FinEst Link

Feasibility Study – Sub-report Tunnel solution

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1. Geological conditions and geotechnical interpretation

The FinEst link rail tunnel between Finland and Estonia is planned to mostly go through crystalline Precambrian bedrock of gneisses and granitoids (Figure 1.1). The bedrock is generally of good quality and very hard compared to younger sedimentary rocks, but it is expected to still contain local weakness zones. Approaching the Estonian coast, the crystalline bedrock dives gently under younger, weaker Ediacaran and Cambrian sedimentary rocks (Figure 1.2). [1]

The Geological Survey of Finland has performed seismo-acoustic investigations along the potential alignment of the FinEst link under the sea [4]. A number of investigations have been done on the Estonian side (Geological Survey of Estonia et al.) including marine geological mapping, core drilling, wells and geophysical studies. Results from these investigations have been incorporated into a 3D model showing the seafloor bathymetry and thickness of the geological units (Figure 1.3) [3]. A profile along the proposed tunnel alignment of the FinEst Link with interpreted geology is shown in Figure 1.4.
Figure 1.3 Data source distribution (Left) and 3D surface of Quaternary sediments (right) on the Estonian side based on 3d model [3]. Red lines – seismo-acoustic profiles, red dots – drillholes and blue dots – wells.

Figure 1.4 Geological profile along the proposed tunnel alignment of the FinEst link based on the investigations shown at the top (vertical exaggeration 1:50).

On the Estonian side, in the focus area of Viimsi peninsula and Aegna island there are 4 diamond drillholes bored (M17/1993, F126/1973, F127/1971, F167) and several groundwater wells logged (Figure 1.5). On the site visit to Estonia the original core samples were not found but cores of similar type of rock were studied. Based on the core images of original ones (GEO Portal of Estonia) and visual interpretation of core samples found, the contact zone of the crystalline basement seems to be hard and of a good rock quality (Figure 1.6). There were no samples of Ediacara sandstone, because it is too soft for sampling.
Figure 1.5 Drillholes (red crosses) and groundwater wells (black dots) in Aegna island and Viimsi peninsula.

No samples from Ediacara (mid layer)

Figure 1.6 Example of core images drillhole M17. Section of blue clay with some sandstone layers (above) and crystalline basement (below). Core diameters are 112 and 89 mm. (GEO Portal of Estonia)
Summary of main rock types along planned tunnel of FinEst Link are described in following:

Precambrian crystalline basement (About 85% of tunnel length):

- Mostly very hard rock (Uniaxial compressive strength 100-240 MPa) with varying amounts of fractures and weakness zones
- There is a lot of investigations and mapping data in Finland about rock quality and also information about known weakness zones that can be used for further studies
- There is available accurate rock surface model over the area of Helsinki city central
- On the Estonian side surface contact of crystalline basement can be covered by weathered contact zone but based on drilling samples and core images studied it looks good rock quality.

Blue clay (depth about 0-80 m from ground surface) (About 8% of tunnel length):

- No water leakages (very low permeability) (Figure 1.7)
- Water content ~13% of dry weight
- Soft rock (Uniaxial compressive strength 2-4 MPa)
- Well suitable for tunnel construction with tunnel boring method (TBM), Metro of Saint Petersburg is built in similar blue clay (Figure 1.8)
- Some new investigation available:
  - Study of mineralogy and geology investigation Lontova Blue Clay Inc. XRD
  - New laboratory measurements done for blue clay sample from the quarry: water content, hydrometric test for granularity, consistency limits for swelling clay and Oedometer test

![Figure 1.7 Blue clay quarry in Estonia (As Kunda Nordic Tsement).]
Figure 1.8 Metro tunnels built in blue clay in Saint Petersburg (Image Matti Hakulinen).

Ediacara sandstone (depth about 80-140 from ground surface) (About 5% of tunnel length):
- It is mid layer between hard crystalline bedrock and blue clay
- Very soft (no samples from existing drillholes)
- Challenge for tunnel construction because of high water conductivity
- Important groundwater reservoir of Tallinn and its surroundings

Quaternary sediments (buried valleys 0-150 m):
- Soft sediments on surface: filled with till and loose silt, sand and gravel
- Thickness varies and they can cut through complete geology layers
- Challenge for tunnel construction => need right choose of tunnel boring machine
- Can include some hard rock boulders from crystalline bedrock loosen during ice age

Following table 1 presents properties of different types of rock along the tunnel alignment of FinEst Link [5,6].

Table 1. Rock properties of different formations along the tunnel alignment of FinEst Link [5,6].
1= volumetric weight, 2= compressive strength, 3= porosity, 4= P-wave velocity ca. 6000-6500 m/s, 5= thickness of formation.
In the area of the Helsinki-Vantaa Airport, a groundwater area called Ruskeasanta should also be taken into consideration in the tunnel planning. Rock fractures in the vicinity of the Helsinki-Vantaa Airport contain Glycol (from ice-protection sprayed on airplanes) which can react with bacteria to produce substances harmful to tunnel structures and air quality. This issue was encountered during construction of the Kehärata railway and was remedied with the addition of costly tunnel structures.

The following geological, engineering geological, and hydrogeological studies are further needed to bolster the next iterative design phases:

- Boreholes to calibrate the seismo-acoustic results.
- Seismo-acoustic sounding along the missing part of the proposed tunnel alignment (chainage 79’000 m – 91’000 m) and local parallel profiles beside the alignment to ascertain the 3D geometry and continuity of possible weakness zones.
- Further studies (possibly involving costly drilling in the final phase) to confirm rock surface and possible weakness zones in valleys under the sea.
- Seismo-acoustic surveys along the alignment at the Viimsi peninsula to the portal of tunnel.
- More diamond drilling along the alignment on Estonia side, for example Aegna island, to confirm geological surfaces and rock quality in the crystalline basement.
- More geotechnical and geology investigations in location of artificial islands including diamond drilling.
- Proper geotechnical logging and hydrological surveys of all new drilling investigations.
- A thorough compilation of geophysical and geological data from both land sides of the tunnel to identify potential weakness zones more precisely along the tunnel alignment.
- Hydrological studies of the Helsinki-Vantaa Airport area and Estonian side of the tunnel to estimate its impact on groundwater reservoirs during and after construction.
- More detail rock mechanical studies including drillcore samples, rock quality estimations from borehole mapping and laboratory tests for TBM relevant rock hardness parameters.
- Collection of all existing rock surface data along the alignment and an investigation program for places where more precise rock surface data is needed.
2. **Fixed Link Tunnel Solution**

2.1. **Tunnel concept**

Six transversal tunnel schemes were evaluated in a generic way in order to define in a plausible and robust manner the best-suited tunnel system for Finest link.

The following tunnel schemes were taken into consideration:

- **A** – one double-track tunnel with dividing wall
- **B** – one double-track tunnel and one service tunnel with cross passages
- **C** – two single-track tunnels with cross passages
- **D** – two single-track tunnels and one service tunnel with cross passages
- **C** – three single-track tunnels with cross passages
- **F** – immersed tunnel with separate cross sections and cross passages

For the evaluation process a matrix was developed to assess the different tunnel options by using seven criteria categories like tunnel construction, maintenance and operation or tunnel safety management with several subordinate criteria each.

For decision-making in the assessment of the tunnel schemes, a utility value analysis (a variants analysis based on a “scoring model”) was used. A scale of grades, ranging from one (worst solution) to five (best solution) was selected for the evaluation of the individual criteria. The total score determined for each tunnel scheme was composed of the correspondingly weighted section scores. Additionally, the cost benefit ratio was calculated based on the estimated relative construction costs for each design.

In order to make sure that the decision was made in a stable and robust manner, the weighting of the section scores was varied within a certain bandwidth to simulate the sensitivity of the system decision with reference to the various project requirements.

As the result of the performed evaluation it was concluded, that transversal tunnel scheme **D** consisting of two single-track tunnels and one service tunnel with cross passages is the most suitable and best-possible tunnel solution for Finest link.

![Figure 2.1. Chosen transversal tunnel scheme for Finest link](image)

The design of the running tunnels is based on a clearance profile for European standard gauge 1435 mm railways (according to TSI UIC GC standard). Thus, the two single-track running tubes have an excavation diameter of 10 m and an inner diameter of approx. 8.4 m. In this feasibility study, the
use of Finnish gauge 1524 mm or a dual gauge solution (1435 mm and 1524 mm) was also analysed. As the Finnish clearance profile (based on RATO 18) results in an enlarged tunnel diameter of almost 1 m, both alternatives were rejected. However, in a next stage it is to study if a Finnish clearance profile with fixed overhead catenary instead of the traditional wire suspended one could fit into a tunnel profile close to the one designed for 1435 mm European standard gauge.

The service tunnel can be built with a smaller diameter. An excavation diameter of 8 m has been designed to allow the crossing of two maintenance vehicles. The distance in-between the tubes has to be determined based on geotechnical requirements. At this stage, a horizontal distance of 35 m between the axis of running tunnel and service tunnel (70 m between axis of the two running tubes) is taken into account.

During construction, the service tunnel will be excavated in advance of the running tubes. This allows the service tunnel to be used as an exploratory gallery for the main tunnel drives. During operation, the service tunnel is an important part of both maintenance and safety concept of the tunnel. As most of the tunnel equipment is placed either in the service tunnel or in the cross passages, it can be freely accessed through this tunnel 24/7 without any negative influences on train operations. In the night periods when train operations are shut down the service tunnel also provides access to the running tunnels via the various cross passages. Hence, the service tunnel is best situated between the two running tunnels.

For the vertical position of the service tunnel, generally three options are possible:

- Same level as the running tubes (Channel tunnel)
- Below the running tubes (Brenner Base tunnel)
- Above the running tubes

The optimum position was evaluated with respect to the usage during operation of the Finest link. As described in chapter 8, service tunnel and cross passages will serve as temporary safe haven and are the primary measures to facilitate self-rescue in case of a forced train stop in the tunnel. In order to allow handicapped people to access the service tunnel with wheelchair, the gradient of cross passages should be as low as possible. To fulfil this requirement, the service tunnel will be situated almost at the same level as the two running tubes with cross passages having a gradient of 1.5‰. This layout also allows any incoming water to be drained through the service tunnel.

The described tunnel layout can be seen in the following Figure 2.2.

![Figure 2.2. Tunnel layout for Finest link – typical cross section](image)
persons only. This concept was questioned as it was considered doubtful that passengers would be able to distinguish between “service cross passages” and “safety cross passages” in case of emergency. Nonetheless, this concept might be re-evaluated in a later phase of the project.

Latest findings and scientific studies have shown that bypass tunnels for overtaking have no benefits on train operations, especially if the speed difference of trains is small like it is assumed for Finest link (refer to chapter 9). Therefore, bypass tunnel will only be constructed at the underground stations but not along the tunnel section. In order to offer more flexibility for train operations as well as for maintenance reasons, a single cross-over linking the two running tubes will be constructed approx. in the middle of the tunnel. However, the number of cross overs and their best locations are to be analysed and studied in detail in the next phases.

Intermediate attacks reduce significantly the construction time of long tunnels like Finest link. In addition, the provision of intermediate access points is beneficial for:

- Construction logistics (ventilation, flexibility, accessibility, etc.)
- Operations (temperature, air quality, drainage, etc.)
- Safety management
- Risk mitigation

For subsea tunnels intermediate accesses have to be located in not too deep water and preferably at locations which split the entire tunnel in portions of fairly similar lengths. One solution is the installation of vertical shafts with a platform on top like it’s common-practise in the oil and gas industry. Another option is the creation of artificial islands, from which vertical access shafts or inclined access tunnels are built down to the tunnel level. For the Finest link the second option was chosen. The following Figure 2.3 shows a longitudinal profile of the subsea section and the two locations of the intermediate accesses.

![Figure 2.3. Longitudinal profile of subsea section](image)

Artificial islands offer several advantages compared to platform solutions, namely for instance:

- the intermediate access to the tunnel system is protected by the surrounding island. There is a lot of ship traffic in the Baltic Sea and islands mitigate the risks that a ship crashes into the platform which would have devastating consequences.

- harbour facilities can be constructed on an island. As logistics are a key parameter for the construction process, this offer more flexibility and supply reliability.

- the space available on an artificial island can be used for several purposes like temporary material storage (both excavation material and construction material) or installations for waste water treatment, machinery, ventilation, energy, etc. Later during operations of the Finest link, the intermediate accesses can be used for ventilation purpose, whereas the artificial islands can be used for wind power plants or even be transferred into recreation areas.
However, the intermediate accesses do not serve in any case as emergency exits for train passengers during operations.

On the other side artificial island may have a more relevant environmental impact on the sensitive maritime ecosystem (see chapter 10).

Two artificial islands will be created for the construction of Finest link. They are located in water depths of approx. 15m and 20m and will be built of material coming from the Finnish onshore tunnel excavation (refer to chapter 6.3.1). During tunnel construction, 6 tunnel drives have to be supplied from each island more or less simultaneously. As space is needed for muck handling, muck deposit, material deposit, silos, batching plants, workshops, offices, harbour and logistic infrastructure etc., a total size of approx. 400 x 300m has been defined as being adequate.

Once the artificial islands are created, they serve as launching basis for the construction of the intermediate accesses to the tunnel system. Due to different geological conditions two different sorts of access types will be constructed:

- One the island closer to the Estonian coast vertical shafts will be sunk to a depth of approx. 215m below sea level as thick layers of sedimentary rocks and loose quaternary deposits overlay the crystalline bedrock. For logistic aspects but also for security reasons two shafts are considered being necessary.

- At the location of the island closer to the Finnish coast the crystalline bedrock is quite close to the surface an approx. 1’500m long inclined access tunnel with a max. gradient of 10% to ensure heavy truck traffic will be built. As the dimensions of the artificial island are limited the access tunnel is built helix-shaped (see Figure 2.4 below).

The diameter of the shafts as well as the width of the tunnel depend on the equipment and material that are to be transported through the shaft/tunnel both for construction and operational phase and hence it is designed with 9m also to allow the crossing of two trucks.

Figure 2.4 below shows the tunnel system and two intermediate access.

![Figure 2.4. Finest tunnel system and intermediate accesses](image)

**2.2. Constructional aspects**

Construction time is a key parameter in tunnelling and it is common practise to use tunnel boring machines (TBM) whenever economic viable. Compared to drill-and-blast excavation the advance rates of TBMs are to 2 - 3 times higher even in difficult rock conditions.
As discussed in chapter 6.2.2, the Finest link tunnel will be mainly situated in competent and stable crystalline bedrock. These tunnel sections will be constructed either with single shield TBMs or double shield TBMs. Figure 2.5 shows an illustration of a typical single-shield TBM. For tunnelling, the cutterhead at the front equipped with disc cutters is pressed against the rock at the tunnel face. Due to the rolling movement of the discs, so-called chips are broken out of the rock. Hydraulic thrust cylinders, which are positioned around the circumference push the shield forward from the previously built tunnel ring. Buckets, muck chutes as well as belt conveyors or transport vehicles provide an efficient removal of the excavated material.

![Figure 2.5. Single shield TBM with segmental lining](source: www.herrenknecht.com)

In the Edicara sandstone and the blue clay formations in Estonia an active face support in the TBM is required. There either a Mixshield or EPB Shield TBM is deployed for tunnel construction.

The tunnel is lined single-shell with a segmental lining. The lining is composed of pre-cast concrete segments which form individual rings. Each ring is normally composed of six segments and one key stone with conical shape. The segments are approx. 60cm thick and form a ring of 1.8 to 2m length. The segmental lining is installed few metres behind the face of the TBM under the protection of the shield of the TBM. When leaving the shield, the segments are stepwise backfilled with pea gravel or mortar. In this way, the shield (temporary) and the segmental lining continuously support the tunnel circumference which minimizes the risk of geological hazards like for instance falling rock.
The ring is designed against the rock and water pressures. Gaskets are used in both the transverse and longitudinal joints between the concrete elements to ensure the water tightness of the lining. With a vertical alignment of some 215 m below sea-level the water pressure will exceed 20 bar. There are already several references of TBM drives under similar high water pressure like Oslo Ski/Follobanen (Norway, 33 bar), Le Perthus Railway Tunnel (Spain, 18 bar), Hallandsastunnel (Sweden, 15 bar) or Arrowhead Feeder (USA, 22 bar). Should it become necessary, rock grouting works can be executed directly from the TBM in order to reduce rock permeability and thus also the water pressure.

The segments are produced in a segment production plant on the various rig areas or are transported from a centralized production plant to the various sites. The pre-casting of the segments results in a production of high quality concrete and efficient quality assurance.

For excavation of the cross passages, cross overs or rescue stations and intermediate accesses drill-and-blast technique is applied. Rock bolts and shotcrete are used as rock support. To reach water tightness a waterproof membrane and a secondary lining is installed, the inner lining is made of cast in place concrete.

2.2.1. Construction time schedule

For the calculation of Finest construction time schedule, the following assumptions were made:

- Working hours: 24/7
- Working days per year: 336
- Working days per month: 28

and, based on excavations rates of TBMs in similar rock and ground formations, for the advance rates

- Shield TBM: 15 meters per day
- Mixshield/EPB: 10 meters per day
The number of working days per year is calculated on the basis of 365 days per year by taking into account 14 days of Christmas holiday, 8 public/national holidays and 10 additional days for urgent maintenance works.

At the beginning of each tunnel drive, it is well known that advance rates are lower (so-called learning curve). In order to address this fact, only 50% of the average advance rates were taken into account in the calculation (represented by different gradients of curves at the starting areas in Figure 2.7 below). As time-consuming grouting works may be required at the transition point from one to another geological zone or in sections along the tunnel alignment with low rock cover, a reduced advance rate is also applied for this sections.

There are two intermediate access points from which the tunnel is constructed in two directions each. Thus, Finest link can be divided into the following construction sections/tunnel drives:

- drive 1: Estonian portal to the north (16.4 km)
- drive 2: artificial island Estonian side to Estonian coast (16.2 km)
- drive 3: artificial island Estonian side direction north (17.8 km)
- drive 4: artificial island Finnish side direction south (17.8 km)
- drive 5: artificial island Finnish side to Helsinki main railway station (17.3 km)
- drive 6: Finnish portal to Helsinki main railway station (21.9 km)

The excavation material from the Finnish onshore TBM drive (section 6) in crystalline bedrock is used for the construction of the artificial islands, thus this section needs to be built first. Before the tunnelling starts all the installations have to be brought to the site and preparation works at the portal need to be done. 15 months are assumed for this work and during this time the TBM is manufactured and delivered to the site.

The excavation material of tunnel drive 1 in blue clay and sandstone cannot be used for the creation of the artificial islands. Hence, this TBM drive (Mixshield or EPB shield TBM) can run more or less independent of the others. Tunnelling this section takes about 5.25 years.

The construction of section 6 lasts approx. 4.5 years. In parallel the two artificial islands are created so that no excavation material needs to be stored (temporarily) around Helsinki. Since the excavated volume of material of TBM drive 6 is not enough additional material of the tunnel drives 2 to 5 is required for approx. 9 months in order to finish the island construction. However, for the construction of the intermediate access infrastructure, only parts of the islands need to be finished. It is assumed that shaft sinking resp. the excavation of the access tunnel can begin around 3 years after the start of the island creation. The shaft sinking takes around 6 months the construction of the inclined access tunnel around 9 months. After reaching the tunnel level caverns for the TBM assembly need to be built (15 month). The excavation of additional infrastructure in this area takes another 3 months. The TBM is assembled within approx. 3 months and can start the excavation.

Based on the given advance rates for a single shield TBM, drives 2 and 3 take approx. 3.75 years each, drive 4 approx. 4.0 years and TBM drive 5 around 3.75 years to be built. The disassembly of the TBM at the breakthrough has to be studied in detail in the next planning phase, for the time being 6 months are considered as sufficient.

After the completion of the tunnel construction, 3 years are taken into account for the installation of the railway equipment and approx. 1 year for tests and commissioning.

The entire construction time till the regular railway operation could start is estimated to be 183 months which means (according to annual breaks etc.) approx. 15.25 years. No buffer time is included in this calculation.
Material management and logistics is a complex matter: it is time dependent, includes treatment of the raw excavation material for different usages of the Finest project itself and third party usages, land-fill localisation and transport means and links etc. The financial aspects of the re-use of the excavated material and the whole material management for Finest have no reliable base and are only referring to other similar large infrastructure projects. In a next phase, it is crucial to study this matter in detail and to design a logistic concept taking into account all the different aspects, requirements and boundary conditions of Finest project.

In regard to the usage of the excavated material the benchmark reference of the Gotthard base tunnel shows that 22% of the TBM excavated material can be used for concrete aggregates. As the total excavation volume of Finest link is almost 23.1 Mio m$^3$, this is equal to approx. 5.1 Mio m$^3$. Additionally, approx. 7.6 Mio m$^3$ or 33% of the excavated material are required for the creation of the artificial islands. The rest of the material, around 10.4 Mio m$^3$ (45%) can to be recycled or deposited by third parties, for instance as filling material for cultivation. The excavated rock is of good quality so it can be assumed that most of it can be sold.
2.3. Ventilation

2.3.1. Basics and Preconditions

The Finest tunnel does not have an overburden which is influencing the tunnel climate in a negative way. Therefore, heat transfer from the tunnel walls and consequently cooling requirements of the tunnel air is not an issue.

The tunnel will be operated with electrically powered engines only. Diesel engines are not foreseen. Thus, there are no exhaust gases from train operations. Fresh-air supply to dilute and remove exhaust gases is not required.

Due to the length of the Finest tunnel considerable portal pressure differences are possible caused by meteorological effects.

2.3.2. Normal operation

Tunnel ventilation during normal operation is required to remove dissipated heat from tunnel equipment and trains, as well as to ensure a minimum air exchange. Thus, the ventilation requirements during normal operation are lower than in long Alpine tunnels with considerable need for cooling (high rock temperature heats up tunnel air).

The tunnel will be naturally ventilated during normal operation. The piston effect from circulating trains will result in an air flow in driving direction of the trains.

Jet fans are required at least at both portals to support the induced air flow in cases with a high adverse meteorological pressure as well as for fresh air supply during maintenance.

If necessary, the smoke extraction and fresh-air systems of the rescue stations can be used for air exchange to remove polluted air from the tunnel. This may be necessary in case of heavy maintenance works in the tunnels.

2.3.3. Emergency operation

In case of emergencies, tenable conditions shall be preserved as long as possible in the incident tube. The service tunnel and the cross passages shall be protected against penetration of smoke.

Preservation of tenable conditions in the incident tube is based on the following approach (note that only two rescue stations can be equipped with a smoke-extraction system, see chapter 3.4):

- If train stops in a rescue station with smoke-extraction system: Smoke extraction and symmetrical longitudinal air flow to the extraction point
- If train stops in a rescue station without smoke extraction or at any other location in the tunnel: keep longitudinal air velocity below 1.5 m/s and extract smoke from tunnel at the next rescue station

Protection of service tunnel and opposite tunnel tube is based on the following approach:

- Fresh air supply to the service tunnel in order to over-pressurize service tunnel and cross passages against the incident tube
• Activation of jet fans at portals of parallel tube towards the tunnel center in order to over-pressurize the parallel tube against incident tube.

A detailed analysis of the ventilation concept needs to be executed in the next project phase.

2.4. **Additional functions of the tunnel**

2.4.1. **Current design concept / State of the art**

The main purpose of Finest link is to transport passengers and goods. In addition to that, the tunnel offers several other possibilities for connecting the two countries.

The chosen tunnel layout of Finest link with a separate service tunnel offers lots of space for additional functions such as for:

• Communication in general
• Telecommunication
• Electricity
• Gas and oil

For placing cables or smaller tubes in a tunnel, several options are feasible. For instance, they can be situated in cast in cable tubes and cable ducts in the invert segment. Another option could be a utility duct below the carriageway or simply by placing cable structures along the site wall of the service tunnel.

In the regard to additional functions, also technical, safety and legal issues need to be investigated, for instance explosive risks, environmental damages or the requirement of a physical separation of different cables.

The next phase is to be used for a survey on the demand of additional functions as well as to address issues mentioned above and to detail the service tunnel design.

2.4.2. **New technologies and smart services**

Currently smart solutions and disruptive technologies pop up in lots of different fields. Also for mass transportation systems, innovative and more efficient solutions can be expected within the next few years.

A new developed concept for both passenger and cargo transportation is Hyperloop, a tube-based system working with magnetic levitation and propulsion in evacuated (airless) tubes.

Thinking of more traditional tunnel tubes, the company *Arrivo* presents a so-called one platform solution (see Figure 2.8 below). The using this service in a tunnel link, several needs can be addressed by only one smart solution.

*Figure 2.8. Arrivo’s one platform solution (copyright Arrivo, http://www.arrivo-loop.com/*)
Having the aim to make travel fast, seamless and green, new technologies and smart services should be considered within the next project stages of Finest.

3. **Tunnel safety management**

3.1. **Safety goals**

Safety goals define the level of safety to be reached and they also define the residual risks to be accepted by the tunnel operator.

Safety goals are defined for the protection of:

- passengers and staff
- freight
- infrastructure (availability)

The minimum safety goals are defined by relevant regulations and by the “state of the art” of safety solutions for long rail tunnels:

- National normative documents of Finland and Estonia
- International accepted national standards: NFPA-130
- Relevant recommendations issued by international organizations such as UIC and ITA-COSUF
- The safety standards established by the new very long tunnel in the Alpine area

The TSI represent an international standard which has to be respected by all European countries. It specifies the minimum safety requirements for Finest link. National standards of Estonia or Finland may prescribe a higher safety standard for certain subjects which then override the TSI.

In case of differing requirements between the two countries, the most demanding one will be selected and applied to the whole tunnel.

The new long railway tunnels in the Alps represent the most relevant reference for the state of the art for very long railway tunnels. The safety standards adopted there are significantly higher than the minimum requirements stated in the TSI. Considering the exceptional characteristics of Finest, this should be considered as a minimum reference level.

3.2. **Safety principles**

3.2.1. **General principles**

A tunnel safety concept consists of prevention, mitigation, escape (self-rescue) and rescue. As illustrated in Figure 3.1, the most effective way to reduce the risks is prevention. Preventive measures reduce the occurrence of incidents. Mitigation, evacuation and rescue reduce the consequences of incidents and are less effective.
Figure 3.1. Layers of defense for the promotion of safety in tunnels, starting with the most effective layer to consecutively reducing the residual risk (according to TSI SRT)

Figure 3.2. Overview of railway risks and mitigation measures (from TSI SRT)
3.2.2. Safety principles for train operation

Based on the above mentioned general principles, some tunnel specific principles for operation are deduced. This starts with prevention. Only trains in proper operating conditions are allowed to drive through the tunnel (trains are checked by sensors for indications of fire, displaced goods, etc. before they enter the tunnel).

In case of fire, the following principles for mitigation are adopted in tunnels. The priorities in case of fire on a passenger trains are:

1. Stop at the next rescue station or reach the tunnel portal
2. Prevent uncontrolled stop at any location in the tunnel

The priorities in case of fire on freight trains are:

1. Exit the tunnel if possible
2. Stop only at suitable locations (i.e. dedicated freight-train emergency stop points, e.g. sections equipped with fixed firefighting system) if it’s not possible reaching the tunnel exit
3. Prevent endangering passenger trains
4. Prevent as much as possible damages to the tunnel infrastructure

In the Finest link the "trains help trains" principle is applied, which means:

- Interventions are done by train
- Passenger evacuation is carried out by train

Use of tunnel tubes in case of emergency:

- Self-rescue towards the cross passages (safe haven) and the parallel safe tunnel tube where people wait for rescue
- Evacuation by train through the safe tunnel tube
- In case of fire intervention through the safe tunnel tube only
- In case of “cold” incidents both tunnel tubes can be used for intervention
- No traffic trains or maintenance vehicles access the service tunnel in case of emergency

3.3. Qualitative identification of risk

Finest is a tunnel with a length of over 107 km and most of it is a subsea tunnel. This tunnel is characterized by some specific risks which are addressed in the following:

- Intervention and self-rescue: in case of an incident intervention forces need up to 1.5 h to reach to the incident location. Persons in the tunnel have to rescue themselves and cannot wait for support by the rescue services
- Sub-sea tunnel: the construction of direct connections to the surface, as emergency exits or accesses for rescue or for smoke extraction / fresh air supply is seen as impossible. Fresh-air supply and smoke extraction have to be arranged along the traffic tunnels or service tunnel.
- Mixed traffic, including transport of dangerous goods, implies a substantial risk of very large fires (higher heat-release rate etc.) and thus increases the requirements on fire protection.

Further characteristics of very long tunnels need to be considered:
• Several trains circulate through the tunnel system at any time. In case of relevant incident train management is an important issue in order not to extend the safety threats to further trains.
• Only rolling stock with electrical traction is allowed to circulate.

3.4. Safety measures

Infrastructural measures and operational or organizational measures are both important to reach the safety goals. The most relevant infrastructural measures to reach an acceptable safety level according to the state of the art are as follows.

3.4.1. Rescue stations for passenger trains

In case of Finest link only trains of TSI category B (minimum running time of 20 minutes at 80 km/h in case of fire) are allowed to enter the tunnel. Therefore, safe points for self-rescue and intervention (so called rescue stations) are required at maximum intervals of approx. 20 km.

For the Finest link a combination of rescue stations and regular underground stations will provide the required safe points. Four rescue stations are built along the subsea section of the tunnel. Along the Finnish mainland section, three regular stations (Helsinki main railway station, Pasila and Vantaa Airport) serve as safe points.

Rescue stations along the subsea tunnel section and regular stations along the mainland tunnel section are designed only for passenger trains. Freight trains shall not stop in these stations in case of a fire emergency. The fire load (Heat Release Rate) of freight trains can reach values which are 3 to 5 times the fire load of a passenger train and could severely damage the tunnel infrastructure. Freight trains shall stop in specially equipped dedicated freight-train emergency stop points.

3.4.1.1. Equipment of rescue stations

The generic lay-out parameters and the equipment of the rescue stations are as follows:

- Length about 450 m (maximum passenger-train length +50m)
- Minimum net clear surface in safe area inside the service tunnel (secured waiting area for train occupants): 1'000-1'500 m²
- cross passages (emergency exits) every 50 m
- enlarged walkway / small platform
- fresh air supply to protect the service tunnel and cross passages against inflow of smoke and guarantee user comfort
- good lighting
- communication facilities (emergency phones and loudspeakers)
- extinguishing water for fire fighters
- Drinking water
- First-aid kits

Two of the four rescue stations are located in a subsea area where no connection to the surface can be created. Thus a smoke-extraction system to maintain tenable self-rescue conditions and limit smoke propagation cannot be realized in these stations. Instead of a smoke-extraction system, these two rescue stations are equipped with fixed firefighting systems (FFFS) similar to solutions which have been applied in the Channel tunnel. A FFFS system limits fire development, heat release rate, smoke production and fire propagation along the incident train. In other words, it provides sufficient control of fire until the intervention forces arrive. It eases the access to the fire for the intervention
forces and prevents serious damage to the tunnel infrastructure. In the next project phase an in deep analysis shall clarify if it is worth to install a FFFS in all rescue stations.

The other two rescue stations are located at the two intermediate access points and allow for the construction of an exhaust stack. These two rescue stations will be equipped with a smoke-extraction system according to the international state of the art.

3.4.1.2. **Equipment of underground stations**

Underground stations cannot be compared with rescue stations. Underground stations are designed for train stops and exchange of passengers. Therefore, they provide usually high capacity for self-rescue and have typically a high standard for lighting, communication, firefighting equipment, etc.

A crucial safety element is the smoke-extraction system. This system is implemented not only for providing good self-rescue conditions for the passengers of a possible incident train, but also in order to protect other persons and the infrastructures connected to the underground station. Only a smoke extraction system can prevent smoke propagation to the other levels and buildings (airport, main train station) above the underground station.

3.4.1.3. **Bypass tunnel for underground stations**

Underground stations are connected to further buildings and infrastructures and could be occupied by a high number of persons on the platforms or within the building. Freight trains shall therefore be separated from passenger trains in these areas. In consequence, in each station bypass tracks for freight trains are built which are separated from the passenger tracks by a dividing wall. As the tunnel is open for hazardous goods the separation of freight trains and passenger trains in the underground stations is an important preventive measure.

3.4.2. **Emergency stop points for freight trains**

Freight trains, which are not able to leave the tunnel, shall stop at dedicated emergency stop points. These stop points are designed to withstand a possible freight train fire (e.g. FFFS, higher level of thermal protection, etc.).

Emergency stop points for freight trains have limited influence on the tunnel design as they do not require the construction of large infrastructural elements as it is required for a smoke extraction system or self-rescue facilities for a large number of passengers.

3.4.3. **Cross passages**

Cross passages are the primary measures to facilitate self-rescue in case of a forced train stop in the tunnel. They connect the two tunnel tubes with the service tunnel. The service tunnel serves as temporary safe haven. The cross passages allow to evacuate the passengers from the incident tube within a short time span to the temporary safe haven.

The “train helps train” principle requires that passengers and personnel wait in the service tunnel to be rescued. Clearly indicated collection points along the service tunnel, equipped with loudspeakers, means for communication and first aid shall support an efficient self-rescue process.

Cross passages are located at intervals of 333 m and are equipped with:

- a fire-protection door on the tunnel side (door width > 1.4m)
• fresh-air supply through the service tunnel in order to set cross-passages and service tunnel on overpressure and protect them against smoke.

Further measures to facilitate self-rescue in case of forced train stop in the tunnel:

• longitudinal ventilation in tunnel tubes (jet fans)
• walkway along tunnel on the service tunnel side with a width of 1.0-1.2 m and handrail
• emergency lights, signing and communication

Cross passages are the most important safety measure to mitigate the consequences from fire incidents with train stop at an undesired position, outside of a rescue station. They need proper design and adaptation to the specific requirements of the Finest tunnel.

4. Train operation concept

The FinEst Link is a natural prolongation of the Rail Baltica line, which will run through the Baltic countries and – via Poland – connect to central/western Europe. The Rail Baltica project is currently switching over from planning to design phase (Rail Baltica official webpage) and will, according to present time plan, be completed in year 2026.

Due to the interoperability with Western Europe, Rail Baltica will be built with the 1435 mm rail-gauge. The current rail infrastructure in the Baltic countries is built according to the Russian 1520 mm gauge, in Finland 1524 mm railway-gauge is used. In order to gain rail-access to Western Europe and to the Baltic countries (without the need to travel via Russia), the recommendation is to also build FinEst Link according to the 1435 mm gauge.

The traffic through the tunnel is planned to comprise:

• Passenger trains (shuttle traffic) from Helsinki Airport (via Pasila and Helsinki central) to Ülemiste station. Dedicated rolling stock for FinEst Link.
• Car & truck shuttles i.e. rolling motorway trains for trucks and cars running between certain terminals on the Finnish and Estonian side. Dedicated rolling stock for FinEst Link.

Conventional freight trains with conventional, covered goods wagons and/or intermodal wagons for containers, swap bodies etc. This rolling stock is general and can run all the way to Western Europe and is therefore not dedicated/tailor made for the FinEst Link.

4.1. Passenger and cargo forecasts and proposed concepts

This section presents the forecasts for passenger and cargo train traffic as well as proposed concepts for train operation. In the development of an operation concept input from WP2 regarding passenger and freight volumes have been used as well as assumptions regarding volume distribution, train properties and train operation.

4.1.1. Passenger trains

The information and assumptions that underlie the proposed concept for passenger trains are presented in Table 4.1 below.
Thurs- and Fridays busiest days during the week. These are chosen for dimensioning.

September (= 30 days) highest volumes per day, chosen for dimensioning.

Busiest direction hour by hour (Helsinki - Tallinn or vice versa) chosen for dimensioning.

**Assumptions, train properties and train operation**

- Top speed: 200 km/h
- Only seated passengers
- Fill ratio of trains at peak hour: 90%
- Train length: 200 metres for single train set (capacity approx. 500 passengers) or 400 metres for two multiple coupled sets (max)
- Traffic with one or two train sets enables capacity matching to demand and improves possibilities to even out the frequency per hour (= a stable and predictable time table).

If number of departures per hour with single train sets >2, multiple coupled train sets are used.

Theoretical number of trains per hour finally adjusted manually to recommended frequency.

**Table 4.1: Information and assumptions for passenger trains**

Table 4.2 and Table 4.3 below show the number of passengers per category of trips on average week days.

**Table 4.2: Number of passengers 2050 per category during average week day, Tallinn-Helsinki (Source: WP 2)**

**Table 4.3: Number of passengers 2050 per category during average week day, Helsinki-Tallinn (Source: WP 2)**

**Results/recommendations passenger train operation**

The required number of trains every hour is calculated from the passenger demand forecast (from WP2) and is based on the busiest (dimensioning) direction hour by hour. Quite naturally, the time table for the less busy direction must be equal in order to maintain the rolling stock balance between the Helsinki and Tallinn starting points.

The tables (Table 4 - Table 6) below show the calculated (theoretical) number of passenger trains per direction hour by hour for weekdays, Saturdays and Sundays (the grey rows). As can be seen, these values vary quite much over the day, from less than one train per hour during early morning and late night, up to more than five at 16:00 hours.

In order to reduce the impact of the travel demand variation, the use of one or two train sets can to some extent enhance a more balanced time table. The white row in the tables below indicate the
calculated/recommended use of single or multiple coupled train sets over the hours of the day. The orange rows further below indicate the theoretical number of necessary trains every hour based on the use of single or double train sets.

Final rows ("Manual suggestion") show the recommended number of trains per hour and direction, and is not just a mathematical round-off of the figures in the rows above, but an adjustment to what should be most functional. For instance, 5 a.m. during weekdays (see Figure 4.4 below) the figures say that one train during that hour should be sufficient, but two trains are recommended to keep a stable time table and a satisfying level of service while operational. Similarly, Sunday mornings between 9 and 10 o’clock, one train per hour should be enough from demand perspective, but the recommendation is two trains in order to have the same Satur- and Sunday time table.

Furthermore, the recommendation is – based on the very low demands between 1 and 4 a.m. – that the passenger train operation should be stopped during those hours. With regards to those low night-time travel demands, a 24 hour operation is not justifiable from a cost-revenue point of view. It should also be pointed out that, since the majority of city metros are closed a few hours during nighttime, it is reasonable that FinEst Link is partially closed too. Additionally, the tunnel Link is rather a regional-international train connection than comparable to a metro system, which makes it even more realistic that is is non-operational for a few hours. The train-stop also opens a time window enabling maintenance of the rail-infrastructure and equipment in the running tunnels, which is very important for the functionality of the system over time.

Thanks to the variable capacity provided by the use of single or dual train sets, a stable train table can be achieved. Apart from peak-hours in the morning and afternoon – where three trains per hour are running – the normal weekday operation is constituted by two trains hourly until late evening where the traffic is reduced to one per hour. For Saturdays and Sundays, two trains per hour are recommended during the entire day, 9.00-18.00, and one train per hour before and after this time interval.

Table 4.4: Monday to Friday, number of trains per hour and direction

| Time | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
| Max weekdays | 3 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| # trains per hour | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Manual # trains above | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

Table 4.5: Saturday, number of trains per hour and direction

| Time | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
| Max Saturdays | 3 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| # trains per hour | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Manual # trains above | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

Table 4.6: Sunday, number of trains per hour and direction (departures at 9 a.m. are harmonized with Saturday => same traffic as Saturday)
4.1.2. Car & truck shuttles

Transportation of cars (automobiles) and trucks is planned to be done in the same type of rolling motorway trains (shuttles). These 750 meter trains consist of two locomotives and approx. 720 meters wagon set (whereof potentially two or three wagons for car passengers or truck drivers). The wagons are open in both ends to allow driving through. Furthermore, they are covered with a cage-structure (see Figure 4.7 below), which is advisable from a safety perspective. For instance, the cage prevents a loose trailer tarpaulin from fluttering widely, or – in worst case – to get stuck in some fixed equipment/installation in the running tunnel.

Figure 4.7: Rolling motorway wagons (source: Eurotunnel)

The recommendation is to use the same rolling stock for cars as for trucks. This dual-use – in combination with the fact that the loading/unloading terminals are preferably common for cars and trucks – is the best way to deal with uncertainties and variation in demand and to achieve a high utilization of the rolling stock. With common terminal and rolling stock, a sudden change in demand for cars and trucks respectively doesn’t have to influence the train operation too drastically. A slot time for cars could be switched to a departure for trucks instead and vice versa. In this way, the train and terminal operation is less sensitive to variation than if one or both of rolling stock and terminals are unique/for single-use.

4.1.3. Car shuttle traffic

The information and assumptions that underlie the proposed concept for car shuttle trains is presented in Table 4.8.

<table>
<thead>
<tr>
<th>Input from WP2</th>
<th>Annual volume of cars: 554 000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Directional distribution</td>
<td>Directional distribution: 50/50</td>
</tr>
<tr>
<td>Assumptions, travelling distribution</td>
<td>Weekly distribution: Evenly distributed over the week</td>
</tr>
<tr>
<td></td>
<td>Number of operational weeks per year: 50</td>
</tr>
<tr>
<td></td>
<td>Number of operational days per week: 7</td>
</tr>
<tr>
<td>Assumptions, car shuttles</td>
<td>Car shuttle handling co-located with truck handling at rolling motorway terminal.</td>
</tr>
<tr>
<td></td>
<td>Cars assumed to be prioritized before trucks on day time slots</td>
</tr>
<tr>
<td></td>
<td>Max waggon length: 700 metres¹</td>
</tr>
<tr>
<td></td>
<td>Utilization/fill ratio: 75 %</td>
</tr>
<tr>
<td></td>
<td>Automobiles per train carriage: 3</td>
</tr>
<tr>
<td></td>
<td>Passenger carriers per train: 3²</td>
</tr>
</tbody>
</table>

¹ Max train length of 750 metres (due to steep Z-alignment) including two locomotives gives a max waggon length of 700 metres
² If unnecessary, train capacity increases with nine cars
Table 4.8: Information and assumptions for car shuttles

Results/recommendation

With the prerequisites given above, the number of daily trains per direction need to be approximately 11 dedicated for cars (car shuttles). The travel demand for cars is assessed to be mainly during morning and afternoon-evening hours. During the mid-day hours the demand is expected to be lower.

4.1.4. Freight traffic – truck shuttles and conventional freight trains

Below in Table 4.9 are the assumptions presented, on which the proposed traffic of truck shuttles and conventional freight trains is based.

<table>
<thead>
<tr>
<th>Input from WP2</th>
<th>Total transport 2050 (thousands of tonnes): 4 200</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Direction Est-Fin: 1 600</td>
</tr>
<tr>
<td></td>
<td>Direction Fin-Est: 2 600</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Assumptions, freight distribution</th>
<th>Tonnage distribution 2050 between truck train (rolling motorway) and conventional: Truck shuttles 70%, freight trains 30%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of operational weeks per year: 48</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Assumptions, car shuttles</th>
<th>Average wagon length needed per truck: 20 metres</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Train length (including locomotive), truck shuttle: 750 metres</td>
</tr>
<tr>
<td></td>
<td>Average load factor in dimensioning direction, truck shuttle: 75 %</td>
</tr>
<tr>
<td></td>
<td>Average load per metre train, freight train: 2</td>
</tr>
<tr>
<td></td>
<td>Train length (including locomotive), freight train: 750 metres</td>
</tr>
<tr>
<td></td>
<td>Average load factor in dimensioning direction (weight-wise), freight train: 75 %</td>
</tr>
</tbody>
</table>

Table 4.9: Information and assumptions for freight trains

Results/recommendations

Calculations based on the information above gives a transport volume of 6344 tonnes per day in the dimensioning direction (Fin-Est) for truck shuttles. The corresponding volume for freight trains is 2719 tonnes per day. This yields a recommendation for the train operation of 19 truck shuttles and 3 freight trains per day and direction.

<table>
<thead>
<tr>
<th>Transport volume (tonnes per day in dimensioning direction)</th>
<th>Truck shuttles</th>
<th>Freight trains</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theoretical number of trains per day</td>
<td>18.6</td>
<td>2.6</td>
</tr>
<tr>
<td>Recommended number of trains per day</td>
<td>19</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 4.10: Results for train operation, truck shuttles and freight trains

The truck shuttle travel demand is estimated to be fairly low during mid-day and higher during mornings and – most of all – during evenings depending on the general transportation patterns from the industry.

The conventional freight train line-hauls are probably concentrated to evening-night time and follow the general pattern: goods allocation in the afternoon, line haul in the night and distribution before noon the day after.

Below in Figure 4.11, is the total traffic volume per day illustrated and also assumed distribution over the day per train type.
As described earlier, the hourly distribution of passenger trains is based on hour by hour forecast from WP2. Such detailed forecasts have not been done/available for the three freight train types, and the presented distributions for those categories are estimated. The hours with stopped train-service, which is a window for maintenance, are also illustrated. Based on this preliminary compilation, the traffic during the busiest hours consists of up to five trains per hour and direction.

The theoretical maximum capacity of a tunnel can be defined in several ways based on different train operation models. If we assume that passenger volumes will grow 1,5 times higher than in the current passenger forecast and the hourly volume pattern is the same, it will raise the need of shuttle trains from 40 to 49 trains per each direction per day.

If we optimise the remaining available capacity on tunnel with car shuttles, truck shuttles and conventional cargo trains in same proportion it will chance amount of car/truck shuttles from 30 trains to 71 trains per each direction and conventional cargo trains from 3 trains to 18 trains per each direction. In conclusion, it can be stated that there is capacity available in the tunnel for considerably higher traffic volumes and demand. Despite the daily capacity challenge of demand at peak hours for passenger traffic and cargo (truck shuttle traffic), this should be studied closely in next planning phases.

### 4.2. Timetable construction and capacity

In the following section will the conditions for the train traffic be described, such as travel times, speed and tunnel capacity.

#### 4.2.1. Train operation conditions

The assumptions that underlie the proposed train operation are presented in Table 4.13 below.

**Table 4.12: Overview of daily traffic volumes and distributions per train type – max. capacity**

| Time | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
| Trains per direction | | | | | | | | | | | | | | | | | | | | | | | | | |

- **Passenger Trains 200 km/h**: 49
- **Car shuttle 120 km/h**: 35
- **Truck shuttle 160 km/h**: 36
- **Conventional cargo trains / 120 km/h**: 18

### Figure 4.11: Overview of daily traffic volumes and distributions per train type

As described earlier, the hourly distribution of passenger trains is based on hour by hour forecast from WP2. Such detailed forecasts have not been done/available for the three freight train types, and the presented distributions for those categories are estimated. The hours with stopped train-service, which is a window for maintenance, are also illustrated. Based on this preliminary compilation, the traffic during the busiest hours consists of up to five trains per hour and direction.

The theoretical maximum capacity of a tunnel can be defined in several ways based on different train operation models. If we assume that passenger volumes will grow 1,5 times higher than in the current passenger forecast and the hourly volume pattern is the same, it will raise the need of shuttle trains from 40 to 49 trains per each direction per day.
Table 4.13: Information and assumptions for passenger trains

As described earlier, based on the travel forecasts from WP2, necessary number of passenger trains hour by hour has been calculated and these trains have been distributed according to figure 4.11 above. Travel time calculations and time table construction have been done to clarify tunnel capacity and what number of freight trains can be fitted in every hour between the passenger trains.

The most critical part of the Link, from a capacity point of view, is the distance between Helsinki Central and the tunnel split point on the Estonian side. From this point, passenger trains solely run on the tracks to Ülemiste station and freight trains run a separate path towards the goods terminals. During this approx. 100 km journey there are no possibilities for a train to overtake another heading in the same direction.

At the stations however, there will be dedicated passenger train tracks at the platforms and outside (separated from the platforms) certain goods tracks for the freight trains. In this way, the freight trains don’t have to pass the station areas close to passengers. Furthermore, this track arrangement enables overtaking.

For the car & truck shuttle trains, travel time from Helsinki C to the split point has been calculated for both 120 and 160 km/h to analyse the capacity impact of that certain trains speed. This speed is fairly important, since the total of car & truck shuttles are so many (28 per day and direction). The conventional freight trains are – as mentioned above – limited to 120 km/h, which is a harmonization with Rail Baltica and they are few (3 per day & direction) and the capacity impact therefore much less.

As can be seen in Table 6 below, passenger trains run every 30:th minute between 6 and 7 a.m. and every 20:th minute the following hour, all according to Figure 3 above. The passenger train journey to Ülemiste takes approx. 34 minutes. In the 34 minute travel time is acceleration and retardation in connection with stations considered and included. Furthermore, it is calculated that the trains run at just below 200 km/h in most of the sub-sea tunnel length. At three points along the sub-sea tunnels there is a calculated speed reduction down to 160 km/h (including retardation and acceleration) when passing rescue stations/potential cross overs.

Three minutes after a passenger train has left Helsinki C, a shuttle train can leave Helsinki C and follow after. The shuttle train needs approx. 45 minutes to reach the split point (max 120 km/h). How many shuttle trains that can be fitted in between the passenger trains has been tested for the two different hours. During the first hour, three shuttle trains can run between the first and the second passenger train. This is indicated by the blue and green figures in Table 4.14, where the third shuttle train arrives at the split point more than three minutes before passenger train number two.
Between 7 and 8 o’clock there are three passenger trains, giving a 20 minute gap other traffic. Illustrated by the blue and red figures above, not even one shuttle train can run between the passenger trains during this hour. This is also well illustrated by the train graphs in Figure 4.15 below. The graphs show rather well the problem with a relatively large speed difference between the train types.

A conclusion from this is, that during hours with three or more passenger trains, there is no capacity for any 120 km/h freight trains. This situation occurs three times per day according to the time table in Table 4.14 above. If the passenger train traffic grows beyond the forecast figures, and three or more trains per hour will run most of the day, there wouldn’t be enough capacity for the totally 30 daily car & truck shuttle trains per direction.

**Table 4.14: Time table for passenger trains and shuttle trains (120 km/h)**

<table>
<thead>
<tr>
<th></th>
<th>Pass. 1</th>
<th>Shuttle 1</th>
<th>Shuttle 2</th>
<th>Shuttle 3</th>
<th>Pass. 2</th>
<th>Pass. 3 Shuttle 4</th>
<th>Shuttle 5</th>
<th>Pass. 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Helsinki Cent</td>
<td>06:00:00</td>
<td>06:03:00</td>
<td>06:06:00</td>
<td>06:09:00</td>
<td>06:30:00</td>
<td>07:00:00</td>
<td>07:03:00</td>
<td>07:06:00</td>
</tr>
<tr>
<td></td>
<td>06:01:11</td>
<td>06:04:40</td>
<td>06:07:40</td>
<td>06:10:40</td>
<td>06:31:11</td>
<td>07:01:11</td>
<td>07:04:40</td>
<td>07:07:40</td>
</tr>
<tr>
<td></td>
<td>06:01:40</td>
<td>06:05:21</td>
<td>06:08:21</td>
<td>06:11:21</td>
<td>06:31:40</td>
<td>07:01:40</td>
<td>07:05:21</td>
<td>07:08:21</td>
</tr>
<tr>
<td></td>
<td>06:29:32</td>
<td>06:59:32</td>
<td>07:00:13</td>
<td>07:00:32</td>
<td>07:00:13</td>
<td>07:29:32</td>
<td>07:49:32</td>
<td>07:50:13</td>
</tr>
<tr>
<td></td>
<td>06:29:52</td>
<td>06:59:52</td>
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<td>07:00:32</td>
<td>07:00:13</td>
<td>07:29:52</td>
<td>07:49:52</td>
<td>07:50:13</td>
</tr>
<tr>
<td></td>
<td>06:30:13</td>
<td>07:00:13</td>
<td>07:00:32</td>
<td>07:00:13</td>
<td>07:00:13</td>
<td>07:30:13</td>
<td>07:50:13</td>
<td>07:50:13</td>
</tr>
<tr>
<td></td>
<td>06:30:34</td>
<td>07:00:34</td>
<td>07:00:13</td>
<td>07:00:32</td>
<td>07:00:13</td>
<td>07:30:34</td>
<td>07:50:34</td>
<td>07:50:13</td>
</tr>
<tr>
<td></td>
<td>06:30:59</td>
<td>07:00:59</td>
<td>07:00:32</td>
<td>07:00:13</td>
<td>07:00:13</td>
<td>07:30:59</td>
<td>07:50:59</td>
<td>07:50:13</td>
</tr>
<tr>
<td></td>
<td>06:31:30</td>
<td>07:01:30</td>
<td>07:00:13</td>
<td>07:00:32</td>
<td>07:00:13</td>
<td>07:31:30</td>
<td>07:51:30</td>
<td>07:51:30</td>
</tr>
<tr>
<td></td>
<td>06:32:14</td>
<td>07:02:14</td>
<td>07:00:13</td>
<td>07:00:32</td>
<td>07:00:13</td>
<td>07:32:14</td>
<td>07:52:14</td>
<td>07:52:14</td>
</tr>
<tr>
<td>Ülemiste</td>
<td>06:34:14</td>
<td>07:04:14</td>
<td>07:00:13</td>
<td>07:00:32</td>
<td>07:00:13</td>
<td>07:34:14</td>
<td>07:54:14</td>
<td>07:54:14</td>
</tr>
</tbody>
</table>

**Table 4.15: Graphical presentation of time table for passenger trains and shuttle trains (120 km/h)**
As a consequence of the conclusion above regarding car & truck shuttles running in maximum 120 km/h, a similar calculation was made for a situation where the rolling motorway shuttles are allowed to run at 160 km/h. Below in Table 4.16 is a time table for the same hours (6 and 7 a.m.) with the same passenger train frequency, but with faster car & truck shuttles (160 km/h).

Illustrated by Table 4.16 below, passenger trains run every 30:th minute between 6 and 7 a.m. and every 20:th minute the following hour, just as in Table 4.14 above. The passenger train journey to Ülemiste takes approx. 34 minutes, as mentioned earlier. Shuttle trains need ca 35 minutes to reach the split point (max 160 km/h).

<table>
<thead>
<tr>
<th>Passenger train</th>
<th>Shuttle 1</th>
<th>Shuttle 2</th>
<th>Shuttle 3</th>
<th>Shuttle 4</th>
<th>Shuttle 5</th>
<th>Shuttle 6</th>
<th>Shuttle 7</th>
<th>Shuttle 8</th>
<th>Shuttle 9</th>
<th>Shuttle 10</th>
<th>Shuttle 11</th>
<th>Shuttle 12</th>
</tr>
</thead>
<tbody>
<tr>
<td>06:00:00</td>
<td>06:03:00</td>
<td>06:06:00</td>
<td>06:09:00</td>
<td>06:12:00</td>
<td>06:15:00</td>
<td>06:18:00</td>
<td>06:21:00</td>
<td>06:24:00</td>
<td>06:27:00</td>
<td>06:30:00</td>
<td>06:33:00</td>
<td>06:36:00</td>
</tr>
<tr>
<td>06:01:40</td>
<td>06:05:40</td>
<td>06:08:40</td>
<td>06:11:40</td>
<td>06:14:40</td>
<td>06:17:40</td>
<td>06:20:40</td>
<td>06:23:40</td>
<td>06:26:40</td>
<td>06:29:40</td>
<td>06:32:40</td>
<td>06:35:40</td>
<td>06:38:40</td>
</tr>
</tbody>
</table>

Table 4.16: Time table for passenger trains and shuttle trains (160 km/h)

Shown by the blue and green figures during the first hour, there can be up to seven car & truck shuttle trains running between passenger train 1 and 2, which should be compared with three in the situation with max speed 120 km/h. A significant capacity improvement achieved by the reduced speed difference between the train types.

The hour from 7 to 8 o’clock, there is room for at least three shuttle trains between the passenger trains (see blue and orange figures). The fourth and last shuttle train time table shows, that there is slightly less than three minutes until the passenger train reaches the split point (therefore the passenger train time is in orange).

Table 4.17 below graphically presents the train operation and the difference compared to the 120 km/h situation presented in Figure 8 above is significant.
The impact of a speed increase of 40 km/h from 120 to 160 km/h for the car & truck shuttle trains is (surprisingly) substantial. In fact, the theoretical capacity during the first hour with half-hour traffic is more than doubled (from three to seven trains). It is even more dramatic during the second hour, where there is a passenger train every 20:th minute. In this case, the rolling motorway shuttle capacity goes from 0 to 3 trains per hour. This is very important since, as indicated in Figure 7 above, it is probable that the higher demands for these shuttles – to a large extent – will vary in correlation with the passenger trains demand, i.e. be concentrated to morning and afternoon/evening time.

Results/recommendations

Based on the conclusions above, a strong recommendation is to design for car & truck shuttle traffic running at max 160 km/h. Since the rolling stock will be dedicated for the tunnel link, and not run elsewhere, and will be procured for the specific purpose, it should be possible to tailor it for those running conditions. It should be mentioned, that similar trains run at those speeds in the Eurotunnel.

4.3. Train fleet

In the following section, a short description on rolling stock needs and investments for those is presented.

4.3.1. Rolling stock for passenger traffic

Based on the train operation described in earlier section, a number of necessary train sets for upholding the traffic needs to be estimated. As indicated earlier, the travel time between Helsinki C and Ülemiste is calculated to approximately 34 minutes. Since the starting point is Vantaa Airport, about ten minutes have to be added to the 34, adding up to a total travel time of circa 45 minutes.

Below Table 4.18 shows the prerequisites on which the rolling stock size is based. The dimensioning has to consider those hours when three multiple-coupled (double) train sets are running in each direction.
For example, at 07:42 a.m. the third passenger train (07:40) has just left Vantaa Airport, but at the same time the 07:00 train has not really reached Ülemiste Station. Mathematically slightly more than three trains are in this case in active operation per direction. Additionally, two train sets (per direction) are short-term parked close to the departing station being tidied up and prepared for departure. This means that approx. 20 single train sets are operational (running or short-term parked) and in addition to these there needs to be extra rolling stock capacity enabling maintenance. The rolling stock reserve for maintenance is assumed to be 10%, which is slightly low, and the general reserve level is 15-20%. However, since this peak situation is only occurring during three hours per day and the rest of the day the practical reserve is clearly higher, it is deemed reasonable. Therefore the passenger train fleet is calculated to comprise about 23 train sets (single 200 meters).

**Investment amounts for rolling stock**

Regarding investment amounts for the rolling stock, a few benchmark examples indicate a bit over €100 000 per train meter. In these cases, the trains have been about 110 meters long and between 5 and 20 pcs have been procured at the same time. Since rolling stock for FinEst Link would encompass more than 20 train sets which are 200 meters each, the assumption is a in investment cost indication of ca €100 000 per train meter. That would call for a passenger rolling stock investment in the range of € 460 000 000.

### 4.3.2. Rolling stock for car & truck shuttle traffic

Analogue with the section above, dimensioning of car and truck shuttles is calculated similarly. The shuttles require about 35 minutes at 160 km/h from Helsinki C to Ülemiste. Since the starting point is at the car & truck terminal north of Vantaa Airport, the total travel time is estimated to be about 50 minutes.

Below Table 4.19 shows the basis for the rolling stock dimensioning. According to Figure 4.11 above, there are a few peak hours during which three shuttles per direction are running.

<table>
<thead>
<tr>
<th>Number of trains per peak hour (multiple coupled)</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel time Vantaa - Ülemiste (min)</td>
<td>45</td>
</tr>
<tr>
<td>Number of active trains per direction</td>
<td>3.75</td>
</tr>
<tr>
<td>Additional waiting at each start point</td>
<td>2</td>
</tr>
<tr>
<td>Number of train sets [200m] per train</td>
<td>2</td>
</tr>
<tr>
<td>Operational number of single train set</td>
<td>21</td>
</tr>
<tr>
<td>Additional for back-up &amp; maintenance (%)</td>
<td>10%</td>
</tr>
<tr>
<td>Total number of needed train sets</td>
<td>23</td>
</tr>
</tbody>
</table>

**Table 4.18: Assessment of passenger train fleet**

For example, at 07:42 a.m. the third passenger train (07:40) has just left Vantaa Airport, but at the same time the 07:00 train has not really reached Ülemiste Station. Mathematically slightly more than three trains are in this case in active operation per direction. Additionally, two train sets (per direction) are short-term parked close to the departing station being tidied up and prepared for departure.

This means that approx. 20 single train sets are operational (running or short-term parked) and in addition to these there needs to be extra rolling stock capacity enabling maintenance. The rolling stock reserve for maintenance is assumed to be 10%, which is slightly low, and the general reserve level is 15-20%. However, since this peak situation is only occurring during three hours per day and the rest of the day the practical reserve is clearly higher, it is deemed reasonable. Therefore the passenger train fleet is calculated to comprise about 23 train sets (single 200 meters).
Due to the 50 minute journey time, three train sets are in active operation per direction. Moreover, it is estimated that unloading and loading a train and completing all preparations for departure take about an hour. This implies, that there are three trains busy in the terminal operation. On top should be added the portion of train sets tied up in maintenance, which here is appraised to be 15 percent. Adding it all up, the estimate is a need of 15 complete shuttle train sets, which all consist of two locos and just over 700 meters of wagons (whereof up to three for passengers).

**Investment amounts for rolling stock**

Based on the € 40 million order to WBN Waggonbrau Niesky GmbH in 2016, an assumption of 17 000 €/m wagon stem has been set. In addition, locomotives (2 per train) are considered to cost approx. 4,5 M€ per pcs based on other benchmarked locomotive investments. This all add up to an investment volume of about 315 M€ for the car & truck shuttle fleet.

### 4.4. Terminals and depots

There are three infrastructural functions (terminals and depots) essential for, and directly related to, the rail operation on the FinEst Link. One is needed in Helsinki and one in Tallinn of each of the categories:

1. Passenger train depot
2. Car & Truck rolling motorway terminal
3. Intermodal terminal (road-rail/rail-rail-terminal)

On the Finnish side these functions area planned to be located north of the airport (see Figure 4.20 below), which is suitable with respect to noise and limitation regarding habitation caused by the air-traffic.

---

**Table 4.19: Estimate of car & truck shuttle fleet**

| Number of trains per peak freight hour | 3 |
| Travel time Finnish depot - Estonian depot (min) | 50 |
| Number of active trains per direction | 3.50 |
| Additional waiting (loading/unloading) at each start point | 3 |
| Operational number of single train set | 13 |
| Additional for back-up & maintenance (%) | 15% |
| Total number of needed train sets | 15,0 |

---


Figure 4.20: Planned localisation of depot and terminal functions on Finnish side

Figure 4.21 below illustrates indicative locations of the functions. The passenger train depot (common with Rail Baltica) is planned north-east of the Tallinn Airport and the car & truck terminal south-east of the airport. The intermodal terminal could either be located close to the car & truck terminal or in the Muuga area depending on what is most rational.

Figure 4.21: Indicative localisation of depot and terminal functions on Estonian side

Each of the functions will be further described below.

4.4.1. Passenger train depots

The passenger train depot has two primary functions for the passenger trains:

- Maintenance and reparation
• Short-term and over-night parking

In Estonia the assumption is, that there the passenger train depot is coordinated and co-used with Rail Baltica. That is most reasonable. Since that infrastructure will be ready earlier, it is rational that the Rail Baltica-project includes a depot dimensioned to cope with all passenger trains related to Rail Baltica and FinEst Link.

On the Finnish side, there needs to be a depot capable of handling half of the total passenger train fleet. Below in Table 4.22, is an assessment of number of necessary tracks.

<table>
<thead>
<tr>
<th>Total number of needed trainsets</th>
<th>23</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of needed single set positions per depot</td>
<td>12</td>
</tr>
<tr>
<td>Skew track capacity for skewed train distribution</td>
<td>25%</td>
</tr>
<tr>
<td>Total number of single train tracks required</td>
<td>14</td>
</tr>
<tr>
<td>Possible expansion factor due to traffic growth (1.5% per year)</td>
<td>1.5</td>
</tr>
<tr>
<td>Grand total track capacity</td>
<td>22</td>
</tr>
</tbody>
</table>

*Table 4.22: Estimated dimensioning of passenger train depot*

In the track-need assessment, two factors have been considered:

• Skewness. Theoretically there should at all times be a 50/50 physical distribution of the trains between Finland and Estonia. Due to operational issues, there can at times be an offset distribution, for which there needs to be a sufficient parking track capacity.

• Expansion. Due to the practical and necessary life time of a depot, it must have the ability to take on more traffic over time. Even if not all is built from the start, there must be a dedicated reserve for future expansion in order to avoid extra ordinarily high future costs for expanded capacity.

Both the above mentioned factors are, as can be seen in the table, considered. The estimate for a depot is tracks for 22 train sets. A conceptual layout and rough dimensions for such a depot are presented in Figure 4.23 below.

*Table 4.23: Schematic layout passenger train depot (~170 000 square meters)*

The level of investment for such a depot is calculated in the range of 25 million Euros. In that amount, costs for machinery and equipment (turning machines, wash hall, lifting etc.) inside the maintenance facility are not included.
4.4.2. Car & truck shuttle terminals

For the car & truck shuttle service, one terminal on each side is necessary. Apart from the rail infrastructure (loading tracks and marshaling yard), those terminals include an extensive infrastructure of road systems, ramps and gates etc.). This is well visualized in Figure 4.24 below.

Figure 4.24: Example Folkstone - Truck/car terminal for rolling motorway. Width 350-400 meters, length approx. 2.5 km (~900 000 square meters). The terminal in Calais has similar dimensions.

It should be pointed out, that the Folkstone terminal has a much higher traffic volume than foreseen for the FinEst Link-terminals. However, with a similar functional layout as the Folkstone terminal, the corresponding FinEst Link-terminals would have roughly the same length, but could be a bit narrower – due to a lower number of loading tracks. The necessary number of tracks for respective of the two terminals is showed in Table 4.25 below.

<table>
<thead>
<tr>
<th>Total number of needed trainsets</th>
<th>15,0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of loading tracks</td>
<td>5</td>
</tr>
<tr>
<td>Number of parking/marshalling tracks</td>
<td>4,0</td>
</tr>
<tr>
<td>Spare marshalling track capacity for skewed train distribution</td>
<td>30%</td>
</tr>
<tr>
<td>Total number of marshalling tracks required</td>
<td>5</td>
</tr>
<tr>
<td>Possible expansion factor due to traffic growth (15% per year)</td>
<td>1,5</td>
</tr>
<tr>
<td>Grand total marshalling track capacity</td>
<td>8</td>
</tr>
</tbody>
</table>

Table 4.25: Estimate of necessary track resources in car & truck shuttle terminals

As mentioned earlier, up to three shuttle trains are expected to un-/load at the same time due to the arrival-/departure frequency of 20 minutes in peak hours, and due to the expected turn-around time of about an hour. In order to withstand growth and disturbances, the recommendation is five loading tracks.

Analogue with passenger train depots, skewness and expansion have been considered regarding the dimensioning of the marshalling track capacity. The recommendation is eight tracks.

An indication of investment amount for such a terminal is around 250 M€, i.e. approx. 500 M€ for both.
4.4.3. Intermodal terminal

In order to enable transhipment of containers, trailers and swap bodies between truck and train transports and also train-train, intermodal terminals need to be established on both sides. On particularly the Finnish side, there is a need to have track connections to the terminal of both 1435 and 1520 mm gauge in order to make it possible to lift goods from a domestic freight train to an international for the FinEst Link and vice versa.

With respect to the predicted dominance of the truck shuttle trains compared to conventional/intermodal freight trains, it is advisable to build modest terminals from the start, which later on can step-wise be expanded.

It is also recommended to consider whether terminal function for handling conventional wagon loads i.e. covered and/or open wagons with – for instance – fork lift truck should be included in the functionality of those terminals.

Below in Table 4.26 is a very schematic layout of a general train terminal with some indicative dimensions.

![Generalized drawing intermodal terminal (road-rail/rail-rail-terminal)](image)

**Table 4.26: Generalized drawing intermodal terminal (road-rail/rail-rail-terminal)**

From the start the recommendation is to build two-three loading tracks and a small arrival/departure yard with three to four tracks, road system, gate and a small depot-area for containers and/or trailer.

An assessment of the investment level of terminals described above is in the range of 25 M€.

5. Strategic environmental assessment

The Strategic Environmental Assessment (SEA) of the Finnish Estonian Transport Link is reported as whole in separate SEA report. This chapter contains main results of the assessment.

5.1. General about SEA

Current SEA has been conducted as an informal procedure not following fully Estonian and/or Finnish relevant legal procedures, however best practice of SEA of infrastructure developments has been applied. SEA is based on existing studies; no new inventories or baseline studies have been performed. The SEA process has not been carried through as a separate process; it has been tightly
connected to the tasks performed within the formulation of the fixed link strategic options, locational and technical alternatives of proposed activity and especially in the case of consultation with the public, stakeholders and authorities.

5.2. Impact assessment summary

This section contains short summary of assessment results in different scales and stages. Also, recommendations for further studies and mitigation measures are given.

Climate change
- Both building as well as operation of the tunnel and related transport causes emissions of greenhouse gases resulting effects to the climate. Origin of the electricity used in the construction and operation stage has a significant effect on the CO2 emissions.
- It is advised to use Finnish electricity as much as possible in the construction and operation stage due to the significantly lower CO2 emission factor, compared to Estonian electricity. Also using energy from renewable sources and by carefully planning transport needs and material use would be a good way to mitigate impact to the climate.

Groundwater and soil
- Building and operation can cause changes in groundwater quantity and quality, also effects could be manifested in surface water and soil conditions causing changes in water regime that can in turn affect vegetation, buildings etc. The situation is more complicated in Estonian side.
- Tunnel structures should be designed considering complicated hydrogeological conditions. Ground and surface water monitoring system should be designed and executed prior to the building and continued throughout the life cycle of the tunnel.

Aquatic habitats
- Building of tunnel can cause disturbance in habitats of underwater flora and fauna due to relocation of sediments, the habitats listed in EU habitats directive will be relatively far from the artificial islands but there is a possibility of long term wider impacts (release of toxins, changes in current systems etc.) caused by building time sediments relocation and artificial islands.
- Prior to the design of the tunnel thorough study assessing affected habitats and species of both pelagic and benthic species should be conducted specifying building and operation conditions of the tunnel. The study should also help to specify specific mitigation measures necessary to mitigate harmful effects of building structures, eg. artificial islands, in the water (eg. silt curtains to prevent sedimentation flow etc). Study should also lay foundation on follow up system of monitoring of state and measures effectiveness assessment on marine ecosystems.

Terrestrial habitats and valuable objects
- For the Natura 2000 values, the possible impact is with relevance to the wider biodiversity. There will be several Natura areas and natures reserves vicinity of preferred alternative (eg. Aegna SAC) but as tunnel is situated deep underneath there will not be likely impacts.
- Impacts on the Natura 2000 conservation objectives on Pirita SAC should be avoided by selection of appropriate building technologies (bridge alternative with no building or operation time impacts on river water. Natura 2000 assessment is necessary.

Human health (noise, air pollution, vibration, radiation)
- Building time impacts of the air quality will be considerable as ships and other machinery related to the building process will be operating in but will not mean. Locally the traffic, both trains and
cars, can cause adverse effect on sensitive objects (residential and recreational areas, social objects etc). Vibration can cause deterioration of buildings. Also, the area is sensitive on radon, the tunnel structures should be designed to minimize the harmful effects to human health.

- Appropriate studies and followed assessment should be performed in further design stages to develop suitable mitigation measures and plan follow-up procedures.

**Community structure and city image**
- Construction and operation of the fixed link has positive impact on community structure and city image both in Helsinki and Tallinn metropolitan area. Fixed link brings work and enterprises, intensifies cooperation between capitals, condenses the community structure and improves the image of Helsinki and Tallinn as attractive place to live, work, study and start a business.
- Measures: Both metropolitan regions need supportive strategic measures to mitigate adverse effects (redirecting mobility from city centres)

**Exploitation of natural resources**
- Tunnel and related structures will need natural resources but on the other hand, potentially suitable material for the building (eg. roads in Estonia) will be made available.
- The special study should be launched to map the needs of Estonian and Finnish building materials needs, storage and transport capacities etc.

**Land use**
- Building process and tunnel operation can cause structural changes in land use (changing connectivity, changes in functions) in regional and local scale.

**Cultural objects**
- Changes in traffic can cause local adverse effects (vibration) on buildings and other structures.
- Vibration should be assessed within separate study and appropriate measures designed and follow up procedures provided.

**Social aspects (property, wellbeing)**
- Proposed action may cause positive changes in property value and wellbeing due to increased mobility, several economic sectors can benefit. On adverse effect, direct effects of increasing traffic can cause adverse effects on property, eg. vibration can cause structural damage on houses.

Adverse effects (vibration) should be assessed within separate study and appropriate measures designed and follow up procedures provided

5.2.1. Assessment on strategic level

Strategic impact significance was assessed concerning climate, aquatic and terrestrial habitats, community structure and city image, exploitation of natural resources, land use, social aspects and groundwater and soil. Baseline led assessment and comparison of strategic variants is presented in Table 5.1 below.

<table>
<thead>
<tr>
<th>Aspect</th>
<th>0 variant</th>
<th>0+ variant</th>
<th>Tunnel option</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate</td>
<td>Impact to the climate will remain similar to the current situation.</td>
<td>Transport demand will be increased and also CO₂ emissions will be increased.</td>
<td>Impact to the climate will be greatly determined by the origin of electricity</td>
</tr>
</tbody>
</table>
used in the construction and operation stage see (see more details in the Appendix 1). CO₂ emission of construction stage would be 434 000 t, with Finnish electricity and 1 953 000 t, if Estonian electricity is used. It would take about 43 years of tunnel operation with Finnish electricity to save equal amount of CO₂ emitted in the construction stage, with Estonian electricity used and about 9 and half years if Finnish electricity would be used in the construction stage.

<table>
<thead>
<tr>
<th>Terrestrial habitats and Natura 2000 values (see figure 5.2)</th>
<th>No significant terrestrial habitats will be affected by present ferry traffic</th>
<th>With improved ferry connection and operation of Rail Baltic there will be few impacts (coastal habitats) due to intense ferry connection (eg fast ferries)</th>
<th>With improved tunnel construction there will be few impacts due to railway system development, mainly in Estonia (Pirita SAC) where additional assessments are necessary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marine habitats</td>
<td>Marine habitats are currently affected by ferry traffic, especially fast ferries have reportedly adverse effect on e.g. Coastal habitats.</td>
<td>Marine habitats are currently affected by ferry traffic, especially further developing traffic of fast ferries have reportedly increasingly adverse effect on e.g. coastal habitats.</td>
<td>Fast ferries traffic will be likely to some extent replaced by commuter trains. Habitats listed in the EU Habitats directive will be several kilometres away from artificial islands, however building process could indirectly affect habitats (sediments relocation, changes in currents) and also pelagic species could be affected by building.</td>
</tr>
<tr>
<td>Community structure and city image</td>
<td>No changes</td>
<td>Planned improvements will induce some changes. With supportive measures the effect can be positive</td>
<td>Improved mobility causes changes in regional scale inducing changes in both metropolitan regions. With supportive measures the effect is largely positive</td>
</tr>
<tr>
<td>Exploitation of natural resources</td>
<td>No changes</td>
<td>No changes</td>
<td>Possibility to use excess rock material as a building material</td>
</tr>
<tr>
<td>Social aspects</td>
<td>The present development continues</td>
<td>Improved accessibility offers better conditions for education, employment, businesses and innovation.</td>
<td>Joined metropolitan area offers good conditions for education, employment, businesses and innovation. Fixed link influences positively also real estate investment activity. With supportive measures the effect is largely positive</td>
</tr>
<tr>
<td>Land use</td>
<td>Land use changes will be minimal and positive programs optimizing land use will be not applied (revitalization of port areas)</td>
<td>Changes in land use will be related to port and Rail Baltic development. Revitalization projects of port areas will continue, connectivity will be further developed.</td>
<td>Building process and tunnel operation can cause structural changes in land use. With supportive programs (connectivity, revitalization) the changes will largely be positive</td>
</tr>
<tr>
<td>Groundwater and soil</td>
<td>No changes</td>
<td>No changes</td>
<td>Complicated geological conditions cause uncertainties assessing probability of complications and necessity of preventive measures to ensure groundwater quality and quantity (on Estonian side)</td>
</tr>
</tbody>
</table>

Table 5.1: Baseline led assessment and comparison of strategic variants
5.3. **Assessment of locational variants on regional scale**

In Estonia Viimsi option was chosen on environmental grounds. Table 5.2 below explains why.

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Alternative A - Naissaar</th>
<th>Alternative B - Kopli</th>
<th>Alternative C - Viimsi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate</td>
<td>Shorter tunnel, less building and operation time impacts</td>
<td>Longer tunnel compared to Naissaar option means more building and operation phase impacts</td>
<td>Longer alignment than other options means most building and operation phase impacts</td>
</tr>
<tr>
<td>Terrestrial habitats</td>
<td>Naisaar is environmentally valuable (Natura 2000 SAC with 14 listed terrestrial habitat types), bridge and railway construction and operation certainly would destroy the habitats</td>
<td>Tunnel will be built underneath the Aegna SAC with 8 listed terrestrial habitat types. They will not be situated within the area of influence and therefor impact is not predicted. As tunnel would surface next to existing railway, the impact will be minimal.</td>
<td>Tunnel will be built underneath the Aegna SAC with 8 listed terrestrial habitat types. They will not be situated within the area of influence and therefor impact is not predicted. As tunnel would surface in industrial area next to existing railway the impact will be minimal. However, in Iru the alignment will be crossing Pirita SAC, the impact can be avoided with careful bridge technology selection but Natura assessment is necessary.</td>
</tr>
<tr>
<td>Marine habitats (see picture 5.1)</td>
<td>Disturbance to marine habitats (habitats 1110 sandbanks and 1170 shallows, listed in EU Habitats Directive) due to artificial islands. More disturbance to the coastal marine habitats due to building of bridge.</td>
<td>Disturbance to marine habitats (habitats 1110 sandbanks and 1170 shallows, listed in EU Habitats directive) due to artificial islands.</td>
<td>Disturbance to marine habitats (habitats 1110 sandbanks and 1170 shallows, listed in EU Habitats directive) due to artificial islands. Possible impact to animals (fishes, birds, mammals) due to relocation of sediments.</td>
</tr>
<tr>
<td>Connectivity, community structure and city image</td>
<td>Direct connection between Tallinn centre and Helsinki, connection to Rail Baltic and Muuga is weak. Impact to the community structure and city image would be greatest.</td>
<td>Direct connection between Tallinn centre and Helsinki, connection to Rail Baltic and Muuga is weak.</td>
<td>connection between Tallinn centre and Helsinki will be indirect, connection to Rail Baltic and Muuga is good.</td>
</tr>
</tbody>
</table>
### Exploitation of natural resources
- Possibility to use excess rock material as a building material, challenges in relocating and temporary storage of large quantities of material
- Possibility to use excess rock material as a building material, challenges in relocating and temporary storage of large quantities of material
- Possibility to use excess rock material as a building material

### Social aspects
- Joined metropolitan area offers good conditions for education, employment, businesses and innovation. Fixed link influences positively also real estate investment activity. Tunnel is located in centre of Tallinn
- Joined metropolitan area offers good conditions for education, employment, businesses and innovation. Fixed link influences positively also real estate investment activity. Tunnel is located in centre of Tallinn
- Joined metropolitan area offers good conditions for education, employment, businesses and innovation. Fixed link influences positively also real estate investment activity. Tunnel is located well with respect of existing/planned transport system

### Land use
- It is very difficult to connect/build railway through existing town structure and settlement from Kopli via Tallinn center to Ülemiste on surface
- Underground passenger station would not create considerable land use conflicts
- Area reservations in Harju county plan and Viimsi municipal masterplan

### Soil and groundwater
- Rock conditions to bring tunnel up to Naissaar are extremely challenging. Conditions for bridge constructions are very difficult
- It is challenging to build underground station in bad rock conditions under Tallinn center as there are thick quaternary sediments between Tallinn bay and Ülemiste lake, which are down to level 80, impact to ground water.
- More suitable construction conditions compared to other options meaning also less impact to the soil and groundwater

### Table 5.2: Comparison of different Alternatives – Estonian side

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Alternative A</th>
<th>Alternative B</th>
<th>Alternative C</th>
<th>Alternative D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate</td>
<td>Greater negative impact due to longer tunnel length caused by FinEst &amp; Airport Link tunnel reaching to city of Kerava.</td>
<td>Greater negative impact due to longer tunnel length caused by the separate freight tunnel to Vuosaari.</td>
<td>Greater negative impact due to longer tunnel length caused by the separate freight tunnel near Helsinki region.</td>
<td>Lesser negative impact due to being alternative with the shortest tunnel.</td>
</tr>
<tr>
<td>Terrestrial habitats and Natura 2000 values</td>
<td>No major conflicts with valuable terrestrial habitats or Natura values. Depots and terminals are located in unbuilt areas.</td>
<td>Possible significant negative impact to the Natura area of Mustanvuoren lehto ja Östersundomin lintuvetet. Passenger</td>
<td>No major conflicts with valuable terrestrial habitats or Natura values. Depots and terminals are located in unbuilt areas.</td>
<td>No major conflicts with valuable terrestrial habitats or Natura values. Depots and terminals are located in unbuilt areas.</td>
</tr>
</tbody>
</table>

In Finland D option was chosen on climate, land use and environmental grounds. Table 5.3 below explains why.
<table>
<thead>
<tr>
<th>Marine habitats</th>
<th>Disturbance to marine habitats due to artificial islands.</th>
<th>Disturbance to marine habitats due to artificial islands.</th>
<th>Disturbance to marine habitats due to artificial islands.</th>
<th>Disturbance to marine habitats due to artificial islands.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connectivity, community structure and city image</td>
<td>Great positive impact on connectivity and city image. The community structure in metropolitan area will condense.</td>
<td>Great positive impact on connectivity and city image. The community structure in metropolitan area will condense.</td>
<td>Great positive impact on connectivity and city image. The community structure in metropolitan area will condense.</td>
<td>Great positive impact on connectivity and city image. The community structure in metropolitan area will condense.</td>
</tr>
<tr>
<td>Exploitation of natural resources</td>
<td>Longer tunnel length will cause more use of natural resources</td>
<td>Longer tunnel length will cause more use of natural resources</td>
<td>Longer tunnel length will cause more use of natural resources</td>
<td>Shorter tunnel will cause less use of natural resources</td>
</tr>
<tr>
<td>Social aspects</td>
<td>Joined metropolitan area offers good conditions for education, employment, businesses and innovation. Fixed link influences positively also real estate investment activity. Tunnel is located well with respect of existing/planned transport system</td>
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<td>Joined metropolitan area offers good conditions for education, employment, businesses and innovation. Fixed link influences positively also real estate investment activity. Tunnel is located well with respect of existing/planned transport system</td>
</tr>
<tr>
<td>Land use</td>
<td>Terminal location north of Kerava is unbuilt and agriculture area.</td>
<td>Due to ongoing land use planning (Östersundom masterplan), Natura 2000 areas and other environmental aspects, allocating facilities to north of Vuosaari is challenging. The green corridor from S to N is stated in Uusimaa regional plan. Thus, area for FinEst facilities should be allocated from residential land use, which is contrary to city of Vantaa’s development plans.</td>
<td>Aircraft noise areas can be used for FinEst facilities</td>
<td>Aircraft noise areas can be used for FinEst facilities</td>
</tr>
<tr>
<td>Soil and groundwater</td>
<td>No construction in groundwater areas important for water supply. Underground construction can have effect on groundwater level and quality.</td>
<td>No construction in groundwater areas important for water supply. Underground construction can have effect on groundwater level and quality.</td>
<td>No construction in groundwater areas important for water supply. Underground construction can have effect on groundwater level and quality.</td>
<td>No construction in groundwater areas important for water supply. Underground construction can have effect on groundwater level and quality.</td>
</tr>
</tbody>
</table>

Table 5.3: Comparison of different Alternatives – Finnish side
5.4. Assessment of technical variants

Comparison of tunnel schemes is presented in Table 5.4 below. It contains also comparison of artificial island variants.

<table>
<thead>
<tr>
<th>Aspects</th>
<th>Bored tunnel variants</th>
<th>Submerged tunnel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material management</td>
<td>The construction material can be for most part obtained from the excavated material. The excess material can in principle be reused. For instance, the road construction in Estonia has chronic material shortage of good building material.</td>
<td>The submerged tunnel option is least favourable as the building material should be taken from elsewhere and this will cause additional environmental burdens as viable sources could be a far (sand for the concrete on Estonian side, for instance). Also, submerged tunnel option would not provide any relief on the construction material shortage on Estonian side.</td>
</tr>
<tr>
<td>Building phase impacts</td>
<td>The underground excavation process of the bored tunnel variants would have some impact to the groundwater quality and availability, especially in Estonian side where geological conditions are more complicated. Impact on the Aegna Landscape reserve Natura 2000 area can be avoided by careful alignment of the tunnel. The bored tunnel variants will have impact by establishing intermediate boring points in the sea by establishing vertical shafts (lesser impacts to seabed but larger by transport of material to the storage places) or artificial islands (more impacts to seabed and lesser by transport of materials to the storage places on land).</td>
<td>With submerged tunnel option where in addition to the groundwater complications and Natura issues there would be considerable impact to the benthic habitats as substantial areas of the seabed should be cleaned and sediments relocated. Also building process would mean considerable disturbance to the aquatic ecosystems.</td>
</tr>
<tr>
<td>Impact to the third parties</td>
<td>(Adverse) impact to third parties will be minimal</td>
<td>Impact will be manifested mainly on submerged tunnel option to the limited operation of ships.</td>
</tr>
</tbody>
</table>

Table 5.4: Comparison of tunnel schemes

5.5. Conclusions and recommendations for further studies

Conclusions
- Building time carbon footprint of tunnel will be considerable. Origin of the electricity used in the construction and operation stage has a significant effect on the CO2 emissions.
- Transport and handling of excavated material is a challenge
- Maintenance and logistic nodes need land and access that causes direct and indirect impacts
- Impact to the underwater habitats will likely be considerable, especially in the case of larger artificial islands
- Indirect and social impacts need further studies and appropriate supportive measures
Need for further studies

- Study of impacts to the marine ecosystems
- aquatic plants, invertebrates, fish, sediments, water quality and flow
- Study on maintenance and rock deposit site selection
- Natura 2000 study (Pirita SAC)
- Study of indirect and cumulative impacts of tunnel to the Tallinn and Helsinki metropolitan regions
- Study of social and socio-economical impacts of tunnel.

6. Economic and financial feasibility study

Cost estimation for Finest Link is based on chosen technical solutions and benchmark cost comparison on same type of projects. During Feasibility Study planning process there is made decisions to choose different technical solutions for a base to investment cost calculation. On table below is describing each cost component, chosen solution and background of cost estimation method:

<table>
<thead>
<tr>
<th>Infrastructure investment cost</th>
<th>Tunnel concept</th>
<th>Safety concept</th>
<th>Alignment and station locations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tunnel cross section, running tunnels + service tunnel</td>
<td>Tunnel cost is estimated by using other long tunnels as a benchmark: Channel Tunnel, Gotthard Base Tunnel and BBR. To this project applied estimated average price tunnel tube 24 000€/meter including cross passages based on facts: 1) There is no exact information about geology in all areas 2) With available information and chosen tunnel construction technology</td>
<td>Rescue stations and firefighting stations cost estimated by benchmarking Gotthard and Brenner Base Tunnel</td>
<td>Alignment: Ülemiste-Vimsi-Helsinki-Pasila-Hki-Vantaa Airport. Cargo rail connection to Hanko-Hyvinkää track</td>
</tr>
</tbody>
</table>
| 3 pcs Cross-overs | | | Total length of tunnel system
<p>| | Tunnel cost is estimated by using other long tunnels as a benchmark: Channel Tunnel, Gotthard Base Tunnel and BBR. To this project applied estimated average price tunnel tube 24 000€/meter including cross passages based on facts: 1) There is no exact information about geology in all areas 2) With available information and chosen tunnel construction technology | Station price estimated based on Pisara and benchmark projects europe, added 15% for cargo bypasses | Preliminary estimated railway |</p>
<table>
<thead>
<tr>
<th>Terminals and depots</th>
<th>Truck and car shuttle terminals, cargo terminals, train and maintenance depots</th>
<th>Cost calculation is based on estimated amount of trainsets (based on traffic forecast) and areas need for running traffic 40 passenger shuttles per day each direction 11 car shuttles 17 truck shuttles 3 conventional cargo trains</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rail technology and utility equipment</td>
<td>Equipment covers whole tunnel section on surface track connections</td>
<td>Calculations is based on tunnel length, tunnel concept, safety concept and train operation concept – level of equipment in tunnel system</td>
</tr>
<tr>
<td>Construction</td>
<td>Intermediate accesses (2), mass logistic solution, artificial islands (2) TBM/Segmental lining chosen as main tunnel construction method</td>
<td>Calculations are based on preliminary construction order and estimated amount of needed space for construction utilities</td>
</tr>
<tr>
<td>Material management</td>
<td>Approximately 20M cubic meters of material has to be handle during construction process</td>
<td>The cost calculation for the material management is based on the assumption that roughly 1/3 of the excavation costs are needed for transport, 1/10 for material treatment and 1/10 can be re-gained for the sale of the material.</td>
</tr>
<tr>
<td>Maintenance</td>
<td>Infrastructure maintenance for 103km tunnel system  - Maintenance of equipment (equipment is 15% of civil structures, costs 8 times of initial cost during 100yrs lifecycle)  - Energy cost for maintenance  - Maintenance Staff cost (approx. 170 person)</td>
<td>Cost estimation is based on benchmark figures (unit prices) from Channel tunnel</td>
</tr>
<tr>
<td>Operation cost</td>
<td>Train operation cost includes – investment and replacing</td>
<td>Cost estimation is based on benchmark figures (unit prices)</td>
</tr>
</tbody>
</table>
### Table 6.1: Cost estimation calculation summary

Estimated cost are presented in following tables. Calculation and background calculation sheets are attached to report (excel sheets).

The cost calculation is divided into infrastructure investment costs and operation and maintenance costs which includes investment of rolling stock.

#### 6.1. Investment cost estimation

As state-of-the-art at feasibility study level, the accuracy of the cost estimation is +/-30%. The estimated prices represent mean values and are based on prices from benchmark projects with similar design solutions (tunnel concept, terminals, depots, stations, etc.). For Finest project, the accuracy was refined by giving a lower and upper value of estimated costs based on experience from each discipline’s expert. In the presented cost estimation, no additional costs for risk provision are included. According to Austrian tunnel guidelines, the typical risk reserve at feasibility study level is 24%.

The price base is for the cost estimation is autumn 2017 (Finnish MAKU 111 (2010 = 100)). No VAT is included.

<table>
<thead>
<tr>
<th>Category</th>
<th>Mean value</th>
<th>Lower value</th>
<th>Upper value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tunnel Construction, shafts and artificial islands</strong></td>
<td>8 426 300 000 €</td>
<td>7 583 670 000 €</td>
<td>10 954 190 000 €</td>
</tr>
<tr>
<td><strong>Surface rail connections</strong></td>
<td>217 000 000 €</td>
<td>195 300 000 €</td>
<td>238 700 000 €</td>
</tr>
<tr>
<td><strong>Stations, terminals and depots</strong></td>
<td>1 985 000 000</td>
<td>1 588 000 000</td>
<td>2 580 500 000</td>
</tr>
<tr>
<td><strong>Rail technology and utility equipment</strong></td>
<td>2 130 000 000</td>
<td>1 917 000 000</td>
<td>2 449 500 000</td>
</tr>
<tr>
<td><strong>Material management</strong></td>
<td>465 000 000</td>
<td>325 500 000</td>
<td>604 500 000</td>
</tr>
<tr>
<td><strong>Owners costs 15% (planning, administration etc.), environmental cost 3%, investigations 3%</strong></td>
<td>2 776 900 000</td>
<td>2 397 000 000</td>
<td>3 483 600 000</td>
</tr>
<tr>
<td><strong>Infrastructure investment TOTAL</strong></td>
<td>16 000 200 000</td>
<td>13 811 170 000</td>
<td>20 072 290 000</td>
</tr>
</tbody>
</table>
Table 6.2: Infrastructure investment costs

6.2. Operation and maintenance cost

Operation and maintenance cost estimations are based on benchmark cost information from other similar projects (e.g. channel tunnel) and adjusted to Finest Link solutions, conditions and traffic volumes. Operation and maintenance costs have been estimated for a lifecycle of 100 years, divided and stated in calculations for 1 year period.

<table>
<thead>
<tr>
<th>OPEX AND MAINTENANCE COST</th>
<th>Opex and maintenance cost / 1 year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Train operation and maintenance cost</td>
<td>67 660 000€ / year</td>
</tr>
<tr>
<td>- rolling stock investment and replacement (passenger shuttles, 22 trainsets, car and cargo shuttles 15 trainsets</td>
<td></td>
</tr>
<tr>
<td>- preventive and corrective maintenance of rolling stock</td>
<td></td>
</tr>
<tr>
<td>- energy costs</td>
<td></td>
</tr>
<tr>
<td>- staff costs</td>
<td></td>
</tr>
<tr>
<td>Maintenance of infrastructure</td>
<td>57 766 280€ / year</td>
</tr>
<tr>
<td>- maintenance and replacement of installations</td>
<td></td>
</tr>
<tr>
<td>- railway</td>
<td></td>
</tr>
<tr>
<td>- civil structures</td>
<td></td>
</tr>
<tr>
<td>- energy cost of maintenance</td>
<td></td>
</tr>
<tr>
<td>- maintenance equipment</td>
<td></td>
</tr>
<tr>
<td>- staff costs</td>
<td></td>
</tr>
<tr>
<td>OPEX and Maintenance in total</td>
<td>125 426 280€ / year</td>
</tr>
</tbody>
</table>

Table 6.3: Operation and maintenance

7. References


9. Safety in railway tunnels, UIC-Codex 779-9, August 2002