part of a solution, attention should be given to instruction and implementation as well.

SOLUTIONS: TASK SUPPORT

11) Decide for which tasks procedures are useful;
12) Write the procedures using knowledge and experience of all relevant parties;
13) Make sure everyone who plays a role in a procedure has access to it;
14) Make sure that time-critical procedures are well-known and can be found fast (for example: short instruction card on operator's desk).
15) Exercise the procedures on a regular basis.

5.3.5 Control room and interface design

The operator's work place should provide an adequate environment for him to keep alert and perform his tasks efficiently. Control room and interface design provide opportunities to support an optimal cognitive task load.

An interface should provide complete and correct information on the situation in the tunnel as quickly and easily accessible as possible.

During normal operation, incoming signals warn the operator about low traffic speed in the tunnel or equipment malfunctions. Depending on the situation, the tunnel operator may decide to act on those incoming signals one way or the other. When, however, an incident is in progress, several alarms will sound and keep going, distracting the operator from more important tasks such as guiding tunnel users towards a safe exit.

Ideally, during an incident, the operator should only hear or see alarms that directly influence the safety in the tunnel at that time. For example, a low traffic speed alarm is no longer relevant if the operator already knows that there has been an accident and the tunnel is blocked. On the other hand, if at some point fire detection gives a signal, he should immediately instruct the tunnel users to escape.

Tools are available to limit the time needed for certain tasks and limit incoming signals (as illustrated in Figure 5-2).

Control room and interface design may also assist in keeping the cognitive task load above a minimum level (see also 5.2.1). For example, temperature in the control room can influence alertness. Another example: generating a sound signal if the system has registered no activity during a specified period of time.

Using technology to improve operator performance only works if it supports other measures, and if its operation is trained on a regular basis.

Figure 5-2: Standardizing operator tasks

SOLUTIONS: CONTROL ROOM AND INTERFACE DESIGN

Possible tools:

16) Tools for cognitive support (A.3.4). Such tools, if based upon the correct procedures, can assist the operator in the course of action.

17) A command group (see A.3.5): two or more actions are triggered by one button, limiting the number of actions required to complete a task.
For example: the so-called 'calamity button' in the Westerschelde tunnel (The Netherlands) [2]. As soon as a serious incident is detected, the operator pushes the button, and the lighting level goes to maximum, ventilation kicks in, escape route systems are activated, and so on.

18) Tools facilitating the evacuation process (see A.3.6). Communication with tunnel users to guide their escape is a time-consuming and high-pressure task for the operator during the incident.

19) A switch for the operator to disable all irrelevant alarms during an incident. If a calamity button is applied, the underlying commands may include such a suppression mode. An additional solution is creating the possibility for the operator to stop a specific signal, as soon as he is aware of the problem.

20) A combination of loud alarms and visual signals if a crucial factor, for example fire, has been detected to make sure that, even if the operator is less alert than usual, the disturbance is noticed.

6 A strategy

A tunnel owner can follow these steps to improve operator performance.

STEP 1: MAKE AN INVENTORY OF THE OPERATOR'S TASKS.

In this report, mainly tasks related to incident management are mentioned. However, in many cases, the operator has additional tasks, such as maintenance tasks, traffic control tasks or manning toll booths. These extra tasks should also be taken into account, and may even provide possible solutions to some bottlenecks. For example, cognitive underload may be prevented by having two or more tunnel operators switching roles from time to time, and performing monitoring tasks for only a limited number of hours at a time.

The first step is to make an inventory of all the operator's tasks. This could be done using the cognitive load model and scenario analysis (see Chapter 3 and A.3.1).

STEP 2: IDENTIFY BOTTLENECKS, USING THE TASK LIST, KNOWLEDGE AND EXPERIENCE.

The task inventory could already reveal threats, such as possible task overload at certain times during an incident. Using the cognitive task load model and the combined European experiences with minor and major incidents, possible bottlenecks can be identified the way this was done in Chapter 4.

Also, tunnel owners and operators usually have sufficient knowledge and experience in handling (minor) incidents to identify additional bottlenecks specifically applicable for the local situation and the tunnel owner's organisation.

STEP 3: INTERVIEW TO CHECK, COMPLETE AND PRIORITIZE THE BOTTLENECK LIST.

The lists of tasks and bottlenecks may be used as a basis for interviews with tunnel operators and other relevant parties (such as emergency services). They may provide new suggestions from a different point of view.
Appendix A.1 is a questionnaire that may be useful for interviewing operators.
Operators and rescuers may also help prioritize the bottlenecks.

STEP 4: FIND SOLUTIONS FOR THE MOST IMPORTANT BOTTLENECKS AND DESIGN AN IMPROVEMENT STRATEGY.

Using the prioritized list of bottlenecks and the general methods for influencing operator behaviour mentioned in Chapter 5, generate possible solutions for the most important bottlenecks.

For different tunnels, different solutions or combinations of solutions may prove to be the most efficient. Sometimes, two birds can be killed with one stone.
For example, an exercise in cooperation with the emergency services may (1) improve the operator's skills, (2) improve communication between the tunnel

management organisation and the emergency services, and (3) reveal irregularities in incident procedures.

On the other hand, in most cases, there is more than one effective solution to a problem and some improvement methods even inherently require combination with another one in order to be effective. For example, it serves no purpose to provide software to log and evaluate incidents, if the organisation culture punishes those, who admit to making mistakes.

Which way to choose, then? An effective strategy to reduce the most important bottlenecks relevant to a tunnel (or set of tunnels) should be a balanced mix, depending on, amongst others, the following factors:

- which, and how many, bottlenecks are relevant to the situation;
- local circumstances (for example: if the tunnel lies in two language regions, control centre personnel could be selected from both);
- presence of other problems that need to be solved;
- characteristics of the tunnel owner's organisation.

Your strategy for improving operator performance is now complete.

STEP 5: PLAN AND EXECUTE YOUR STRATEGY.

Based on the strategy, a plan can be written to implement the chosen solutions. This plan should include assessment: when and how to check if the solutions were effective in attaining the goals of the strategy.

Depending on the factors mentioned in the former step and the means available to the tunnel owner, a large number of tools and techniques supporting the solutions is available. Appendix A.3 may be helpful at this point.
When the plan is ready and approved by the proper authorities, it is executed.

STEP 6: ASSESS THE EFFECT.

Based on the plan, at several times during the implementation process and at the end, the effectiveness of the chosen strategy is assessed.

Progress can be measured by comparing the original lists of tasks and bottlenecks to the present situation. Interviewing operators again, using the questionnaire (A.1), may be helpful in finding the answer to the question: "Do the solutions really work?"

Revision of the strategy may be necessary if the outcome is not as desired.

Appendices

A.1 Interviewing the operator

A.1.1 Introduction

In the UPTUN deliverable 3.2 [1] the COLFUN framework was described. This framework is used to describe the tasks and the mental load of operators in process control environments. This model was used in this task to
1) identify problems that can occur within the work of tunnel operators and
2) define solutions for these problems.

Because the model is quite extensive, a simplified version of it is presented in this document. The framework can be used to analyse existing data or acquire new data.
This document is aimed at part (1).
For this purpose, it contains a questionnaire and some guidelines for its use.

A.1.2 Method

STEP 1: TASK IDENTIFICATION

For task identification, an inventory is made of all operator tasks, classified in situation assessment and decision making and control. This concerns tasks during normal situations (e.g. a traffic jam) and incidents or accidents (e.g. a fire). Tasks can be listed like below (see also the main text of the deliverable, Chapter 3):

Situation assessment task	Decision making and control task
Tasks, especially relevant in normal tunnel operations: situation awareness and disturbance assessment. E.g. watching camera images, alarm handling, et cetera.	Tasks, especially relevant in incident situations: decision making, direction and control. E.g. speed limitation in tunnel, close barriers, call police.

STEP 2: INVENTORY OF BOTTLENECKS

The results from the questionnaire can be used to make an inventory of bottlenecks in the operator task:
- Which task or combination of tasks can cause problems?
- Why do they cause problems?

Bottlenecks in the operators task design can be identified by using the cognitive load model.

STEP 3: DEFINITION OF POSSIBLE SOLUTIONS

See the main text of this deliverable, in which this document was used to make an inventory of operator tasks and bottlenecks and solutions were defined, based on the results.

A.1.3 Analysing existing data

In retrospect, available data can be analysed following the method. At first, the data has to be filtered that is related to the tunnel operator. Secondly, from this data the operator tasks have to be identified as much as possible. Third, supported by the cognitive load model bottlenecks should be identified. When bottlenecks are already mentioned, it should become clear to what tasks these bottlenecks are related. Finally, solutions for the bottlenecks should be defined.

A.1.4 Operator interviews

The method can also support in making a questionnaire for the operator interviews. The questionnaire should cover items about the operator tasks during normal and incident situations. At the same time, it should cover items about the cognitive load of the operator. It should facilitate the operator to uncover tasks / situations that are difficult to handle.
The questionnaire in A.1.5 was developed according to the method. It is possible to send the questionnaire to the tunnel operators and ask them for a written reply. However, in order to get a good understanding of the operator and possible issues that are not on the list, we recommend using the questionnaire in a face-to-face interview.

A.1.5 Questionnaire

CONTROL SYSTEM

1. What means are available to inform you about the status in the tunnel?
   - q Cameras
   - q Speed detection system
   - q CO sensors
   - q Sight sensors
   - q Temperature
   - q Smoke detectors
   - q Height detectors
   - q Aid station sensors
   - q Communication system in tunnel
   - q Others: …..

2. What means are available to control the situation in the tunnel?
   - q Electronic traffic signs
   - q Intercom
   - q Traffic lights
   - q Barriers
   - q Ventilators
   - q Others: ….

3. When does the system produce alarms to notify certain events? Indicate if these alarms are presented visually, acoustically (sound) or both.

	Visual	Acoustic	Both
q The system does not produce any alarms			
Low traffic speed	q	q	q
CO level too high	q	q	q

Temperature too high	q	q	q
Limited sight	q	q	q
Vehicle too high	q	q	q
Aid station in use	q	q	q
Smoke in tunnel	q	q	q
Others: ….	q	q	q

4. What is the mean number of alarms (more or less) that is presented within an hour?
   ……

5. Are you satisfied with the alarms? (You're allowed to tag more than one answer)
   - q Yes
   - q No, because there are too many alarms
   - q No, because some alarms are not relevant
   - q No, because some alarms are missing
   - q No, because …

6. Do the cameras give you a good view on the situation inside the tunnel? (You're allowed to tag more than one answer)
   - q Yes
   - q There are no cameras available
   - q No, because the distance between cameras is too long
   - q No, because the cameras don't cover every spot in the tunnel
   - q No, because the images are unclear
   - q No, because takes a long time to find the camera that covers the right location
   - q No, because …

7. When the cameras are not usable (e.g. when it is covered by a vehicle or in case of smoke), is there another way to get informed about the situation inside the tunnel?
   - q No
   - q Yes: ……

INCIDENTS

8. What are the things that can happen in the tunnel which you have to be aware of? (You're allowed to tag more than one answer)
   - q Congestion
   - q Poor sight
   - q CO level too high
   - q Vehicle that is too high
   - q Tunnel system malfunctions (e.g. illumination, electronic signs, ventilators)
   - q Load fallen off from truck
   - q Broken car
   - q Car against barrier
   - q Collision
   - q Fire
   - q Others, …

9. Which of these things happen the most often?
   ……

10. How much time (more or less) does it take before you detect such an incident?
    ……

11. When this happens, do you immediately know what to do?
    - q No, it takes some time to find out what to do
    - q Yes, then I will do the following: ……

12. What incident you can think of do you consider as the most severe?
    ……

13. How much time (more or less) does it take before you detect such an incident?
    ……

14. What is the first thing you do when this happens?
    ……

15. What is your main task during these incidents?
    ……

16. Are there emergency plans for severe incidents?
    - q Yes
    - q No, go to question 19

17. If yes, do you know what procedures to follow? (You're allowed to tag more than one answer)
    - q No
    - q Yes, I know them by heart
    - q Yes, they are on paper in the control room
    - q Yes, they electronically available in my system
    - q Yes, I have access to them in another way: ……

18. Do the emergency plans work properly during these incidents?
    - q Yes, they do
    - q I don't know, I never experienced such an incident
    - q No, because …

19. How much time does it take for the emergency services to arrive at the tunnel from the moment you warn them?
    ……

20. In the meantime, what tasks do you have to perform? (You're allowed to tag more than one answer)
    - q Monitoring the tunnel
    - q Evacuate tunnel users
    - q Communicate with tunnel users
    - q Communicate with others (e.g. superiors, authorities, emergency services)
    - q Other tasks: ……

21. Do you have to perform these tasks alone?
    - q Yes
    - q No, in such situations I get assistance from …

22. Are you able to perform these tasks properly? (You're allowed to tag more than one answer)
    - q Yes
    - q No, because I have to do too many things at the same time
    - q No, because it is not clear what actions to take
    - q No, because I get unclear or conflicting instructions
    - q No, because the incidents do not occur very often, so I don't know exactly what to do
    - q No, because the system is too difficult to operate
    - q No, because …
    - q …….

23. Do you know what procedures to follow specifically with respect to the rescue services?
    - q No
    - q Yes, I know the procedures
    - q Yes, they are on paper in the control room
    - q Yes, they are electronically available in my system
    - q Yes, I have access to them in another way: …..

24. If yes: do you know if these procedures have been agreed upon between the tunnel owner and the rescue services?
    - q Yes, I know they have.
    - q Yes, I know they have not.
    - q No, I do not know.

25. What do you do after the situation has returned to normal? (You are allowed to tag more than one answer)
    - q Write an incident report
    - q Inform a superior about what has happened
    - q Register the incident in a computer system
    - q Other tasks:….

SHIFTS

26. Do you work in shifts?
    - q Yes
    - q No

27. If yes, what are the working hours of the different shifts?

    Shift 1:

    Shift 2:

    Shift 3:

    Shift 4:

28. What shift do you prefer the most?
    ……

29. What shift do you prefer the least?
    ……

30. How many breaks do you have during your work?
    ……

31. Who is watching the tunnel during your break?
    ……

32. When your shift is over, do you have to report to your colleague of the next shift?
    ……

33. If yes, how does this take place?
    ……

TRAINING

34. Did you get any training before you started to work as a tunnel operator? (You're allowed to tag more than one answer)
    - q No
    - q Yes, I got training 'on the job' from an experienced tunnel operator
    - q Yes, I did a training course of … weeks
    - q Yes, I had another form of training: ……

35. Do you have any training courses to refresh your skills and knowledge?
    - q No
    - q Yes, every … months

36. Are there training sessions with the emergency services to learn what to do during severe incidents (e.g. a fire in the tunnel)?
    - q No
    - q Yes, every … months

37. If yes, do you consider these training sessions as useful?
    - q Yes
    - q No, because …

A.2 Additional tables

The tables in this appendix were used to specify recommendations in Chapter 5 of the main text. The first table (A.2.1) shows the analysis of the bottlenecks identified after analysing the operator tasks (see also Table 4-1 in the main text). Solutions are listed for each of the bottlenecks. The second table (A.2.2) shows roughly the same information, only rearranged into categories that represent the general methods for improving operator performance.

A.2.1 Bottlenecks and possible solutions

#	Bottleneck	Bottleneck type	Generic solution	Improvement method	#	Solution
01	During long periods of normal operation, vigilance may be threatened. This is especially critical during the night (3-6 a.m.), when tunnel users are also less alert.	Cognitive underload risk	Increase cognitive task load	Training and exercise	04	Provide means and time to switch between the monitoring task and studying new procedures or other activities.
				Personnel and organisation	12	Make sure there are enough operators on duty so no one has to monitor the tunnel(s) for too long a time and other tasks may be executed.
				Control room and interface design	18	Provide the necessary means to keep the operator alert. Example: temperature in control room; force him (using alarms) to take certain actions.
02	Bad or absent incident handling procedures; especially unclear allocation of responsibilities and authority to personnel.	Rule-based mistake: no rule or bad rule	Make rule or change rule	Training and exercise	11	Evaluate exercises to reveal flaws or inefficiency in operation procedures.
				Task support	16	Provide standard emergency plans; coordinate these with rescue services and make sure these plans are written, verified, well-known, used and revised if necessary.
				Control room and interface design	27	Provide tools to support disturbance handling and incident procedures. Tools should correspond with written procedures.
03	Insufficient skills due to lack of practice exercises, especially with the rescue services.	Knowledge-based mistake	Educate or change personnel	Training and exercise	06	Test operators periodically to make sure that training and exercise plans are executed.
04	Overdue, incorrect or	Suboptimal	Optimize	Training and	05	Use operation procedures in

#	Bottleneck	Bottleneck type	Generic solution	Improvement method	#	Solution
	incomplete detection of incident due to combination of suboptimal cognitive load and suboptimal detection of risk factors in tunnel.	cognitive load	cognitive task load	exercise		training and exercise: activities can move from knowledge-based to rule-based or from rule-based to skill-based.
					04	Provide means and time to switch between the monitoring task and studying new procedures or other activities.
				Personnel and organisation	12	Make sure there are enough operators on duty so no one has to monitor the tunnel(s) for too long a time and other tasks may be executed.
					13	Make sure there are enough operators present (and standing by) to, if necessary, take over certain tasks.
				Control room and interface design	18	Provide the necessary means to keep the operator alert. Example: temperature in control room; force him (using alarms) to take certain actions.
					26	Use loud alarms for important detection signals.
05	Overdue, incorrect or incomplete detection of incident due to combination of suboptimal cognitive load and suboptimal detection of risk factors in tunnel.	No error but lack of tools or wrong tools	Provide adequate tools	Control room and interface design	19	Provide an interface sufficiently effective to alert the operator if anything is wrong, if possible not only a visual signal on screen, but also, for example, a sound signal.
06	Operator is panic-stricken and does not respond (adequately) to incident.	Unintended action	No generic solution applicable	Recruitment	01	Apply the ability to handle stress as a selection criterium.
07	Starting from the escalation stage, many different decisions and actions are required in a short time.	Cognitive overload risk	Lower cognitive task load	Training and exercise	05	Use operation procedures in training and exercise: activities can move from knowledge-based to rule-based or from rule-based to skill-based.
				Personnel and organisation	13	Make sure there are enough operators present (and standing by) to, if necessary, take over certain tasks.
				Control room and interface design	21	Equip the work place so as to make sure that a minimum of actions (and time) is required to execute decisions.

#	Bottleneck	Bottleneck type	Generic solution	Improvement method	#	Solution
					20	Apply group commands for sets of actions that are the same for all serious incidents.
					27	Provide tools to support disturbance handling and incident procedures. Tools should correspond with written procedures.
08	Too many incoming signals, not all of which are relevant at this time.	Cognitive overload risk	Lower cognitive task load	Control room and interface design	23	Make it possible for the operator to switch off alarms during an incident.
					22	Make it possible to suppress all alarms that are irrelevant during an incident in progress.
09	Insufficient means to communicate with other operators, rescue services or tunnel users.	No error but lack of tools or wrong tools	Provide adequate tools	Control room and interface design	25	Make sure that means of communication for operators and rescue services are reliable and accessible to all parties concerned.
					24	Apply tools to address, guide and communicate with tunnel users.
10	Insufficient skills and / or knowledge to communicate with other operators, rescue services or tunnel users.	Knowledge-based mistake	Educate or change personnel	Training and exercise	07	Train communication procedures. If necessary, provide a language course.
				Personnel and organisation	14	If language is an issue: assemble control room crew from both language regions.
11	Operator does not succeed in convincing tunnel users to escape.	Rule-based mistake: misapplication	Educate or change personnel	Recruitment	02	Apply the presence of communication skills as a selection criterium. Staff should be able to communicate with tunnel users in a decisive and calm manner.
				Training and exercise	08	Train and exercise communication skills.
12	Operator does not indicate right way for fleeing or does this too late.	Knowledge-based mistake	Educate or change personnel	Training and exercise	09	Include knowledge of tunnel lay-out and tunnel equipment in procedures, training and exercise.
13	Absence of or insufficient coordinated procedures between operators and rescue services.	Rule-based mistake: no rule or bad rule	Make rule or change rule	Task support	16	Provide standard emergency plans; coordinate these with rescue services and make sure these plans are written, verified, well-known, used and revised if necessary.

#	Bottleneck	Bottleneck type	Generic solution	Improvement method	#	Solution
				Control room and interface design	27	Provide tools to support disturbance handling and incident procedures. Tools should correspond with written procedures.
14	Absence of adequate incident evaluating and registration procedures.	Rule-based mistake: no rule or bad rule	Make rule or change rule	Task support	17	Provide an adequate, low-threshold and well-known procedure for incident evaluation and registration.
15	Mistake in incident is not evaluated or registered due to fear for career consequences.	Violation	Educate, change organisation or personnel	Personnel and organisation	15	Make sure the company culture provides a 'safe' environment for learning from mistakes.
16	Incident is not evaluated or registered although adequate procedure is available and known.	Violation	Educate, change organisation or personnel	Recruitment	03	Apply attitude towards improving one's own task as a selection criterium.
				Training and exercise	10	Evaluate exercises and training sessions for improvements in procedures and actions, to convince personnel of the need for experience-based improvement.

A.2.2 Solutions by improvement method

Improvement method	#	Solution	Tools	#	Bottleneck
Recruitment	01	Apply the ability to handle stress as a selection criterium.		06	Operator is panic-stricken and does not respond (adequately) to incident.
	02	Apply the presence of communication skills as a selection criterium. Staff should be able to communicate with tunnel users in a decisive and calm manner.		11	Operator does not succeed in convincing tunnel users to escape.
	03	Apply attitude towards improving one's own task as a selection criterium.		16	Incident is not evaluated or registered although adequate procedure is available and known.
Training and exercise	04	Provide means and time to switch between the monitoring task and studying new procedures or other activities.	Duty rotation; training techniques.	01	During long periods of normal operation, vigilance may be threatened. This is especially critical during the night (3-6 a.m.), when tunnel users are also less alert.
				04	Overdue, incorrect or incomplete detection of incident due to combination of suboptimal cognitive load and suboptimal detection of risk factors in tunnel.
	05	Use operation procedures in training and exercise: activities can move from knowledge-based to rule-based or from rule-based to skill-based.	Training techniques.	04	Overdue, incorrect or incomplete detection of incident due to combination of suboptimal cognitive load and suboptimal detection of risk factors in tunnel.
				07	Starting from the escalation stage, many different decisions and actions are required in a short time.
	06	Test operators periodically to make sure that training and exercise plans are executed.	Training techniques.	03	Insufficient skills due to lack of practice exercises, especially with the rescue services.
	07	Train communication procedures. If necessary, provide a language course.	Standard calamity plan; training techniques.	10	Insufficient skills and / or knowledge to communicate with other operators, rescue services or tunnel users.
	08	Train and exercise communication skills.	Training techniques.	11	Operator does not succeed in convincing tunnel users to escape.
	09	Include knowledge of tunnel lay-out and tunnel equipment in procedures, training and exercise.	Simulations.	12	Operator does not indicate right way for fleeing or does this too late.
	10	Evaluate exercises and training sessions for improvements in procedures and	Training techniques.	16	Incident is not evaluated or registered although adequate procedure is

Improvement method	#	Solution	Tools	#	Bottleneck
		actions, to convince personnel of the need for experience-based improvement.			available and known.
	11	Evaluate exercises to reveal flaws or inefficiency in operation procedures.	Training techniques.	02	Bad or absent incident handling procedures; especially unclear allocation of responsibilities and authority to personnel.
Personnel and organisation	12	Make sure there are enough operators on duty so no one has to monitor the tunnel(s) for too long a time and other tasks may be executed.		01	During long periods of normal operation, vigilance may be threatened. This is especially critical during the night (3-6 a.m.), when tunnel users are also less alert.
				04	Overdue, incorrect or incomplete detection of incident due to combination of suboptimal cognitive load and suboptimal detection of risk factors in tunnel.
Personnel and organisation	13	Make sure there are enough operators present (and standing by) to, if necessary, take over certain tasks.		04	Overdue, incorrect or incomplete detection of incident due to combination of suboptimal cognitive load and suboptimal detection of risk factors in tunnel.
				07	Starting from the escalation stage, many different decisions and actions are required in a short time.
	14	If language is an issue: assemble control room crew from both language regions.		10	Insufficient skills and / or knowledge to communicate with other operators, rescue services or tunnel users.
	15	Make sure the company culture provides a 'safe' environment for learning from mistakes.		15	Mistake in incident is not evaluated or registered due to fear for career consequences.
Task support	16	Provide standard emergency plans; coordinate these with rescue services and make sure these plans are written, verified, well-known, used and revised if necessary.	Standard calamity plan.	02	Bad or absent incident handling procedures; especially unclear allocation of responsibilities and authority to personnel.
				13	Absence of or insufficient coordinated procedures between operators and rescue services.
	17	Provide an adequate, low-threshold and well-known procedure for incident evaluation and registration.		14	Absence of adequate incident evaluating and registration procedures.
Control room and interface design	18	Provide the necessary means to keep the operator alert. Example: temperature in control room; force him (using alarms) to take certain actions.	Simulations; intelligent user interface.	01	During long periods of normal operation, vigilance may be threatened. This is especially critical during the night (3-6 a.m.), when

Improvement method	#	Solution	Tools	#	Bottleneck
					tunnel users are also less alert.
				04	Overdue, incorrect or incomplete detection of incident due to combination of suboptimal cognitive load and suboptimal detection of risk factors in tunnel.
	19	Provide an interface sufficiently effective to alert the operator if anything is wrong, if possible not only a visual signal on screen, but also, for example, a sound signal.	Intelligent user interface.	05	Overdue, incorrect or incomplete detection of incident due to combination of suboptimal cognitive load and suboptimal detection of risk factors in tunnel.
	20	Apply group commands for sets of actions that are the same for all serious incidents.	Group commands, such as calamity button.	07	Starting from the escalation stage, many different decisions and actions are required in a short time.
	21	Equip the work place so as to make sure that a minimum of actions (and time) is required to execute decisions.	Intelligent user interface.	07	Starting from the escalation stage, many different decisions and actions are required in a short time.
	22	Make it possible to suppress all alarms that are irrelevant during an incident in progress.	Calamity button.	08	Too many incoming signals, not all of which are relevant at this time.
	23	Make it possible for the operator to switch off alarms during an incident.	Intelligent user interface.	08	Too many incoming signals, not all of which are relevant at this time.
	24	Apply tools to address, guide and communicate with tunnel users.	Sound beacons, pre-recorded announcements.	09	Insufficient means to communicate with other operators, rescue services or tunnel users.
	25	Make sure that means of communication for operators and rescue services are reliable and accessible to all parties concerned.	Radio.	09	Insufficient means to communicate with other operators, rescue services or tunnel users.
	26	Use loud alarms for important detection signals.		04	Overdue, incorrect or incomplete detection of incident due to combination of suboptimal cognitive load and suboptimal detection of risk factors in tunnel.
	27	Provide tools to support disturbance handling and incident procedures. Tools should correspond with written procedures.	Decision support software.	02	Bad or absent incident handling procedures; especially unclear allocation of responsibilities and authority to personnel.
				07	Starting from the escalation stage, many different decisions and actions are required in a short time.
				13	Absence of or insufficient coordinated procedures between operators and rescue services.

A.3 Tools and techniques

This appendix lists several examples of tools and techniques, which may be used to contribute to improving the operator's performance. The tools and techniques mentioned in this appendix are not the only possible means of support for the operator; maybe even better tools are available to a tunnel manager. Depending on local circumstances and the state of the art at the time, tunnel management organisations choose the most effective or efficient tools for reaching their goals.

A.3.1 Scenario analysis

Analysing a limited number of scenarios for incidents or accidents in tunnels may assist the process of improving operator performance in the following ways:

- It can be used to analyse the operator's tasks and give an insight into cognitive task load (underload and overload threats). In order to do this, the operator's tasks during an incident have to be identified and the time required to perform each of these tasks has to be known. In addition, one has to establish criteria: for example, what is the maximum time between detection of a fire and a fully operational escape route? If the time needed to prepare the escape route is longer than this, the need for improvement is obvious.
- Scenario analysis can also be used to select the most effective (efficient) strategy to improve operator performance.
- Finally, scenario analysis can be used to specify certain improvement measures. For example, incident management procedures can be written for several scenario types. Also, scenario analysis may help decide which commands can be clustered in a group (see A.3.5). Training and exercise as well as training tools can also be based on scenarios (see A.3.3).

Depending on the goal of a scenario analysis, the method and level of detail may vary. However, by comparing different types of scenario analysis a common model can be extracted [5]:

1. Start by recruiting specialists from all fields of expertise that you need (operations in emergency services, tunnel operation, analysis specialist). Form a scenario analysis team.
2. Establish goals and criteria for your analysis: when is a strategy effective? Or: what are the minimum and maximum levels for cognitive task load?
3. Describe the tunnel, safety measures present, rescue service data (such as time until arrival of fire rescue vehicles at the incident site).
4. Choose relevant incident scenarios, of different types and different scales. Ranging from a broken down vehicle via a small and a large fire to an explosion. Which scenarios are relevant to your situation, may depend upon your analysis goals and on the local situation. Describe the circumstances for your scenarios: day time or night time, rush hour? Heavy or light traffic? How many heavy goods vehicles? Busloads of elderly people? Shift switch for the operating crew? In some cases, it may be useful to include one or more scenarios taking place while maintenance work is in progress.
5. Analyse the scenarios.
   First, from the start of an incident scenario until all is again normal, choose time steps.

At each of these steps, establish the situation in the tunnel and in the control centre (make "photographs"). How many vehicles are trapped in the tunnel? Has traffic at each of the tunnel entrances been stopped? How many people are present in the tunnel? Is anyone in need of rescue? Are escape routes ready for evacuation? Are people present in escape passages? What is the operator doing? What are rescue services doing? Et cetera. Drawing schematic pictures may be helpful here.
All photographs together make an album describing the entire scenario.
This is done for each of the chosen scenarios.

6. At this point, the results of the analysis can be compared to the goals and criteria established at the beginning. If goals are not reached, (additional) improvement measures have to be taken.

These steps can thus be schematically represented:

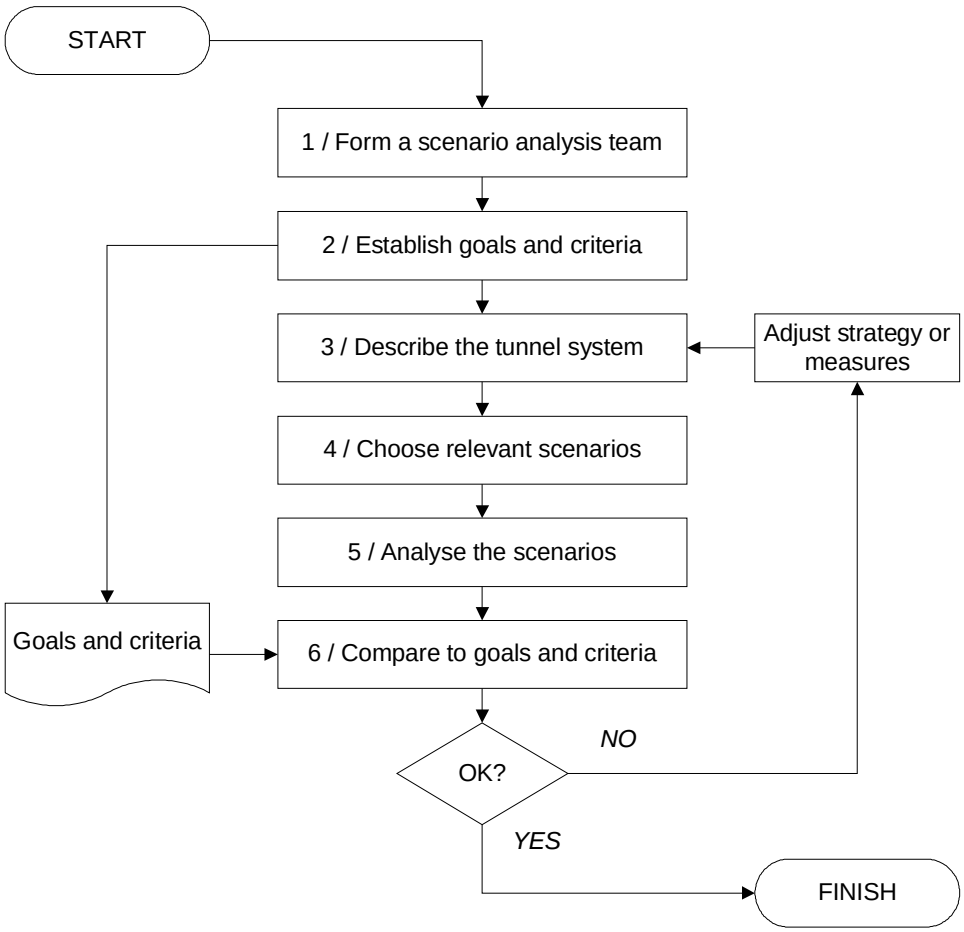

Figure 6-1: Model for scenario analysis

A.3.2 Dutch Standard Calamity Plan for road tunnels

In the Netherlands, several plans and instructions are generated for road tunnels. These plans deal with aspects such as traffic management and maintenance standards.
One of the plans is the so-called calamity plan, which describes the actions that have to be taken by the tunnel operator and the emergency services for several scenarios. The plan is written by the tunnel owner in cooperation with the emergency services to make sure that the efforts of the different parties involved are coordinated.

A standard Calamity Plan for road tunnels [6] has been generated in a coordinated effort by rescue services, the Ministry of Transport, Public Works and Water Management, the Ministry of the Interior, the large municipalities and the provinces. An English version is not (yet) available, but it contains the following information:

- General section:
  - Organisation and responsibilities in case of incidents
  - Geographical location for which the plan is applicable
  - Status of the plan in relation to other plans and documents
  - When and by whom is the plan put into action and how are personnel instructed and trained to use the plan?
- Task description for tunnel operator
  - What protocols are applicable
  - How to act in several types of scenarios: situation assessment criteria and tasks
- Coordination and communication with rescue services and other parties involved
  - When and how to inform rescue services
  - Checklist of data needed for rescue services
  - General approach by rescue services
  - Where to place rescue vehicles in or outside of the tunnel
  - Who is in command of the rescue operation
  - Phone numbers of all relevant parties
  - How to handle contacts with others (general public, media etc.)
  - When and how to restore normal operation of tunnel
  - Incident evaluation checklist
- Appendices
  - Description of the tunnel and its equipment
  - Maps and plans of the surroundings, containing escape routes for tunnel users and approach routes for rescue services
  - Description of scenarios
  - Description of calamity organisation
  - Protocols
  - Exercise and training programmes
  - Background information on rescue and self rescue

Writers of calamity plans should be informed how to use the standard plan (written instruction).

A.3.3 Training techniques and simulations

To support training and exercises, simulations have proven to be effective tools. Simulations vary from simple to complex. For example, only paper, pencil, phone and a conference table may suffice in some cases. More complex (in terms of the technology required) is a complete virtual reality tunnel where scenarios can be played out. In some cases, one may choose to close the tunnel temporarily and perform an exercise on-site.

The choice of training tools depends on

- training goals (operating skills, incident handling skills, communication between organisations, try out procedures),
- number and type of participants (only operators, tunnel owner's management, operator and rescue services?)
- means available.

An effective tool may be a work station that is not in use and can be used by the operator to practice the operation of tunnel equipment.

In Holland, TNO developed an operator training programme for the Westerschelde Tunnel organisation. The operator sits at a desk similar to the normal operator's desk. Incident scenarios start and have to be handled in the correct manner. The system provides feedback: it lets the operator know if he has chosen the best option, the next best option, et cetera, in response to what happens. This proves to be an effective tool in procedure performance: as a consequence the operators can handle incidents based on their skills rather than having to use a procedure book. If an exercise leader is present, he may complicate this with, for example, a phone call from a "distressed tunnel user".

If, however, participants want to practice communication between operator and the on-site commanding personnel of rescue services, other techniques may be more effective. For this purpose, for example, an exercise leader may direct an incident scenario with the participants in a conference room. The exercise leader provides the incoming information about what happens in the tunnel and the participants respond to this information by saying what they would do.

On-site realistic exercises involving all relevant participants may be especially useful for testing procedures.

A.3.4 Cognitive support

To prevent cognitive overload, support systems should be designed that help the operator in assessing the situation and making the right decisions. During high-demand situations, there can be an enormous number of incoming alarms and information. This makes it difficult for the operator to form an accurate picture of what the cause is. Besides that, emergency situations do not occur very often. This means that the operator has no routines in following the right procedures and taking the right actions. Neerincx (2003) [7] describes a number of cognitive support functions that can help the operator during crisis situations. Although these functions were initially designed for a ship's bridge, the functions are also applicable within the domain of the tunnel operator. These functions are: information handler, rule provider, emergency scheduler and diagnosis guide.

INFORMATION HANDLER

In order to enhance the situation awareness of the operator, an information handler should be used. It presents an overview of the tunnels state and alarms. The information is organized according to the tunnels structure and the current events. For example, a schematic representation of the tunnel could be shown, indicating the sector where the incident is including status, alarms and tasks that have to be performed.

RULE PROVIDER

A rule provider supports the operator by presenting the procedures and rules that have to be followed under specific (high-demand) situations. At the same time, it shows the status of the procedure that is followed. For example, in case of an accident, the procedure could be: activate warning signals and speed reduction in tunnel, close the obstructed lane, close the tube, call emergency response team, etc. The rule provider shows this list in the right order and indicates what actions are completed and what action still have to be done.

EMERGENCY SCHEDULER

The emergency scheduler prioritizes alarms that have to handled first. For example, in case of fire, evacuation of tunnel users may have the first priority before attacking the fire. By showing this, the operator knows in which order the alarms should be treated.

DIAGNOSIS GUIDE

A diagnosis guide supports the operator in analyzing the symptom-cause relation of alarms that are generated. The system can show a list of possible causes of a set of presented alarms. For example, the order in which smoke detectors switch on can reveal the location of the fire and the direction of the smoke stream. Speed detectors give alarms when, for example, the traffic speed drops below 50 kph. These detectors give information about the direction in which the cue develops itself. This also indicates where the fire is. With this information, the operator can be advised how to respond. For example, when the smoke stream is moving towards the cue, the ventilation system should be switched on to keep the smoke away from the tunnel users.

A.3.5 Command groups and the calamity button

A calamity button is a command group that enables the operator to save time in an emergency by taking a number of actions pushing only one button. The commands grouped under the calamity button are commands for (almost) all calamity scenarios.
Dutch tunnels usually have unidirectional traffic and thus consist of at least two traffic tubes. Most tunnels have longitudinal ventilation. A calamity button for a Dutch tunnel may start the following actions:

- Close the entrance of the incident tube and the one that is used for access by the emergency services (usually the tube next to the incident tube in the opposite driving direction) using the traffic lights;
- maximize light level in both traffic tubes;
- start longitudinal ventilation in tunnel tubes;
- prepare escape route:
  - if necessary, unlock doors;
  - start ventilation in escape route;
  - maximize light in escape route;

- start pumps for fire fighting system;
- block all drainage pumps.

An example: Westerscheldetunnel[3]: for each of the unidirectional tubes there is a calamity button:

- close tunnel entrance (traffic lights)
- direct all traffic to right lane
- lower speed limit on right lane
- adjust ventilation
- maximize lighting level
- prepare escape route:
  - start ventilation in connecting passages between the two tubes
  - switch on extra lights for escape doors
  - warn drivers in safe tube: "pedestrians on road"
  - unlock escape doors
- start pumps for fire fighting system;
- block drainage pumps.

Another example: in the control centre of the Kiltunnel, for each of the unidirectional tubes there are two calamity buttons: one for any incident that is more than a disturbance, and one that is activated only if there is a fire.

ONE STEP FURTHER

One step further than a command group is an automated response. In this case, when sensors detect certain circumstances in the tunnel, appropriate measures are activated without the intervention of the operator. For example: if fire is detected, the ventilation is automatically started.
Of course, possible consequences have to be thoroughly analysed. A tunnel owner will have to make absolutely sure that a certain response to a certain detection can never have undesirable effects. Additionally, it has to be possible for the operator to undo the response after it has been automatically activated.

A.3.6 Facilitating the evacuation process

Many measures can be used to guide tunnel users on foot towards a safe place. Ideally, the operator should be able to activate these measures with one single action. He should also be able to see when each of the measures is fully operational and whether there are any malfunctions.
For example, in some cases, tunnel users have to flee to another traffic tube. In such cases, the escape doors are locked until there is no more traffic driving in the other traffic tube. Tunnel users that go to an escape door and find it locked, have to be informed about this to prevent them from trying to escape the wrong way. This is a task for the operator.

Two other techniques to assist in the evacuation process are described here.

[3] The 6,6 km long Westerscheldetunnel consists of two one-way tubes, each containing two traffic lanes. In case of an incident in tube A, the left traffic lane of tube B serves as an escape route.

Previously recorded announcements

If there is a fire in the tunnel, a serious threat is posed by the so-called wake up time of the tunnel users. Based on studies of human behaviour in tunnel incidents, the general response to smoke on the outside of your car is: to ignore that there is a problem and stay inside [1, 8]. The car appears to be a safe place in the beginning. Persons do not leave their car until it is too late, when they are unlikely to survive the walk to an escape door. Based on the same studies, announcements by the tunnel operator are effective in activating the tunnel users and starting the evacuation process [8].

Therefore, it is essential that:

- announcements are broadcasted quickly through all available channels (local radio frequency and speakers in tunnel);
- instructions are clear and correct;
- instructions include warning other drivers.

In some tunnels, the operator can select an announcement on his computer. An announcement, previously recorded in several languages by professional native speakers, is then broadcasted. This approach has several advantages:

- the instructions given are correct for the situation and based on the available relevant procedures;
- the announcement can be easily understood, because they are professionally recorded, for example by radio reporters;
- the announcement can be recorded in more than one language;
- the announcement is pronounced more calmly and with more authority, generating a more effective response;
- the operator only needs the time to select the correct message and push the button.

Of course, the operator always has to be able to talk to a tunnel user because one can never predict exactly which messages will be necessary.

Sound beacons

In additions to arrows and pictograms, both of which are visual signals, sound beacons are a relatively new way of guiding tunnel users on foot towards escape doors. This is especially useful in smoke. Sound beacons are successfully used in (military) ships and mining industries. However, these beacons generate a noise that is not necessarily perceived in the right way by an inexperienced person, such as a tunnel user. If you do not know the sound, which resembles machine noise, it will most likely repel persons instead of attracting them.

Ordered by RWS Centre for Tunnel Safety, TNO has developed a new type of sound beacon with a different type of sound (musical chords) and a short message (such as "exit here") [9]. Tests have shown that, if a sound beacon is mounted above an escape door, most people can find the door, even in dense smoke.

If applying sound beacons, additional measures will have to be taken: for example: if the operator wants to broadcast an announcement, the beacons will probably have to be temporarily suppressed. This can be done automatically, for example by linking this suppression to the intercom button. Also, the operator may in some occasions need to instruct the tunnel user to go towards the sound and to inform them that the sound beacons will lead them to an escape door.

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