Fire and Rescue Operations during Construction of Tunnels

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ABSTRACT
The last decades a great deal of research has been performed regarding different fields of fire safety and fire development in existing tunnels. During constructions of tunnels the physical conditions of the establishment as well as the fire load, the possibilities to evacuate and perform a fire and rescue operation are essentially separated from the conditions in the opened tunnel. During the construction phase, the safety installations prior to the finished state, often is not yet installed or in function. Before the break through, the tunnel can have a “dead end”, which can make both evacuation and fire and rescue operations very difficult. Many different organizations can be involved in the construction work with the tunnel and it is not uncommon that the workers have different nationalities. Both these conditions can, in case of an incident, influence the alarm chain and the quality of the information that reaches the emergency services. The incident commander (IC) in a large fire- and rescue operation has to survey a complex situation, where conventional methods and normal tactical approaches can be difficult to use. This paper discusses the fire- and rescue services possibilities to perform a fire and rescue operation during the different phases of the construction. Limitations, based on information from real fires and full-scale tests are analyzed and discussed. Both technical and organizational solutions for self-rescue or as support for the fire- and rescue services are valued and discussed.

KEY WORDS: Tunnel during construction, fire and rescue operation, fire, emergency services

INTRODUCTION
In Europe and around the world many tunnels and underground constructions are built. The need to shorten distances and to use valuable real estate for other purposes makes tunnel construction an important and valuable business. But the necessity to keep the time schedule and the large costs for delays, both for the individual contractor and for the society at large, can cause vulnerable situations as well as incidents. The fire safety, the working environment and the measures at the site to ensure the emergency services being able to perform a fire and rescue operation as efficient as possible, are important tasks for the building contractor.

A specific problem to focus on is the fact that during the construction phase the escape routes can be long and before the break-through only function in one direction. This also means that the escape routes, the natural way for exhaust air and therefore the smoke produced at an eventual fire, and the response route for the rescue services all are located in the same area – the unfinished tunnel tube. The latest two decades show a number of accidents in tunnels during construction and the difficulties to perform fire and rescue operations under these conditions[1-5]. This paper focus on describing the problems from the fire fighting perspective and to propse some tactical solutions and recommendations.

FIRE AND RESCUE OPERATIONS DURING CONSTRUCTION OF TUNNELS
Fire and rescue operations in tunnels are a complex and many times difficult task. Self evacuation and self rescue are always to prefer, but sometimes the emergency services possibility to perform a fire and rescue operation have a direct influence on the choice of the use or location of, for example, rescue chambers. Therefore the tactics, methods and available equipment to support a fire and rescue operation are of importance. Below the different factors that can facilitate or influence the fire and rescue operation are discussed.
The opportunities for a successful fire and rescue operation can be divided into four main parts; I) Preparation - adequate contingency planning and relevant exercises combined with preparation for adequate situation awareness in case if an incident, II) Personnel - competence of the emergency services staff and of the Incident Commander, III) Methods – equipment and methods that are prepared for the situation, IV) The specific scene of the incident - the location of the fire, the number of persons trapped in the tunnel, the fire development and the heat release rate, meteorological conditions and the geometries and appearance of the tunnel.

I) Preparation. During construction of tunnels one of the main problems is that the tunnel constantly alters. A tunnel construction site is the working site for many persons and as the construction of the tunnel is a large project, it is not uncommon that it is divided into smaller contracts, with many different contractors. The free mobility of contractors within the European Union has opened for an internationalization of tunnel contractors, which raises the demands on the main contractor and the orderer for co-ordination. In divided contracts the different sites many times have no contact or connections before the break-through of the different tunnel sections. After the break-through the different contractors can work closely in the tunnel and in their respectively areas, where the conditions of neighboring areas influence the possibilities for evacuation and rescue for the individual contractors.

A tunnel construction site involves equipment that can put the emergency services at risk, for example gas cylinders, storage depots inside the tunnel or the construction vehicles itself. It is therefore very important that the contingency planning also include drawings and maps where the risks, the rescue routes, the evacuation routes including eventual rescue chambers are marked. One of the bigger challenges for the main contractor is to keep these plans updated. In the construction of the North Link in Stockholm Internet based rescue charts have been developed [6]. All the contractors have access to the website and can make necessary changes within their own contract area and study and print the full rescue chart. The emergency services likewise have read-only access to the rescue charts and can study the plan in advance or via their mobile Internet connection in the fire appliances and in the command unit on the way to the site. In case of a fire the responsible contact person at the actual construction site print the updated charts and meet up with the rescue services.

Regular exercises are also of great importance. The exercises give the contractors and the emergency services an opportunity to test their routines before an accident has occurred. The different organizations, both among the first responders and among the contractors, have different qualifications and previous knowledge, different routines and many times different vocabularies [7]. In case of a fire all these organizations down to the individual person needs to communicate in an efficient way to reach the objective of the fire and rescue operation.

II) Personnel. Fire and rescue operations in tunnels in general raise demands of high standard of knowledge and education on the IC. The IC often needs to take decisions on incomplete basic data and information. The conditions at the scene of the fire can change quickly due to reasons out of reach of the rescue services. The IC needs to be able to, based on information from the contractors, the Sector Commanders and the Incident Site Officer, read the fire and the possible risks to choose a direction and strategy that do not put the first responders at risk, but still make a rescue operation possible [8-9].

Severe tunnel fires are statistically infrequent, but can have serious consequences. Not all tunnels are built in areas where the IC, due to different reasons, has enough emergency response calls to achieve a level of attainment so some of these difficult decisions can be made based on earlier experiences. To some extent full-scale and table-top exercises can provide the IC with experience, but at exercises the conditions and basic information is usually better provided than at real fires.

One of the most important capabilities is the awareness of which factors at the scene of the fire or accident that has the largest influence of the outcome of the fire and rescue operation. By identifying these critical factors the IC can take consideration of, or actions against, the conditions that threats the
fire and rescue operation. An exhaustive understanding of the situation is one of the key factors to reach the objectives – to save people in danger and if possible minimize the damage on the equipment, structure and environment.

Another issue to pay attention to is the fact that at a large tunnel project with many international contractors, the native languages between the contractors can vary. At a large tunnel site it can be difficult to find a common language that all tunnel workers can speak well enough to be able to communicate efficiently in case of an accident. This is not only a problem for the rescue services, but in the end a problem regarding the working welfare and safety for the construction workers. It is a strong recommendation to have a working language that as many of the workers as possible understand and that all personnel are trained in alerting the emergency services. If necessary cards in pocket size can be developed to remind about the correct phrases and information to pass on to the emergency service centre.

III) Methods. To support, or in some cases at all make the fire and rescue operation possible, the emergency services can use different equipment as a tactic resource at tunnel fires. One of the most important tasks to facilitate the fire and rescue operation is to make the tunnel as free from smoke as possible and to minimize the heat exposure on the fire fighters. If the tunnel is free from smoke the transportation speed to the fire scene increases and fire and rescue operations can be performed at larges distances into the tunnel. If the heat exposure on the fire fighters is lowered, the time the fire fighters can perform a fire and rescue operation prolongs.

- In cases where a longitudinal flow of fresh air can be established in the tunnel this facilitates the fire and rescue operation. If the velocity is exceeding the critical velocity \cite{10-11} the back-layering can be kept to a minimum which makes it possible for the fire fighters to get close enough to efficiently fight the fire \cite{12}. The heat flux a fire fighter can be exposed to during the actual amount of time the fire fighter fight the fire is approximately 5 kW/m² \cite{12}. Without sufficient ventilation the heat flux from the hot smoke in the back-layering is likely to restrain the fire fighters from getting close to the fire with the water, as the throw length of the water is restricted by the relatively low height of the tunnel \cite{12}. An increased air flow through the tunnel will, in some cases, also increase the heat release rate of the fire \cite{13-15}. The advantages in improved sight and lowered heat flux though most times outweigh the disadvantages. Increased heat release rate is though one of the risks that the IC must take into consideration when deciding on tactical methods. In the cases before the break-through of the tunnel, while the tunnel still have a “dead-end”, longitudinal flow through the tunnel is not possible to achieve. In these cases the ordinary ventilation can be used to clear the tunnel from smoke, but as the tunnel tube itself represent the exhaust air duct as well as the evacuation and response route, the use before the fire is extinguished can be uncertain.

- Longitudinal flow in the tunnel can be created by mobile fans. Large lorry-mounted fans have showed to be efficient in full-scale tests \cite{16-17}. Also combinations of smaller middle flow fans can be used, if combined with a tunnel cover to increase the efficiency of the fans \cite{18-20}. The method is though sensitive for leakage along the tunnel perimeter, why a stationary tunnel cover can be preferable in comparison to a mobile cover. All kinds of stationary equipment demand preparation and contingency planning on beforehand. A middle course could be a crawler driven smaller high flow fan, with or without a tunnel cover. Good results have also been showed at manufacturer demonstrations with remote controlled use and water beam fog in the air stream. Many emergency services in Mid-Europe, close to the trans-European tunnels, have similar equipment. Deeper studies are needed to better determine the limitations at different types of fires \cite{21}.

- In tunnels the transportation distance to the fire can be very long. To save the effort to carry equipment to the scene of the fire, where it is needed, any kind of transportation vehicle will be very helpful. The vehicle can be a simple hand-driven wagon, preferably possible to use both on track and road. The wagon can transport ventilators, foam liquid, rescue equipment or any kind of equipment needed at the scene. If the wagon is large enough it also will be helpful to transport injured persons back to the tunnel entrance.
Especially in station environments or in tunnels with connecting tunnel tubes one of the risks with the fire and rescue operation is the danger that the fire fighters lose the track and not find their way back to safety before the air supply runs out. Different kinds of rope lights are available on the market. The light secures the path back to safety and increase the walking speed for fire fighters behind the front or on the way back.

At severe fires, close to the tunnel face before the break-through, it can be almost impossible to perform a successful fire and rescue operation. Within the MSB-financed project Accident Management during Construction of Tunnels the possibilities to cover the tunnel or a section of the tunnel in cases with no trapped persons in the tunnel, and let the fire self-extinguish, have been discussed. (MSB, the Swedish Civil Contingencies Agency). The method is not yet fully investigated or validated, but if it proves to work efficiently the risks must at all times be considered. A severe fire in fibre materials can keep enough heat for a long time to re-ignite if the oxygen level rises, for example when the cover is removed. A back-draft situation in this environment would put the first responders at a larger risk than the alternate fire and rescue operation.

At severe fires where a fire and rescue operation is impossible to perform, in respect to the risks and working environment for the fire fighters, the only way to rescue persons in the tunnel could be a safe vehicle to transport fire fighters to the fire scene or to save people from safe evacuation places or rescue chambers. A severe fire could easily have a duration that exceeds the time limit where the stipulated compressed air or oxygen is enough. Such a vehicle would need docking possibilities and be hybrid driven, as combustible engines are not an option in this environment. In this field there is though much research and development left to perform.

IV) The specific scene of the incident. In tunnels during construction the safety installations, prior to the finished tunnel, many times are not yet installed. In the early stages of the construction phase the tunnel often lack basic installations or conditions such as light and a plane roadway. In tunnels under construction one of the main issues for the contractor is to keep track on the water flow in the tunnel with respect to the quantity allowed in the water-rights decision. Depending of the type of tunnel construction the ground can partially be uneven and the unevenness filled with water. All these conditions can essentially slow down the pace the emergency services can move with inside the tunnel. The tunnel is not only the response route, but as well a working site for the contractors, where equipment, vehicles and areas for storage of building material can represent a risk for the rescue services. For example gas cylinders are commonly used for welding purposes but can, if left in the response route or close to scene of the fire, in the worst case make a rescue operation impossible. Also outside conditions like weather, wind velocity and direction can support or counteract the rescue operation.

EXPERIENCES FROM PERFORMED EXERCISES

Earlier Swedish research projects have (in Swedish) showed that the walking speed for the rescue services vary between 5 and 8 m/min, when transporting themselves in a smoke-filled tunnel including connection of not water-filled fire-hoses. In the earlier mentioned on-going project about accident management during construction of tunnels an evacuation and rescue exercise was performed in the Hallandsås Tunnel in Sweden. The fire and rescue operation was video filmed and the moving speed later compared with the results in the earlier performed tests. The results from the two occasions are compared below:
### Table 1. Moving distances inside a tunnel

The theoretical maximum distance that can be covered, given the test results, are to be measured from the point where the BA-rescue is counted to start. This discussion, of “point zero” is actually one of the most interesting questions to discuss. Does the BA-rescue always start at the tunnel entrance or can it be moved inside the tunnel if the environment, naturally or aided by ventilation, is smoke free?

A fire and rescue operation in a tunnel consists of combinations of a number of BA-teams, which work alternately on their way to the scene of the fire. The front of the BA-teams will work slower in an unknown environment, than the following BA-teams, guided by the information and equipment provided by the front team. The discussions of the different possibilities for the fire and rescue operations, given later in this paper, are based on the experiences from the results presented in table 1.

The Hallandsås Tunnel exercises also gave valuable information about the importance of communication between the rescue services and the organizations involved in the project [7]. The experiences from the exercise can be summarized as follows:

- It is highly important to keep count of the exact number of persons in the tunnel. Differences in figures consume valuable time, both for the rescue services and the contractor organizations that can be used for more relevant tasks.
- It is valuable for the rescue services to have an updated list of risks and their location in the tunnel. If possible information about vehicles should be completed with amount and type of fuel and other burnable fluids.
- The presence, at the command post, of a person, well informed about the organization and the present situation in the tunnel, are a valuable resource for the IC.
- Same words within different organizations can mean different things. During the exercise was for example the word “life saving activity” (in Swedish) used at the rescue operation in the tunnel. With this expression the emergency services means an activity, usually BA rescue, with the aim to save lives. During the exercise the paramedics instead understood this as HLR-rescue. This can be made clear by information and joint exercises.
- “Over-ride” over command levels and decision making on a not intended level can cause lack of information, which can influence later decisions within the organization. The difficulties with radio communication in combination with the noisy environment caused for example, sometimes an “information vacuum” at some levels. At those occasions sometimes decisions are made at a lower level without communication upwards and sometimes support or information is requested from collaborative organizations without following the strict hierarchic structure the rescue management is supposed to be. This means that some levels can lack of information and therefore later decision-making can be affected. This does not always affect the rescue operation at large, but such a complex
situation that a tunnel fire represents, it is of great importance that everybody has got information that is up to date and a joint picture of the current situation. This observation is though not unique for this exercise and has been noticed at other similar exercises and real life fire and rescue operations [7].

The co-operation, like in the Hallandsås tunnel exercise, between practitioners and the research community gives both groups valuable information and possibilities for knowledge transfer within their respectively field of expertise.

EXPERIENCES FROM REAL FIRES IN TUNNELS UNDER CONSTRUCTION

A tunnel fire during the construction phase not only can cost lives and large amounts of money, it also can cause delays which in turn costs both credibility and reduction of the public utility. During the last two decades a number of fires have occurred that in different proportions have affected the tunnel workers, the tunnel structure and the time plan.

In March 2002 a service train in the A86 tunnel in Paris caught fire. The tunnel workers tried to extinguish the fire without success and the fire spread to the fuel tank of the train and further to the TBM spoil conveyor belt. 19 tunnel workers where trapped in the rescue chamber on the TBM between the water curtain in the rear of the TBM and the tunnel face. The workers had to wait seven hours before they could be saved by the fire fighters and escorted out of the tunnel. The fact that the emergency services had performed a number of exercises in the tunnel showed very valuable when the fire fighters had to walk in dense smoke. As the fire occurred approximately 1400 meters inside the tunnel and the front of the TBM reached was located further 600 meters into the tunnel the fire and the personnel trapped in the tunnel would have been difficult or impossible without a special equipped rescue vehicle. Even with self-contained BA-units, with a longer operation time, it is an almost impossible mission on a water-filled, slippery and uneven surface in a smoke-filled tunnel. The fire damaged the communication cables and the number of persons trapped in the tunnel could relatively early be determined by the registration system, but the exact location of the workers was uncertain for more than four hours. The Paris fire brigade credits the careful contingency planning, the exercises and the special equipment designed for A86 tunnel, the success of the difficult fire and rescue operation [2].

In March 2006 the bore rig caught fire in the 1300 meter deep Björnböle tunnel on the Swedish Botnia Link. The fire occurred before the break-through of the tunnel and the tunnel workers only had one direction for evacuation. They succeeded to evacuate to their parked vehicle and drive out from the tunnel. As no persons were trapped in the tunnel the emergency services decided not to fight the fire because of the dense smoke, the probable fire development and large distance to the fire. The smoke was ventilated and the fire fighters could reach the scene of the fire later when the bore rig almost completely had burnt out. The defensive strategy of the fire and rescue operation would not have been the first choice if persons had been trapped in the tunnel, but it would have been almost impossible to reach the fire given the conditions and available resources [4].

In September 2009 the battery in a working locomotive, used for the bore rig, caught fire on City Line under construction in Stockholm. The locomotive was parked for re-charging on a shut down part of the Stockholm Central metro station, that were put to the City Line’s disposal by the Stockholm Metro. It was a Saturday and no workers were at the construction site. The smoke spread in the tunnel system to the Stockholm Metro and as many as 12 stations, there among the largest ones, had to be temporarily shut down. The Stockholm Metro used replacement buses, but the disturbance in the traffic flow were still considerable. The last three stations could be opened again during the evening. The cause of the fire was an insufficient connection of the charging cable to the battery where the high transition resistance caused electric arcs that lit the battery and the surrounding material. The fire itself was not severe but caused a heavy smoke production. The relatively low risk due to the slow fire development made it possible to reach the locomotive to extinguish the fire. Due to the external and internal charging of the battery the fire was difficult to extinguish and it re-ignited at several occasions. The locomotive was towed to an outdoor parking ground and later investigated [23]. The experiences from the fire show the importance of good communication between the IC and the owner of the site. As the fire occurred on the borrowed station the Accident Manager in duty from
Stockholm Metro was sent to the scene. The Accident Manager was a valuable resource for the IC and many questions regarding the facilities, the information and the shutdown of the metro stations could be easier solved. The condition at the platform at the closed down station, used for the construction work, made the fire and rescue operation more difficult as the response route was obstructed with material. This shows the importance of the systematic fire prevention work \cite{5,24}. A joint view of a high safety level at the construction site and efficient control routines not only secure a safe environment for the first responders, but also a safe working site for the tunnel workers. During the fire, the smoke spread along the tunnel system to the neighboring stations, which bring up the question of the need for sectioning. In a metro system it is natural that the tunnels connect the different stations. To avoid fast smoke spread not only the evacuation routes, but also the tunnels it selves, need effective sectioning. \cite{5,6,24}.

SCENARIOS

In the MSB-financed project *Accident Management during Construction of Tunnels*, numerous fire- and rescue scenarios have been modeled and investigated. The scenarios are chosen to be representative for many different tunnel construction sites, and are based on study visits to tunnel construction sites in Sweden and Finland \cite{6}. The scenarios cover both blasted and bored tunnels as well as conventional cut-and-cover methods. The scenarios are presented in table 2 below and the tactical approach for each scenario is discussed later in the paper:

<table>
<thead>
<tr>
<th>Scenario n:o</th>
<th>Burning item</th>
<th>Position</th>
<th>Conditions</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Bore rig, dumper or blasting vehicle</td>
<td>Tunnel face</td>
<td>Before break-through</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Bus (for visitors)</td>
<td>In middle of tunnel in between tunnel face and entrance</td>
<td>Visitors in bus or visitors in tunnel. N:o of visitors: 50. Fire development: UF, F or M.</td>
<td>Before break-through</td>
</tr>
<tr>
<td>C</td>
<td>HGV/trailer or dumper</td>
<td>In middle of tunnel in between tunnel face and entrance</td>
<td>Only traction vehicle is combustible</td>
<td>Before break-through</td>
</tr>
<tr>
<td>D</td>
<td>Bus (for visitors)</td>
<td>In middle of tunnel.</td>
<td>Visitors in bus or visitors in tunnel. N:o of visitors: 50. Fire development: UF, F or M.</td>
<td>After break-through</td>
</tr>
<tr>
<td>E</td>
<td>Cable fire or fire in pick-up truck</td>
<td>In middle of tunnel</td>
<td></td>
<td>After break-through</td>
</tr>
<tr>
<td>F</td>
<td>Large quantity of combustible tunnel isolation</td>
<td>¼ from one tunnel entrance</td>
<td>Openly exposed</td>
<td>After break-through</td>
</tr>
</tbody>
</table>

*Table 2. Fire scenarios in tunnels under construction. The distance to the tunnel face is put to 1700 m.*
FIRE AND RESCUE OPERATIONS FOR THE CHOSEN SCENARIOS

The tactical approach, the tactics, in an emergency operation can be described as the ongoing decisions by the incident commander (IC) in how to use the available resources, in the most effective manner, depending on objective of the specific operation [8, 9]. A fire and rescue operation in case of a tunnel fire is a rather complex operation with the objective to save people in danger, save the tunnel and valuable things in the tunnel. The tactical approach is very much depending on the specific tunnel, the fire behaviour, the threatened values and the available resources from the emergency services.

Generally the emergency services are able to work with either an offensive strategy (fight the fire) or a defensive strategy (not fight the fire), which you shouldn’t combine at the same time in an operation. There are five different tactical approaches, single used or in combinations, to handle the fire situation in tunnels. These different tactical approaches can be combined in different ways depending on the choice of strategy in the operation [8, 9]. These approaches are the following.

1. Fight the fire from the inside of the tunnel, with the purpose to put out the fire and by this save the people in danger.
2. Assist or rescue the people in danger from the inside of the tunnel and take them to a safe environment.
3. Control the airflow in the tunnel in order to take the smoke away from the people in danger or to support the fire fighting operation [9].
4. Fight the fire from a safe position to reduce the consequences of the fire.
5. Treat and take care of the people that without assistance rescued themselves to a safe environment.

In the best of worlds, all of these tactical approaches could be used at the same time. This is not a normal situation during an emergency due to lack of available resources.

<table>
<thead>
<tr>
<th>Scenario n:o</th>
<th>Tactical approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Number 5</td>
</tr>
<tr>
<td></td>
<td>Number 4 or 2 if fitted vehicle-assistance is available</td>
</tr>
<tr>
<td>B</td>
<td>Number 1 in combination with number 2 and 5.</td>
</tr>
<tr>
<td>C</td>
<td>Number 1 if the fire development is slow and/ or if people are trapped in a dangerous situation, otherwise number 5</td>
</tr>
<tr>
<td>D</td>
<td>Number 1 in combination with 3, 2 and 5.</td>
</tr>
<tr>
<td>E</td>
<td>Number 3 in combination with number 1.</td>
</tr>
<tr>
<td>F</td>
<td>Number 3 in combination with 4.</td>
</tr>
</tbody>
</table>

Table 3. Tactical approaches for the fire and rescue operation in tunnels under construction

To make tactical decisions in advance can be very difficult, because of all the circumstances that are connected to a specific situation. In scenario A there is probably just the tunnel construction and the vehicle on fire that are threatened by the fire, due to the location in the tunnel face. It’s probably also quite long distance from the scene of the fire to the tunnel entrance, where a fire and rescue operation could be started from. Because of the limitations with normal BA-operations, app. 100 - 150 meter in smoke filled environment, it’s impossible to get any success with this method. If there is no vehicle assistance to this operation, it’s not even a method to consider in this situation. The hands-on fire fighting of these types of fires is complicated and it will be very difficult to get an effective result in this tunnel environment. Prior to the break-through it is not easy to control the airflow and reduce the smoke without a pre-installed ventilation system. This leaves really only one tactical approach left
and this is number 5, control the situation from outside the tunnel and assists the self-evacuating people with advanced medical assistance, a classical defensive strategy.

In scenario B the situation will be very difficult to handle, due to all passengers in the bus. In this situation, not consider using an offensive strategy, is not acceptable by anyone, especially not the emergency services community. The situation is not that different from scenario A, considering the lack of effective methods to handle these situations. Depending on the development of the fire and the smoke, this scenario could mean a huge difference in the specific situation. A fire in a bus could be possible to fight. The only way to handle this situation is to fight the fire and by this reduce the dangerous environment in the tunnel. This together with rescue of the people in the bus and advanced medical assistance outside the tunnel would be the strategy for this scenario.

In scenario C the tactical approach will be very dependent on the fire development and the smoke production. A rapid fire development with massive smoke production will be very complicated to handle and very alike the scenario A. The location of the fire in the middle of tunnel in between tunnel the face and the entrance, could mean that people are trapped in between the tunnel face and the fire are also making the tactical situation very difficult to handle. If the fire development are slow and with little or moderate smoke production and if people are trapped in a dangerous environment, the tactical approach would be offensive and using a BA-operation in to the tunnel to fight the fire. If the fire development are rapid and with massive smoke production and if no people are trapped in an dangerous environment, the tactical approach would be to give medical assistance in a safe environment outside the tunnel.

Scenario D is representing a different situation, due to the break-through in the tunnel construction. This gives the emergency services a range of new methods to use in the tactical planning of the operation. The break-through gives the possibilities to control the air-flow in the tunnel with ventilation operation and to have at least two different path-ways to get close to the fire. In this scenario the initial operation would be find the direction of the air-flow and then send in a BA-operation with the air-flow to fight the fire and by this reduce the dangerous environment in the tunnel. The next step would then be to control the air-flow, try to rescue people to a safe environment and give advanced medical assistance outside the tunnel.

Scenario E represents a rather small fire load, but still potential of a lot of smoke production. In this situation, if no people are in danger, the smoke production would be the problem to handle. The air-flow will be controlled by ventilation operation. After this is done a BA-operation will use the air-flow to advance near the fire and the fight it.

Scenario F represents a fire with potential of a very rapid development and massive smoke production. In this scenario a defensive strategy will be chosen. The air-flow will be controlled with ventilation operation and eventually a defensive fire fighting operation will be done to reduce the impact on the tunnel construction.

As described, a fire and rescue operation in a tunnel fire situation is a very difficult operation. If the situation occurs the emergency services together with the construction companies, as to try to handle the situation. Well made contingency planning will not solve the problem, but it will place focus on difficulties in the operation. These identified problem will then have to be solved, a thing that is much harder to handle in the real fire situation.

**DISCUSSION AND CONCLUSIONS**

To use the expression fire to describe the wide range of physical phenomena’s that occur during this complex process is a rather large simplification. A fire can be everything from a small and smoldering fire to a rapid developing fire with a high peak-value of the heat release rate (HRR). Depending of the characteristics of the fire, the consequences will be very different for the evacuation of people and for the demands on the fire and rescue operation. The environmental conditions could really be seen as two different scenarios, one with no break-through in the tunnel and one with the break-through situation. These will influence both the evacuation and the fire- and rescue operation. To combine the
fire characteristics of the fire and the environmental scenario, it will give a way to analyze the needs on the fire- and rescue operation, table 4. In table 4 a “small fire” could be compared to a burning car or a fire in a limited amount of stored burnable material inside the tunnel, while a “large fire” could be represented by a fully developed fire in a bore rig, working locomotive, lorry or dumper.

<table>
<thead>
<tr>
<th></th>
<th>Before break-through</th>
<th>Break-through</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Small fire</strong></td>
<td>Offensive operation</td>
<td>Offensive operation</td>
</tr>
<tr>
<td></td>
<td><em>(Fight the fire with BA-operation teams)</em></td>
<td><em>(Fight the fire with BA-operation teams and if necessary ventilation control)</em></td>
</tr>
<tr>
<td><strong>Large fire</strong></td>
<td>Defensive operation</td>
<td>Offensive/ defensive operation</td>
</tr>
<tr>
<td></td>
<td><em>(Wait outside)</em></td>
<td><em>(Control airflow and fight the fire from a distance)</em></td>
</tr>
</tbody>
</table>

Table 4 Schematic overview of fire and rescue operations in tunnels under construction

The purpose with this rather simplified analyzes is to realize that if there is a large fire, the emergency services generally will not be able to handle the situation. This is especially obvious when there is no break-through in the tunnel construction. It can not be left out by this situation. The emergency services needs to develop equipment and methods to handle the situation with large fires during tunnel constructions. On the other hand, the constructors needs to prepare for a fire and give workers and other persons in the tunnel or tunnel system a reasonable chance to evacuate from the tunnel. The real nightmare is when there are persons still trapped in the tunnel in the fire situation, even if they are temporarily in a safe environment in a rescue chamber. The meaning should be that people evacuates during the fire growth. This could and should be supported with some kind of smoke confinement, which reduces or stops the smoke filling of the tunnel. This alone will though not be enough but needs complementary measures that reduce the fire growth, measures like sprinklers in vehicles, choice of construction materials and organizational fire prevention and preparedness.

ACKNOWLEDGEMENTS

The authors would like to thank MSB – the Swedish Civil Contingencies Agency for the financial support of the project Accident Management during Construction of Tunnels, and Fire Safety Engineer Arne Brodin for valuable support regarding matters concerning contingency planning during construction of tunnels and real life tunnel conditions.
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