Personal Reference.

Ir. J.W. Bosch (1955)

Mr. Bosch obtained his master degree of civil engineering at the University of Delft in 1982 and started working with the Construction Company Ballast Nedam. After three years he moved to the city of Amsterdam working on various positions within the municipal organisation. During this period he was involved in the planning of several major projects such as a submerged tunnel and the new metro extension, the North/Southline. In 1992 he left the municipal organisation and started working as managing director of one of the subdivisions of Tauw, a consulting company active in the fields of civil and environmental engineering. In 1994 he became a board member of Tauw. In the same year he renewed his involvement with the North/Southline project, when he was invited to become part-time manager of the technical side of the project. Since 1999 he is full time involved in the project as the general construction manager and working again for the municipal organisation of Amsterdam.

Abstract.

Title: “North/Southline: the development of a new safety concept”

The safety level of the metro tunnels is a very important and complex matter. Current legislation in the Netherlands does not provide a clear safety framework. A concept had to be developed and this was done in several steps. At first the most dangerous situation was determined, in this case the greatest threat is fire. Then the main principles of the safety concept and the required measurements were determined. By discussing it with relevant parties, this safety concept was further developed. The paper presented will address the process of development and go into detail on some of the structural measurements.
The paper is a policy summary of a document that was drafted by several members of a consultancy group and edited by Mr. A. Snel.

**A CONCEPT FOR AN ACCEPTABLE
SAFETY LEVEL ON THE NORTH-SOUTH LINE PROJECT**

1. Introduction

The safety level of the metro tunnels is a very important point of attention. A safety level has been developed for the North-South Line Project that is attuned to the national guidelines and developments with regard to safety concepts for underground structures. The basic point of departure for the following study and thereby also for the safety concept developed is passenger self-reliance in the event of disaster.

The safety decisions with regard to the preventative structural facilities to be implemented are recorded in the safety concept. The non-structural pro-active, preparative, preventative and repressive measures have also been included in the concept, so that it provides an overview of the main points of the safety concept for the underground system of the North-South Line Project. Precondition is that the non-structural measures are attuned to the intended emergency organisation and system safety of the future operator.

The safety level of the North-South Line Project, as determined on the basis of a quantitative risk analysis has been weighed against the current target values for personal and social risks. The implementation of this safety concept will result in an acceptable safety level for the North-South Line.

This policy summary contains determinative elements of the safety concept as proposed by the North-South Line Project management.

The policy summary will deal with the following subjects in brief: the process so far, the safety study's approach (as the resultant of this process), threats and guiding principles. Then it will indicate the manner in which a) structural measures and facilities and b) non-structural measures and facilities will optimise the North-South Line Project safety concept. Finally, this summary will deal with how the implemented safety level for selected disaster scenarios was quantitatively determined.

Figure 1 Aerial view of the route of the North-South Line Project

2. The process

The North-South Line Project is to be the first bored metro tunnel in the Netherlands. A major part of the line is to be situated deep underground and is intended for the transportation of large numbers of travellers during the rush hour (215,000 passengers per day during the first phase and 300,000 passengers per day during the second phase). From a safety perspective, both these aspects not only require a meticulous planning approach, but definitely also a meticulous approach to the *process*. The safety aspect has therefore already been a point of discussion since the initial phase.

The basic point of departure for the safety concept was already formulated in the initial phase of the project together with the Gemeentevervoerbedrijf (Municipal transport Company) and the Brandweer Amsterdam (Amsterdam Fire brigade). The objective of the concept is that the safety level must at least be equal to that of comparable metro systems in Europe. Besides the pro-active measures, preventative structural measures were also formulated in the concept, including:

- Investments in measures which optimally support passenger self-reliance ;
- Emergency exits every 300 - 350 metres;
- The desire to use escalators as a means of escape.

These basic points of departure with regard to the safety approach have been administratively laid down as part of the construction decision of 27 November 1996.

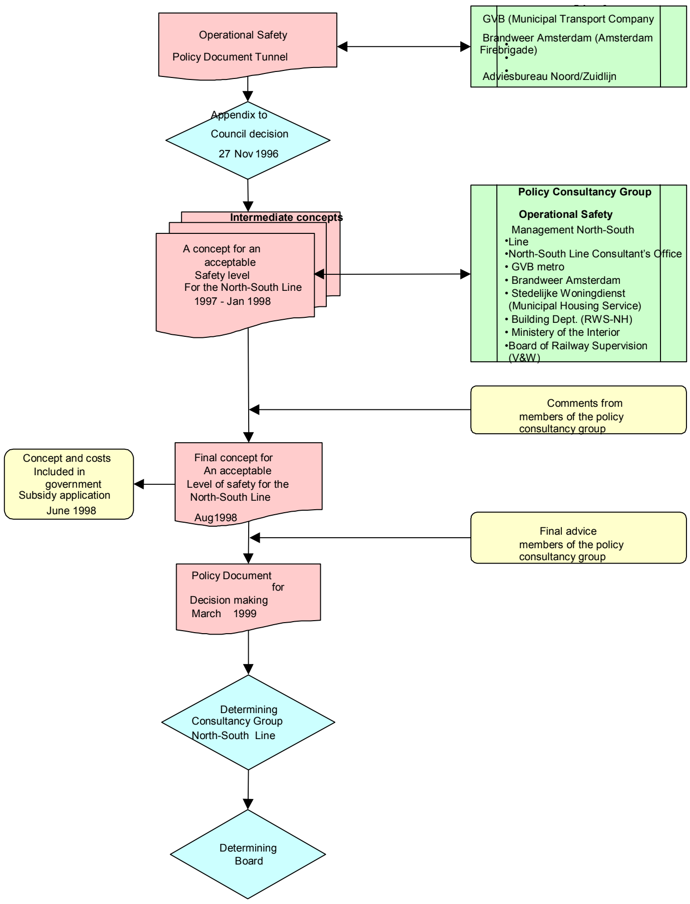
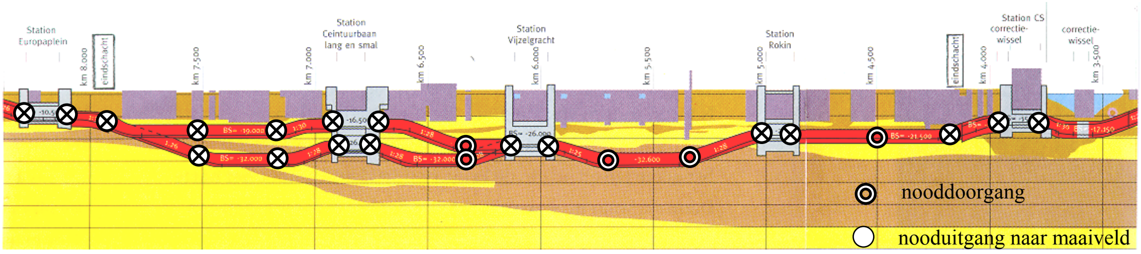


Figure 2 Operational Safety Concept Process

Current legislation in the Netherlands does not provide an unequivocal safety framework, which capitalises on the most recent developments in underground construction. In order to achieve attunement, both at a municipal and a national level for the North-South Line Project a policy consultancy group was set up to develop a safety concept. Besides municipal institutions, the Ministry of Transport, Public Works and Water Management, the Ministry of the Internal Affairs and 'Koninkrijkrelaties' participated in this group. The goal was to arrive at a widely supported safety concept for the North-South Line Project.



[nooddoorgang = emergency door, nooduitgang naar maaiveld = emergency exit to ground level]

Figure 3 Emergency doors in vertical alignment along the underground route of the 'North-South Line Project'

3. Approach to the safety study

The North-South Line Project is to be a high-quality 9.5 km long metro link between (the north of) Amsterdam Noord and Zuid/WTC (the south of Amsterdam and the World Trade Centre), of which approximately 6 km is to be located underground. The following phases determined the approach to the safety study:

- Cataloguing incidents which constitute a risk to operational safety;
- Selecting benchmark undesirable events;
- Indicating main principles and the primary points of departure for the safety concept;
- Optimisation of operational safety by ensuring:
  1. Structural measures and facilities;
  2. Non-structural measures and facilities (proactive, preparative, preventative and repressive);
- Quantitative determination of safety level for selected accident scenarios. Risk reductions as a result of the optimisations implemented were taken into account.

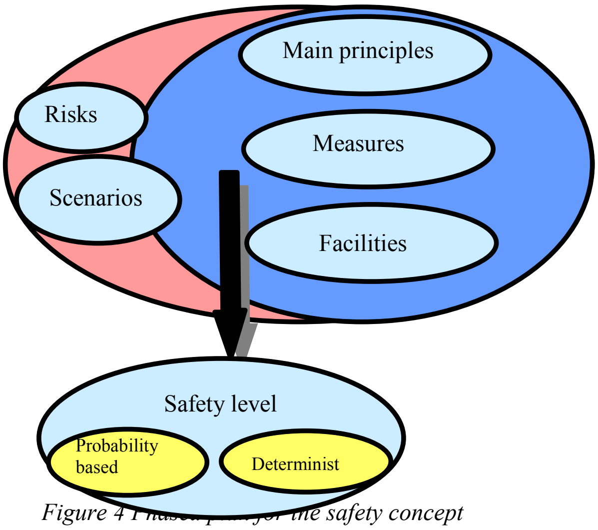


Figure 4 Phased plan for the safety concept

The quantitative risk analysis is a combination of a determinist and a probability based approach. The sensitivity of a number of parameters was also sketched. This increases the objectivity and reliability of the points of departure on which the calculated absolute risks are based. Additionally, the safety level of the North-South Line Project was compared to the current safety level of the Oostlijn (Eastern Line) in Amsterdam.

4. FIRE: the biggest threat

Various threats can endanger the operational safety of the system from within the system or from its surroundings. The causes of the undesirable events can originate in:
- failure or collapse of static parts of the tunnel and/or stations;
- failure or collapse of dynamic parts such as the vehicle, signals and/or track safety systems;
- collision, derailment and fire risks;
- the general public;
- dysfunction of the (safety)organisation

Suicide, terrorist attacks such as explosions, the use of toxic gases and arson other than vandalism have not been taken into account.

On the basis of the inventory of undesirable events, fire – whether a result of other undesirable events or not – proves to lead to the most threatening situation. This applies to personal injury, structural and operational damage. The following fire scenarios can be distinguished:
- Fire in the stations at deep locations;
- A burning train that reaches a full station;
- Fire in the single track bored tunnels;
- Fire in the sunken tunnel under the river IJ.

These scenarios could occur during off-peak hours, but also during the rush hour or delays to the timetable. Owing to the large number of passengers that will have to be brought to safety, the latter situations are benchmarks in this respect.

5. Leading main principle: passenger self-reliance in the event of disaster

The leading principle of the safety concept is passenger self-reliance in the event of disaster. The tunnels are situated at such a depth that emergency crews cannot be on hand immediately. It is important that in the event of a disaster, the passengers can reach a safe area as quickly as possible. In the event of a fire, the signal system (ZUB, communication) and the systems (emergency brake bypass) will be aimed at ensuring that the train can reach the station as this provides the best chance of safe evacuation.

In addition, an acceptable escape scenario will be provided for trains that come to a halt in a tunnel. If a fire also breaks out, the passengers will have to be brought to safety as quickly as possible. The measures required are mainly structural, such as, emergency doors, escape paths, a level ballast bed and ventilation in the stations in order to keep be minimised. The trains in front and behind the train in question must be kept out of the evacuation area (the escape route).

Figure 5 Social safety is an integral part of the design

The study does not deal with aspects regarding how passengers experience their safety. These aspects have been dealt with in separate studies on social safety. The architect has capitalised on the results of the latter study as the transparency and clarity of his design reveal.

A number of points of departure can be indicated for the drawing up of the safety concept:

- No additional facilities have been provided for the evacuation of the handicapped besides the standard facilities for the accessibility of the stations. In the concept, the handicapped are therefore dependent on the aid of their fellow passengers, which in turn influences the escape process of the other passengers. Irrational behaviour has also been implicitly included by means of conservative assumptions;

- In accordance with current policy bicycles will also be allowed on the North-South Line. If bicycles are not left behind during a disaster this can lead to obstructions. This is recognised as a bottleneck. Escape routes will remain available thanks to the fact that there are two directions to escape in and the two escape paths (nevertheless, allowing bicycles on board is not recommended from a safety perspective);

- Smoke diffusion and people being overcome by smoke primarily determine the effects and possible risks. The CO concentrations were used in calculations. The development of other types of toxic gasses, which could have a detrimental effect on safety, will have to be minimised by a judicious choice of materials.

The influence of the above has been catalogued In the sensitivity analysis of the quantitative assessment of the fire risk a spread and variation with regard to the above-mentioned points has been used to catalogue the influence.

6. Structural measures

In the safety concept that has been developed, facilities have been included for which the main objective is determinative: the limitation of the effects in the event of fire. The basic concept for this is creating optimum opportunities for passenger self-reliance in the event of disaster. The following lists the principal structural measures.

Emergency door to safe tunnel
In spite of the measures which have been taken aimed at ensuring that the train reaches a station, the fact that a train could come to a standstill in a tunnel has been taken into account. Emergency doors will be installed in the bored tunnel section, which offer an escape route to a second, safe and smoke-free tunnel. This tube leads to the station. The operation in the second tube will then be closed down. The emergency doors will be installed at 300 - 350 m intervals, which limits the length of the flight through hazardous smoke and the risk of personal injury. In the southern area, where the tunnel tubes are situated above one another, the passageways will be built from ground level. The shaft will then also include a stairwell (overpressured) to enable escape to ground level as well as connecting to the other tube.

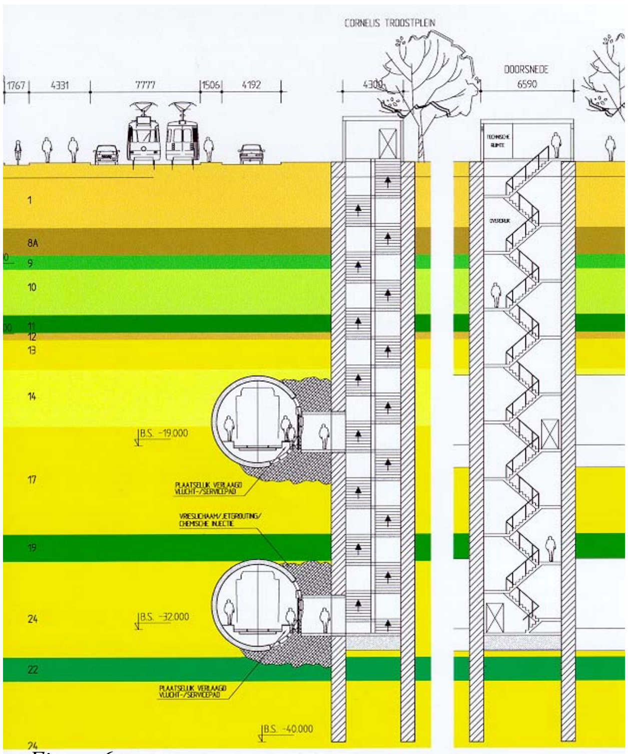


Figure 6
Escape route to the second tunnel tube and to the stairwell

Fitting escape routes into the bored tunnel
Besides the railway technical and structural aspects, the diameter of the red tunnel is to a large extent also determined by having to fit in pathways. The escape time and capacity calculations prove that escape alongside a train is to a large extent determinant for the entire duration of the escape and therefore also for the risk that passengers are exposed to. Furthermore, the pathway's inspection function should also be taken into account. Partly due to the above-mentioned importance of good escape routes alongside the train, pathways on both sides have been opted for: 0.70 m x 2.10 m vertically (an improvement in comparison to current metro systems). In the most acute bends, the width of the pathway will locally be reduced to 0.60 m.

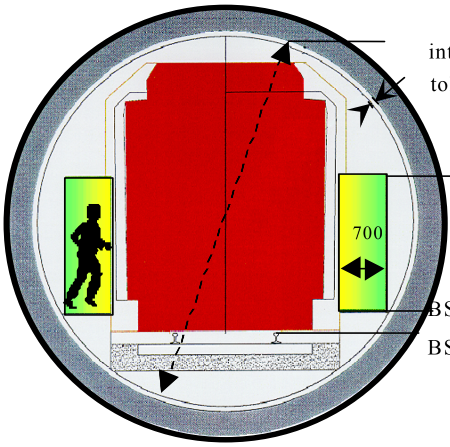
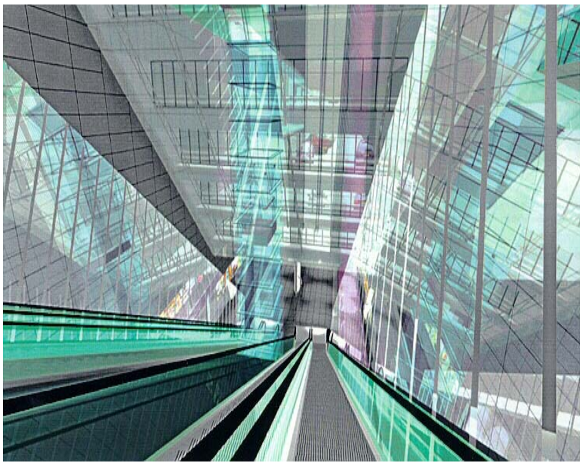


Figure 7 Pathway on both sides of the train

The level of the pathway: BS + 0.30 m offers an average height for getting off the train and onto the ballast bed in the event of escape. It also keeps the step up from the ballast bed in the event of possible inspection or maintenance acceptable.



The safety concept at the stations is generally characterised by the large number of escalators per station, an exit at both end and a clear layout. This enables rapid evacuation. During the rush hour the stations can be evacuated inside 5 - 6 minutes. The escalators are also equipped with a no-break feature (i.e. they continue to operate in the event of a power cut) and are adjustable. Furthermore, the stations are equipped with emergency power supplies, smoke and heat extraction systems, fire and emergency alarm buttons, fire hydrants in the vertical transit areas and fire-proof lifts for possible use by emergency services.

Stations remain smoke free in the event of fire in the tunnel
The platform areas of the underground stations will be equipped with smoke ractors. The smoke that develops and accumulates against the ceilings will be extracted to ground level using fans. The standard ventilation will be switched off in order to prevent diffusion of the smoke. The air supply will take place naturally via the entrance and the vertical transit area(s). The standard ventilation for the transit hall will continue to operate as this helps to keep the escape routes as smoke free as possible. In the event of a disaster in the tunnel, the smoke will distribute itself naturally and the upper part of the tunnel will fill with smoke. If the smoke reaches the ends of the tunnel, it will be transported to ground level by means of smoke fans. This prevents the smoke from entering the station. Smoke access to the tunnels is also combated. In this way the stations and the second tunnel tube remain smoke free.

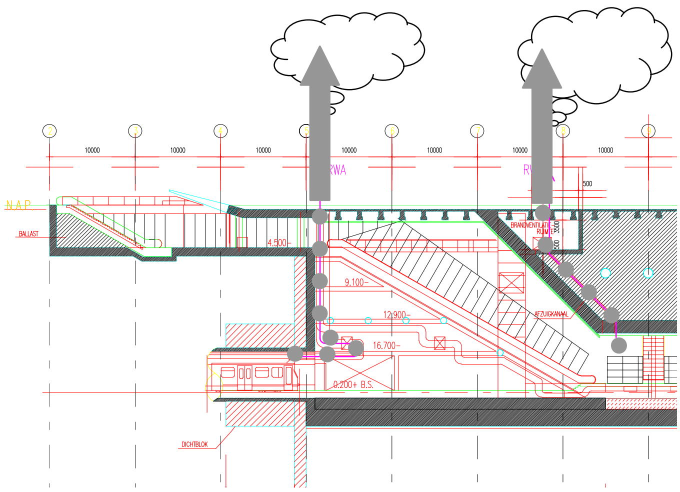
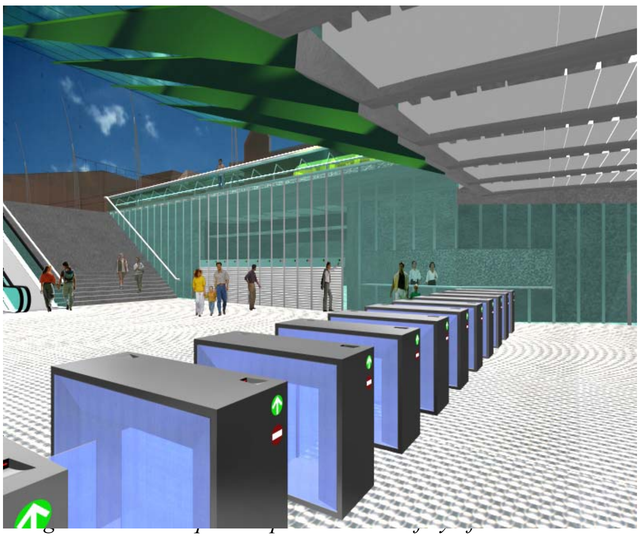


Figure 10 Smoke and heat dissapation from underground areas

Water-control doors limit damage in the event of disaster
The underground section of the North-South Line Project crosses the IJ and the primary water-control structures on either side. In order to maintain the current water-control function of the primary water-control structures and to prevent linking various areas of reclaimed land, two water-control doors will be installed in the tunnel. The primary emergency water-control doors will be located on the Prins Hendrikkade and by the Sixhaven. Two water-control structures with a compartmentalising function will also be installed on the De Ruijterkade and in the Oostlijn metro. These offer protection for the Central Station and the entire North-South Line respectively. By applying these water-control structures, the primary water-control structures (dikes) remain unaltered and in the event of a disaster the North-South Line can be compartmentalised, thereby helping to limit the scope of a disaster and the ensuing damages.



Remaining structural measures
In order to increase social safety tourniquets will be used in the transit hall. Furthermore, in the design of the North-South Line Project an overhead contact wire in the shape of a fixed wire/rail has been opted for safety reasons. However, so as not to lose the compatibility with the rest of the system, the application of a third rail (in the future) remains an option. From a technical point of view it has been decided to use a ballast bed, as this offers the option of easy adjustment in the event of the tracks shifting. The ballast bed will be executed as levelly as possible so as to improve evacuation.

7. Non-structural measures

North-South Line Project requires additional system safeties
The train safety system will have to meet additional requirements, besides the usual (collision) safety. The system is to be rigged in such a manner that the station can always be reached. Furthermore, in the first

phase a safe distance between successive trains can ensure that other trains are involved in an incident. In the second phase, additional measures in the form of an upgrading of the train safety system will have to be taken, particularly with regard to the situation in the event of disruption to the timetable.

Figure 12
Modern Centralised Traffic Control required

Necessity of an alert safety organisation
The Metrobedrijf (metro company) has drawn up the main points of a plan with regard to the emergency organisation for the future operation of the North-South Line Project. It will be the future operators responsibility to see that the plan is further detailed over the coming years. The current design and the systems of the North-South Line Project are in line with the main points of this plan. The driver plays a crucial role in preventing, signalling and alarming with regard to incidents. Communication with the central traffic controller's office, which plays a guiding role for the GVB Metrobedrijf is thereby guaranteed. The traffic controller's office is in turn supported by the disaster team that supervises the fire brigade on site and powers down the area (short circuit).

Metro rolling stock in accordance with latest developments
At the moment the main points of rolling stock requirements has been drawn up. A detailed list will not be required until the rolling stock is ordered and should then be attuned to the latest developments:
- In order to be able to continue to the next station, the metro trains are to be equipped with a emergency brake and door lock bypass systems. The following metro trains should be able to reverse as rapidly as possible (under the supervision of the Central Traffic Controller's Office);
- Metro carriages are to be equipped with bicycle compartments, an ATB system and good, reliable means of communication with the Central traffic Controller's Office and the passengers;
- The materials used in the carriages may only be slightly flammable and may only contain a limited amount of toxic substances. The risk of fire breaking out due to part failure in the metro carriage must also be limited.

Support: emergency services deployment
In the event of fire in the tunnel or at one of the stations, the fire brigade's primary task will be to supervise the fleeing passengers. Evacuation will be in full swing when the fire brigade can be deployed. This underlines the importance of good facilities for self-reliance .

The fire department area in the transit hall is the fire brigade's bridgehead when combating fire. The escalators offer an unequivocal and clear route, but will be used for evacuation in the event of disasters during busy periods. In such situations, the lifts can be used by the fire if need be, due to the unequivocal structure, the location and their fire-retardant nature. To this end, a control panel has been included in the lifts. In quieter situations, the fire brigade can use the escalators. To this end, the escalators can be controlled from the transit hall. The RWA will ensure a smoke-free vertical transit area.

8. Threats to the safety of the North-South Line Project in detail

8.1 Threats

Limited risk of collision and derailment
In general, we can state that the risk of collision and derailment will be limited. The risks with regard to the points, located near the Vijzelgracht and Europaplein stations, require additional attention. Because of the low speed of the metro trains (due to intervention from the track safety system) personal injury as a result of a rear-end collision or derailment at the points will be very limited. This also makes the unusual locations of these points acceptable from a safety point of view.

Points have been planned in the middle of the tunnel under the IJ, which will be used in the event of disruptions to service (left track) and – if need be – for turning in the event that lines are shortened. The location was selected from the point of view of alignment, construction technique and operation. In order to minimise the risk of derailment additional derailment safeties are to be installed in the sunken tunnel. From the point of view of safety, points in the tunnel under the IJ are acceptable owing to the limited increased risk of

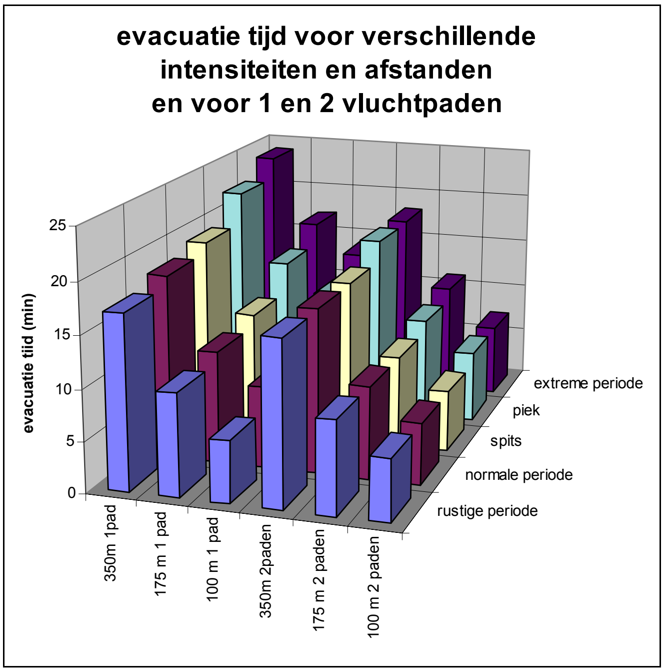
derailment and the less serious consequences in comparison to the single-track tunnels.
The conclusion is that in connection with the track safety system employed and the accompanying safety procedures, the risk of derailment or collision in the entire underground system is very limited. As a result of the minimal consequences of derailment and collision, the resulting risks are seen as acceptable.

Fire risk is determinant
As mentioned above, fire leads to the most threatening situation as far as personal injury and structural and operational damage are concerned. A quantitative assessment of the safety with regard to fire risks can be determined using a combination of determinist and probability based analysis. The determinist approach expresses safety as information on the consequences in the event of extreme scenarios, while the probability based approach expresses safety in information concerning relevant chances and accompanying consequences. Both approaches are complementary and are used side-by-side in the design and development of the system.

8.2 Determinist safety assessment

The determinist assessment of safety can be sub-divided into:
- rapid evacuation in the tunnel thanks to two escape paths;
- acceptable evacuation times in the stations on the North-South Line;
- sensitivity analysis.

Faster evacuations in the tunnel thanks to two escape paths
If – in the event of a fire - a train comes to a halt in a tunnel after all, rapid evacuation is a must with a view to smoke development. During the rush hour, the number of passengers per train averages 400 to 500, within which a short peak occurs during which the average number of passengers rises to between 600 to 750. During the entire escape time, the congestion i.e. the time spent waiting beside the train and the low escape speed due to smoke are determinant. By incorporating escape paths on either side of the train (instead of only on one side) the escape times can be reduced by roughly 2 to 5 minutes depending on the number of passengers. From the point of view of safety, employing two escape paths has clear advantages. Once the train has been passed, flight can then take place along the ballast bed. Distribution then takes place which enables acceptable escape speeds.



Evacuation time for various intensities and distances for 1 or 2 escape pathways
evacuation time in minutes
1 pad = single path
2 pad = 2 paths
extreme periode = extreme peak
piek = peak
spits = rush hour

normale periode = normal period
rustige periode = quiet period

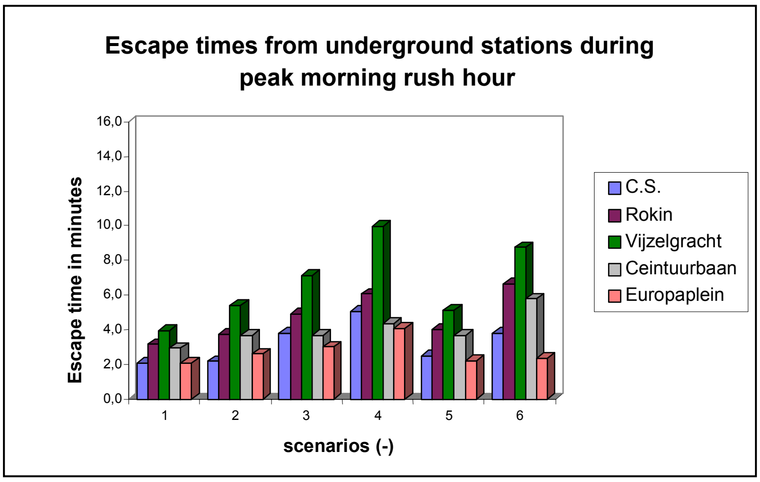
In the event of evacuation during peak rush hour (5% of journeys) and under average escape length passengers can reach an emergency door inside approximately 4 minutes. If one assumes that the escapees are slowed down by smoke development then the escape time increases to 5 minutes, while the last person to make it to safety will arrive there after approximately 8 minutes. In average crowds during the two hours of rush hour, these times are 4 and 7 minutes respectively. The escape times for the various scenarios with variations in the parameters are considered acceptable in relation to the frequency of their occurrence, if two escape paths are implemented. In that case, the escape times will be under the normative 17 minute presence time and the risk of mortality due to smoke therefore remains less than 1%. This is a qualitative assessment on the basis of the results of determinist calculation.

The calculations took place in a safe manner, i.e. they assumed that the smoke development and obstruction would be complete inside two minutes of fire breaking out on board a train. For example, on the basis of the first results of the 'Ventilation Review' carried out by MottMcDonald, it appears that after approximately 6 minutes the fire intensity is still relatively limited. If, for example, smoke obstruction only occurs after these 6 minutes, then the escape time decreases and the risk of a number of fatalities decreases halves in the various scenarios.

Acceptable evacuation times for the North-South Line stations
Both driving directions meet at the stations, which causes a concentration of passengers. Furthermore, the stations act as an evacuation point for the trains as these always try to reach the next station in the event of a disaster. Good and rapid evacuation of the stations is therefore a must.

Each station has two exits from the platform to the transit hall up to ground level. Escalators have been opted for as an escape route; these offer the best opportunities for rapid evacuation. Owing to the considerable height that must be reached from the platform to the transit hall, some 15 to 20 metres, stairwells are not an option. Tired or less bodily able passengers will then increase the evacuation times and stagnate the escape process. The operation of the escalators will be guaranteed using a no-break system, careful maintenance and specific system requirements (start-up under full load).

The evacuation times for various scenarios have been assessed. Under normal operating circumstances, the largest numbers of passengers occur during the evening rush hour. Station Rokin is the busiest station, whereby the number of passengers and waiting travellers to be evacuated could amount to approximately 1,400 in extreme situations. In the event of short or long-term disruptions to the timetable, trains could be even more full. In these extreme situations the number of people to be evacuated could number up 2,200. However, the risk of this type of disruption combined with fire is very small.



Scenarios:

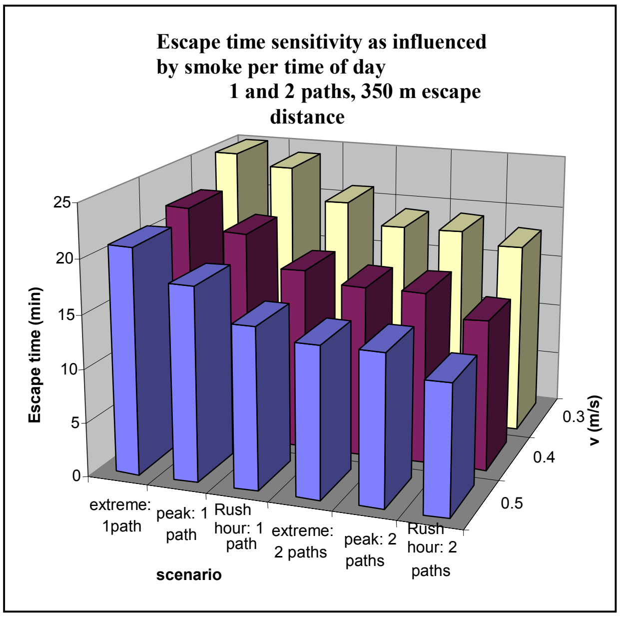
1. All ascending escalators
2 one escalator undergoing maintenance and one descending escalator
3 one vertical transit area unreachable
4 one vertical transit area unreachable and an escalator undergoing maintenance
5 escalators have stopped, capacity reduced to 2/3
6 escalators have stopped, capacity reduced to 1/3

Besides the number of passengers, the availability and/or accessibility of the escalators also plays a determinative role. Various situations per scenario were also assessed with regard to this fact. As far as speed and capacity are concerned the escalators offer good evacuation options in comparison to the stairwells. On the basis of the escape time calculations it follows that under normal rush hour circumstances and the only partial availability of the escalators, the stations could still be evacuated inside 4 to 5 minutes. If the timetable is disrupted, the escape times double.

The prevalent evacuation times are considered acceptable, owing to the smoke extraction in the stations, the limited risk of the occurrence of the most extreme situations and the length of time it takes before smoke development causes obstruction.

Sensitivity analysis
The conclusion of the determinist assessments sensitivity analysis is that the results of the above-mentioned evacuation calculations are sensitive to the escape speed due to smoke, the concentration of CO in the smoke and the level of smoke concentration which leads to people being overcome by smoke and the consequent occurrence of fatalities. The following range of values is included in the assessment for these parameters:

- a conservative range of 0.3 m/s to 0.5 m/s has been used in the assessment for the escape speed once passengers have passed the end of the train, which results in a factor two in the results. Good supervision of escapees, lighting for the pathway, pathway marking and guide rails are necessary for optimisation;
- a range of 1.0% to 2.0% is included for the concentration of CO in the smoke, which leads to approximately six times the expected number of fatalities;
- if escaping passengers can already be overcome by smoke with a low CO percentage this would increase the number of fatalities. A parameter study was carried out into the influence of the CO percentage. The CO dose plays an important role in the expected number of fatalities.



8.3 Probability-based safety assessment

A more probability-based safety assessment of the rail system has provided insight into the risks with regard to the risk of possible fatalities in the event of fire.

The probability-based assessment of the safety concept took place using three characteristic criteria, i.e.: personal risk, group risk and the characteristic value:

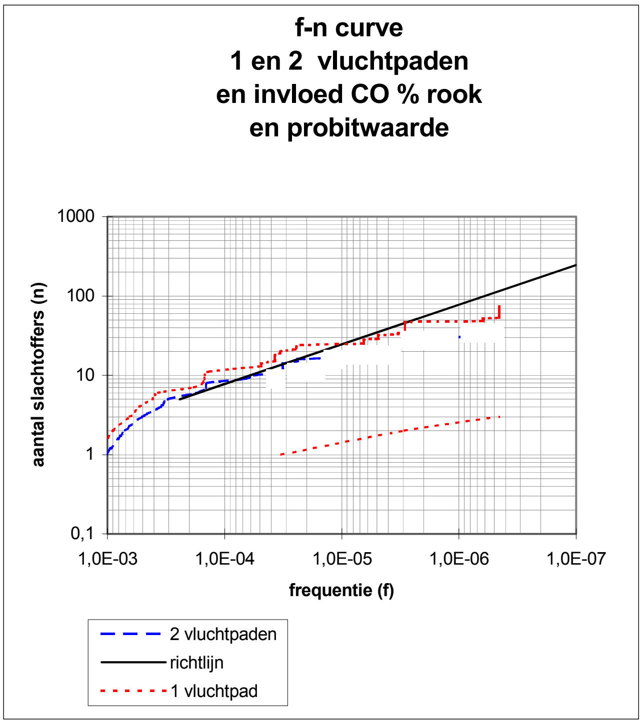
- Personal risk. The acceptable personal risk was defined as the frequency of the occurrence of a particular level of injury as a result of an activity that individuals would accept. In this study the level of injury was 'limited' to death;
- Group risk. This risk can be described as a government tolerated level of risk of a certain number of fatalities as a result of an activity. Group risk exists if there are more than 10 fatalities. The group risk is catalogued using the so-called F-n curve, which displays the relationship between the frequency of accidents and the expected number of fatalities on the basis of risk-result pairs;
- Characteristic value. The characteristic value (CV) of a national activity or inter-local facility indicates the total number of fatalities that in a given year will most probably not exceed a particular level. The CV is a suitable measure of risk for making various modes of transport comparable as far as the characteristic safety is concerned. This makes the CV a measure of risk for decision-makers and administrators.

No unequivocal threshold values or guidelines are present at a national level. In order to create a basis of reference for the North-South Line Project (a normative framework), benchmark values have been formulated on the basis of the national policy currently under development and the infrastructure projects of a similar design.

The derived risk benchmarks were also submitted to Prof. Ir J.K. Vrijling and W. van Hengel of the TU Delft (Technical University) and the Ministry of Transport, Public Works and Water Management 's construction department. In the method-applied risk perception and aversion are expressed using policy factors and aversion coefficients. The objective risk is weighed using these factors and coefficients in order to artificially express the irrational aspects of risk perception.

The following table displays the guidelines derived and the risks calculated for the North-South Line Project. Point of departure for this were the intensities that occur in the second phase of the project, i.e. in the event of passenger numbers over 300,000 per day. The busiest stretch of track has been selected between Central Station and the Rokin. The principal sensitivities have also been included.

The risk levels are therefore not displayed as a single value, but as a range, so that the influence of the assumptions is clarified. This increases the objectivity and reliability of the risk levels calculated.



f-n curve 1 and 2 escape paths and influence of CO% smoke and probity value

aantal slachtoffers = number of fatalities

frequentie = frequency

2 vluchtpaden = 2 escape paths

richtlijn = guideline

1 vluchtpad = 1 escape path

The social risk constitutes a benchmark (group risk and characteristic value). If only one path is present in the tunnel and we assume an upper limit approach to the parameters the guidelines will be exceeded. Only very limited exceeding of the guidelines takes place in the chosen solution with a single bored tunnel and two pathways in the conservative scenarios mentioned. In the normal situation, no exceeding of the guidelines takes place.

Probability-based assessment	***Group Risk***	***Personal Risk /person/year***	***Characteristic value fatalities/year***
Indicative guideline	$6*10^{-3}/n^2$	$1*10^{-5}$	4
Value calculated for a single pathway	$> 6*10^{-3}/n^2$	$5*10^{-7}$ à $5*10^{-8}$	0.03 à 6.0
Value calculated for 2 pathways	$< 6*10^{-3}/n^2$	$3*10^{-7}$ à $3*10^{-8}$	0.003 à 4.4

Table: Indicative assessment risks (two escape paths)

The personal risk remains under the target value indicated. Even in the most extreme situation, whereby smoke and low escape rapidly overcome the passengers speeds in the tunnel.

9. Comparison with the current Oostlijn

The objective such as formulated for the safety level of the North-South Line Project, is partially derived from the safety level of the Oostlijn (Eastern line). The safety level of the Oostlijn is a reference and minimum goal. The results of the probability-based assessment reveal that the first phase of the North-South Line Project achieves these goals. They can also be achieved in the second phase if the metro rolling stock meets a number of (feasible) requirements. Owing to the expectations for the future, the required limitation of the frequency of fire in a metro carriage per kilometre of tunnel can be achieved for the North-South Line Project.

10. Finally: the helicopter view

To sum up, the safety concept is mainly characterised by the following facilities and principles.

Stations:
- forced smoke and heat extraction
- use of a large number of escalators at both ends of the platform with a straightforward and clear layout
- tourniquets in the transit hall
- adjustable and no-break escalators
- emergency power supply and fire-proof lifts for possible use by emergency services
- fire and emergency alarm systems
- fire hydrants in vertical transit areas

Bored tunnel:
- non-disaster tunnel is safe zone
- emergency doors between the tunnel tubes approximately every 350 m
- two escape paths per tunnel
- smoke extractors at end of tunnel - station
- direct communication with above ground (Traffic Control Centre or fire brigade)
- emergency PA system
- fire hydrants in every tunnel
- maximum allowable irregularities in the ballast bed.
- overhead contact wire

Sunken tunnel:
- Also features central escape path
- Additional derailment safeties

Metro carriages:
- Emergency brake and door safety bypass
- Good communications system
- ATB system
- Application of materials with limited capacity for smoke and fire

Miscellaneous:
- Water control structures
- System safety for collision safety and safe mutual distance between metro trains
- Safety organisation based on main principles