HIGH-CLASS TRANSIT IN AALBORG

DEPOT AND WORKSHOP

PRELIMINARY DESCRIPTION OF DEPOT FOR LRT SYSTEM
TECHNICAL NOTE
JUNE 2014
HIGH CLASS TRANSIT IN AALBORG

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PRELIMINARY DESCRIPTION OF THE DEPOT FOR LRT SYSTEM
TECHNICAL NOTE
10.5 Costs 37
10.6 Conclusion 37
1 Resumé

Dette arbejdsnotat omfatter indledende vurderinger i relation til et depot for første etape af en letbane i Aalborg.

De forudsætninger, som er lagt til grund for vurderingerne er beskrevet i “Preliminary Operation Plan” (arbejdsnotat nr. 008-01a) samt “Rolling Stock” (arbejdsnotat nr. 008-01b). I overensstemmelse med disse er det lagt til grund, at depotet til betjening af letbanens etape 1 skal kunne rumme 18 letbanetog, hver med en længde på 32 m. Det er endvidere forudsat, at depotet skal have tilstrækkelig kapacitet til at kunne rumme en fremtidig etape 2 med samme pladskrav. Såfremt behovet for materiel ved en etape 2 skulle blive større vil dette således indebære behov for et sekundært depot.

Depotet skal indeholde faciliteter og udstyr for vedligehold af det rullende materiel (rengøring, dagligt vedligehold, forebyggende vedligehold, reparationer mv.) samt for vedligehold af letbanens infrastruktur og systemer.

Dette indebærer, at depotet skal rumme følgende:

- Opstillingspladser for togsæt
- Værkstedsbygning
- Mulighed for daglig inspektion af togsæt
- Vaskehal og rengøringsfaciliteter
- Bygning for vedligehold af faste installationer
- Kontrolcenter for overvågning af driften
- Administration

Depotet skal designes, så det kan fungere både under normale driftsforhold og i situationer, hvor der optræder driftsforstyrrelser.

Tre mulige lokaliteter for depotet er vurderet: En vestlig ved Mølholmparken nær Renseanlæg Vest, en central ved jernbanen syd for Aalborg Bustransport terminal samt en østlig nær Universitetsboulevarden det det nye Aalborg Universitetshospital.

Ud fra en samlet vurdering baseret på forskellige kriterier (drift, arealanvendelse, miljøforhold, tekniske forhold og omkostninger) er den vestlige placering – trods det at denne også rummer udfordringer - fundet at være den mest optimale med færrest kritiske udfordringer.
2 Executive summary

This technical note provides a preliminary reflection about what will be the future depot for the first line of tramway in Aalborg.

The main assumptions taken to define the depot come from the “Preliminary Operation Plan” technical note (N°0008-01a) and the “Rolling Stock” technical note (N°0008-01b). Correspondingly to these notes, it is assumed that the depot shall offer sufficient space for 18 trams around 32m long at LRT phase 1. Additionally, a reservation for a future LRT phase 2 is also taken: due to the lack of definition for the LRT phase 2, an assumption was made for an additional fleet of 18 tramways of the same length. In case the requested fleet for a LRT phase 2 would be higher, secondary stabling area shall be identified when designing the phase 2.

A depot shall offer both equipment for the maintenance of rolling stock (cleaning, daily maintenance, current preventive maintenance, current corrective heavy maintenance) and the maintenance of the LRT infrastructure and systems.

For this, the depot shall include seven basic functionalities:

- LRT Parking;
- LRT Maintenance Building;
- LRT Daily inspection;
- LRT Cleaning infrastructures;
- Fixed installation maintenance building;
- LRT Operation and control center;
- LRT Administration.

Moreover, it could be operated in the normal mode but also in a degraded mode.

Considering those requirement, three sites were investigated for the LRT depot: a Western yard close to the sewage plant of the city, a Downtown yard close to the train station in the city center, and an Eastern yard close to the University and Hospital.

After a comparison based on various criteria (operation, land use, environmental constraints, technical constraints and cost), it comes out that the Western yard is the one presenting the less critical issues, this despite being a complicated site.
3 Introduction

This document describes the proposed initial characteristics of the depot for the Light Rail Transit in Aalborg.

This document identifies the most important features of a depot, and it compares three preselected sites for the depot.
4 Maintenance assumptions

4.1 Rolling stock maintenance

Offering passengers a high quality service requires a maintenance approach that will allow maintaining high standards of cleanliness, safety and reliability of the fleet. The depot facilities must provide sufficient space and equipment adapted, which are usually planned around the following activities:

- The cleaning activities which include the internal cleaning (daily), the cleaning of exteriors (at least every 3 days) and a reinforced cleaning (15 days-1 month);

- The daily maintenance (safety visits) which is performed every day the tramway returns to the depot after its last run and involves: the filling of sand boxes, windshield washer reservoirs and a visual inspection of the running gear and the pantograph;

- The current maintenance, which consists in checking all the functions necessary for the good operation of the tramway, as well as the adjustments to the various systems and/or the replacement of components. The current maintenance operations are divided into two categories:

  o The preventive maintenance (generally defined as scheduled maintenance (at fixed intervals), on-condition maintenance (subject to measurements or predetermined events) and the planned maintenance (subject to the analysis of the evolution of some parameters on specific systems or components);

  o The corrective maintenance which consists in repairing or changing defective equipment;

- The heavy maintenance which consists in complex operations, requiring a solid technical proficiency (car body modifications or repairs, replacement of bogies, traction equipment and other major components, etc.).

Generally, LRT depot facilities are not designed for heavy maintenance operations such as mid-life overhauls because they require significant space, equipment and skilled personnel and are only performed once every 15 to 20 years. In addition, LRT considers exclusively equipment standards exchange and their light reparation. When removed, the equipment is tested and repaired in case of light operation. Otherwise the equipment is refurbished by the manufacturer.
4.2 Fixed infrastructures maintenance

The depot facilities have to provide the space and equipment required to support the maintenance of the LRT line infrastructures (i.e. buildings, stations and structures, track, tractive energy, overhead contact line) and operation systems (rail and road signaling and communications, fare collection system, video surveillance, passenger information).

The key preventive and corrective maintenance activities that must be supported are:

- **For the track**: visual inspections; checking of rail wear, maintenance of the draining system, and mechanical sweeping of the platform and groove of rails, snow removal, removing ice from the flange ways, maintenance of turnouts, etc.;

- For buildings, stations and structures: inspections and repairs, cleaning, snow removal;

- **For the energy and overhead contact line**: inspection and maintenance of substations, battery maintenance, checking wear, sag and mechanical tension of overhead contact line;

- **For operating systems and signaling**: inspections, troubleshooting fault signals received at OCC, etc.

Depot facilities required consists in:

- Workshops for material maintenance and storage and for the storage of tools and equipment required by employees assigned to the maintenance of each system or infrastructure;

- Storage space for the vehicles used for maintenance;

- Space for the maintenance of these vehicles.
5 CMC functionalities identification

The purpose of this chapter is to qualify the size of the area reserved for the CMC by describing CMC (Control and Maintenance Center) functionality, production flow and fleet size assumptions.

Some parts are referring to VDV 823 "Recommendation on the Design of Depots for LRVs and Tramcars" and modern's tram depot, which gives a thorough description of issues to consider and best practices recommendations.

5.1 Functions on CMC

The basic functions of the CMC are to inspect, maintain and park the trams fleet and to perform all of the operations control. The processes in inspection and maintenance can be illustrated as in the figure below.

![Figure 1: Process sequences in the CMC](image)

As for Odense it is assumed that all maintenance facilities, stabling, storage, office facilities, staff facilities and operations and control center (OCC) must be located at the appointed area. No stabling is assumed on other locations.

In order to provide the basic functionality a number of part functions must be present at the CMC.
5.2 Depots functionalities

There are 7 depot functionalities, identified as it follows:

- LRT Parking;
- LRT Maintenance Building;
- LRT Daily inspection;
- LRT Cleaning infrastructures;
- Fixed installation maintenance building;
- LRT Operation and control center;
- LRT Administration.

5.3 LRT parking

The LRT parking shall accommodate the LRT during off-operations. This area shall be able to park the entire fleet. This area shall be covered in order to park the fleet in optimal conditions.

This area shall be accessible easily from the main line (for quick LRT injection on main line for operation).

Figure 2: Example of covered stabling
5.4 LRT maintenance building

The LRT maintenance building will accommodate all of the scheduled and unscheduled maintenance. The workshop shall be fitted with various tracks:

- Tracks on piles with pits and roof access platforms for inspections and components removing;
- On floor track for various operations: LRT lifting system, doors and seat changing;
- Underfloor wheel lathe track for wheels machining;
- LRT painting booth for body car painting after traffic incident.

![Figure 3: Example of track on piles with platforms](image). The building shall integrate other areas:

- Specialized workshops for test and light reparations;
- Components storage area;
- Maintenance managing offices;
- Workers changing and social rooms.

The building shall have a direct access with the main line and the LRT parking area in order to ensure a high operational level. The building shall integrate an easy access dedicated to trucks unloading.
5.5 LRT daily inspection

The daily inspection shed will accommodate the following activities:

- Interior and exterior arrangement visual checks (including pantograph and power collector);
- Filling up of the fluids (sand and washer fluid);
- Miscellaneous inspections.

Each LRT shall be checked every day in this bay so it is necessary to have this building in the way connecting the main line to the LRT parking area.

In case of detected failure, the LRT could be repaired in this bay (for light failures) or in the maintenance building so it is recommended to have a direct access between them.

Figure 4: Example of daily inspection shed (with washing machine)
5.6 LRT cleaning infrastructures

There are three cleaning activities to be considered:

- **Outside daily cleaning:**
  
  This cleaning shall be performed in an automatic washing machine. The equipment shall be able to wash the entire fleet every day so it is recommended to install the plant between the main line access and the LRT parking.

- **Inside daily cleaning:**
  
  The inside cleaning will be performed during LRT off-operation. The easier mean to clean the LRT is to do it on the LRT parking. The parking building shall be fitted with all of the water and electric supply required for these activities.

- **Reinforced cleaning**
  
  - The reinforced cleaning shall be performed in an adapted stabling position (mobiles platforms, high pressure cleaning equipment, stairs, grated floor …) or in an adapted track of the LRT workshop.

5.7 Fixed installation maintenance facilities

This building shall integrate:

- Storage area for light and heavy components ;

- Flexible workshops to perform various works (turnouts preparation, electronic works on benches, station furniture like automatic doors, etc.) ;

- Fixed installation managing offices ;

- Workers changing rooms.

This functionality could be integrated to the LRT maintenance building or in a dedicated building.

5.8 LRT Operation, Control Center and administration

These activities are located in a dedicated building from which the line will be managed / administrated.
6 Estimated Surfaces

The surfaces provided as follow doesn’t take into account the outside track network which depends on the geometry of the yard to be chosen.

6.1 Operation hypothesis

The pre-design hypotheses are as follow:

<table>
<thead>
<tr>
<th>Rolling stock length</th>
<th>32 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rolling stock width</td>
<td>2.65 m</td>
</tr>
<tr>
<td>Estimated Fleet*</td>
<td>Phase 1: 18 trams</td>
</tr>
<tr>
<td></td>
<td>Phase 2: Not known.</td>
</tr>
<tr>
<td></td>
<td>Reservation for 18 additional trams</td>
</tr>
<tr>
<td>Yearly km/LRT</td>
<td>65 000 km</td>
</tr>
<tr>
<td>Number of working day (for maintenance field)</td>
<td>250 in one service for preventive maintenance</td>
</tr>
</tbody>
</table>

6.2 LRT parking

This area shall be able to park the entire LRT fleet (Line 1 and 2). It will be developed parking for line 1 and reservation for line 2 will be taken into account.

The required surface is about:

<table>
<thead>
<tr>
<th>LRT phase 1 Parking (16 trams)</th>
<th>2 900 m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reservation for LRT phase 2 parking (16 trams)</td>
<td>2 900 m²</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>5 800 m²</strong></td>
</tr>
</tbody>
</table>

*Note: other trams will be stored in the daily maintenance shed and in the workshop prior to maintenance operations.*
6.3 LRT maintenance building
The maintenance plan previously described implies for a fleet of 36LRT (line 1 and 2 fleet with reserve of 3 trams):

<table>
<thead>
<tr>
<th>Operation</th>
<th>Frequency (km)</th>
<th>Duration (day)</th>
<th>Number of operation per year and per vehicle</th>
<th>Number of operation per year for the fleet</th>
<th>Annual working load (day)</th>
<th>Theoretical number of position</th>
<th>Actual number of position</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard revision</td>
<td>Monthly</td>
<td>0,5</td>
<td>12</td>
<td>420</td>
<td>210</td>
<td>1,68</td>
<td>3</td>
<td>These operations are performed on tracks on pile and with pits</td>
</tr>
<tr>
<td>Revision</td>
<td>100000</td>
<td>4</td>
<td>0,65</td>
<td>22,75</td>
<td>91</td>
<td>0,73</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrective</td>
<td></td>
<td></td>
<td>Usually we consider the corrective maintenance as 20% of the revision maintenance</td>
<td></td>
<td></td>
<td>60,2</td>
<td>0,48</td>
<td></td>
</tr>
<tr>
<td>Lifting track (bogie changing)</td>
<td>300000</td>
<td>5</td>
<td>0,22</td>
<td>7,58</td>
<td>37,92</td>
<td>0,30</td>
<td>1</td>
<td>These tracks shall permit various operations which cannot be performed on tracks on pile (doors changing, …)</td>
</tr>
<tr>
<td>Corrective car body painting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 is enough (Systra experience)</td>
</tr>
<tr>
<td>Wheel lathe</td>
<td>20000</td>
<td>0,5</td>
<td>3,25</td>
<td>113,75</td>
<td>56,9</td>
<td>0,46</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

The maintenance building could accommodate easily the LRT fleet of the two lines of the project.

The required surface is about:

<table>
<thead>
<tr>
<th>Track on post (elevated tracks, lifting track, underfloor wheel lathe track and painting booth track)</th>
<th>3100 m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bogie repair area</td>
<td>250 m²</td>
</tr>
<tr>
<td>Flexible workshops</td>
<td>300 m²</td>
</tr>
<tr>
<td>Fixed installation workshops</td>
<td>450 m²</td>
</tr>
<tr>
<td>Electronic workshop</td>
<td>30 m²</td>
</tr>
<tr>
<td>Battery charging room</td>
<td>20 m²</td>
</tr>
<tr>
<td>Polyester workshop</td>
<td>50 m²</td>
</tr>
<tr>
<td>Welding workshop</td>
<td>50 m²</td>
</tr>
<tr>
<td>Storage area (with unloading area)</td>
<td>700 m²</td>
</tr>
<tr>
<td>Heavy storage area</td>
<td>500 m² (outside)</td>
</tr>
<tr>
<td>Test bench storage room</td>
<td>30 m²</td>
</tr>
<tr>
<td>Others (offices, changing rooms, …)</td>
<td>800 m² (in elevation)</td>
</tr>
<tr>
<td>Various technical rooms</td>
<td>500 m²</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>6270 m²</td>
</tr>
</tbody>
</table>

Note: the building design shall integrate a separation between Rolling stock maintenance and fixed installation maintenance.
6.4 LRT daily inspection
The daily inspection and outside cleaning shall be installed in a common building. When arriving in the shed, LRT shall be inspected and fluid filled. Then the LRT shall be cleaned in the automatic washing machine before parking.

The required surface is about:

<table>
<thead>
<tr>
<th>Service-station (with technical rooms)</th>
<th>560 m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automatic washing machine (with technical rooms)</td>
<td>280 m²</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>840 m²</strong></td>
</tr>
</tbody>
</table>

Note: reinforced cleaning will be performed in the workshop, on the painting booth track.

6.5 Operation and Control Center
The building shall accommodate:

- The operation room with its technical rooms;
- The operation managing staff;
- The drivers facilities;
- The cleaners facilities;
- The controller facilities.

The building will have several floors so other functionalities could be added as:

- Administration;
- Training;
- Marketing;
- Human resources;
- Ticketing;
- Etc.
These functions will be defined in futures studied so as a first hypothesis, the building will have a footprint of 700m² on three levels:

- Level 0 : Drivers, controller and training rooms
- Level 1 : Administration, human resources and OCC technical rooms
- Level 2 : OCC room and operation managing offices

As a rough estimate, the space need for this building is estimated to 2100m², distributed on 3 floors. The need will be detailed further at next stages.

7 Depot operation principles

Two operational modes shall be taken into consideration in the depot: the normal mode and the degraded mode.

7.1 Normal mode

The normal mode includes the following operations:

- Tramway starts from the stabling and goes directly to the main line for operation ;
- Tramway come back from operation, pass through daily inspection, washing machine, and stabling or maintenance bay ;
- Periodic maintenance activities imply movement from and to stabling / maintenance bay.

7.2 Degraded mode

To ensure a smooth degraded operation, the following high level requirements shall be met:

- In case of depot traction power supply failure, the main line traction power supply shall be able to provide traction power to the depot in order to continue depot operation ;
- In case of failure of any one turnout, from the insertion/removal of the tramways from the Line shall not be impacted. Disturbance of workshop tracks is acceptable ;
- Double end stabling are preferred to single end to facilitate tramway movement in case of tramway failure ;
- In case of failure or maintenance of daily Inspection bay and tramway washing building it shall be possible to by-pass them.
8 Description of the yards

There are three identified yards for the CMC:

- The Western Yard (1)
- The Downtown Yard (2)
- The Eastern Yard (3)

Figure 5: Aalborg LRT and the 3 locations investigated for a depot
8.1 Generalities

For each possibility, the track layout’s construction principles have been analyzed.

The track layout must be adapted to the studied yard. All the functionalities of the depot will be connected by the track layout which must be designed to:

- Aspire to make possible all natural driving relations, ;
- Allow for flexible shunting :
- Minimize reversing in shunting ;
- Provide redundancy shunting options at incidents and malfunctions.

For an unlimited availability of the space, the ideal CMC shall have the driving relations as defined on the scheme and the layout below.

![Diagram](image)

*Figure 6: Scheme of the ideal driving relations*

**Legend:**

a) **Service-station**: daily inspection, sand boxes filling, daily inspections, daily car body washing (washing machine), trams data unloading, light corrective maintenance

b) **Workshop building**: rolling stock preventive and corrective maintenance, fixed installations maintenance

c) **Stabling area**: inside daily cleaning, heavy cleaning, trams parking
The geometry of the yard is not always suitable to allow all of the direct connections. The most important driving relations are as follow:

- Main line to service-station;
- Main line to stabling;
- Service-station to stabling.

In addition, it can be added that the track is proposed as slab track in the whole depot area. Indeed, even if it could seem interesting to use ballast track in term of investment costs, such solution shall be avoided for maintenance reason. In a line counting with no other ballasted section, the operator would have to provide for the ballast maintenance especially for the depot area. It is not economically sustainable if we consider the operation and maintenance costs.

8.2 Option 1: Western Yard

**Yard presentation**

<table>
<thead>
<tr>
<th>Location</th>
<th>Next to the Marina terminal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yard surface</td>
<td>88.400 m²</td>
</tr>
<tr>
<td>Used surfaces for CMC</td>
<td>38.000 m²</td>
</tr>
<tr>
<td>Implantation constraints</td>
<td>Reservation for future recreational lane along the fjord (10m width)</td>
</tr>
<tr>
<td></td>
<td>Pond preservation</td>
</tr>
<tr>
<td></td>
<td>Develop the facilities in the sewage plant side of the yard</td>
</tr>
<tr>
<td></td>
<td>Earthworks required to prevent from flooding risk</td>
</tr>
<tr>
<td>LRT road</td>
<td>Main Line to service-station</td>
</tr>
<tr>
<td></td>
<td>Main line to stabling (via service station) by-pass track</td>
</tr>
<tr>
<td></td>
<td>Service-station to stabling</td>
</tr>
<tr>
<td></td>
<td>Stabling to maintenance building</td>
</tr>
<tr>
<td>Main line connection</td>
<td>After Marina terminal in double track</td>
</tr>
</tbody>
</table>
**Depot layout**

- Reservation for recreational lane
- Pond
- Service-station with automatic washing machine
- LRT maintenance building
- OCC building
- LRT covered stabling
- Direct access from the main line

*Depot’s emplacement inside the East Yard*
Soil treatment and Earthworks

This section describes the works to foresee in order to realize the embankment, as well as to provide a suitable platform for depot.

According to the topographic survey and google earth data, the ground level varies between +0 and +2.5 on the yard.

For this study, the geological and geotechnical parameters are evaluated according to “GEUS Dansk Boringer” data.

![Figure 7: Geological boring from GEUS](image)

The soil layers are as follows:

- **From +2.50 to -0.50**: fill
- **From -0.5 to -3.50**: silty and muddy soils
- **Below -3.50**: sand and/or clay

The groundwater level is about +0.5m.

The following design hypotheses are retained for earthworks:

- Selected floodplain materials fills up to 0.50m above highest water level (HWL=2.40m);
- Slope inclination is 2h/1v;
- Subgrade class S2 (50MPa);
- The subballast layer should be at least 1.5m above highest water level;
- The compaction of the subgrade layer will be controlled with plate load tests (Ev2). A reception criteria of Ev2>50 MPa should be ensured.

- Subballast layer of 0.20m with granular fraction 0/31.5.

The embankment and the flood protection will have to be realized according to the schemes below.

![Figure 8: Principle for flooding protection](image)

![Figure 9: Layers composing the embankment](image)

The embankment will lie on compressible soils and will be liable to large post-construction settlements under fill load (about 50cm may be estimated at this stage). If no additional treatment is done, the consolidation delay may be significant (several months to several years).

In order to achieve the settlements and to allow for tracks and superstructures installation within a reasonable time-scale, the solution proposed is to accelerate the drainage of the soil foundation with vertical drains. In this case, the consolidation may be carried out in less than one month. Such a soil treatment is integrated in our cost estimate.

The embankment structure proposed should be suitable for shallow foundation of the buildings.
8.3 Option 2: Downtown Yard

Yard presentation

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Location</strong></td>
<td>Next to the Aalborg train station and the bus terminals</td>
</tr>
<tr>
<td><strong>Yard surface</strong></td>
<td>53,400 m²</td>
</tr>
<tr>
<td><strong>Used surfaces for CMC</strong></td>
<td>53,400 m²</td>
</tr>
<tr>
<td><strong>Implantation constraints</strong></td>
<td>Demolition work of old railway workshops</td>
</tr>
<tr>
<td></td>
<td>Access constraints (bus depot and real estate development)</td>
</tr>
<tr>
<td><strong>LRT road</strong></td>
<td></td>
</tr>
<tr>
<td>Main Line to service-station</td>
<td></td>
</tr>
<tr>
<td>Main line to stabling (via service station) by-pass track</td>
<td></td>
</tr>
<tr>
<td>Main line to maintenance building</td>
<td></td>
</tr>
<tr>
<td>Service-station to maintenance building</td>
<td></td>
</tr>
<tr>
<td>Service-station to stabling</td>
<td></td>
</tr>
<tr>
<td>Stabling to maintenance building</td>
<td></td>
</tr>
<tr>
<td>Stabling with double access</td>
<td></td>
</tr>
<tr>
<td><strong>Main line connection</strong></td>
<td>Triangle connection between Aalborg St./ JF.Kennedys Plads and Politigarden stations</td>
</tr>
<tr>
<td></td>
<td>Single track between the triangle connection and the CMC</td>
</tr>
</tbody>
</table>
Soil treatment and Earthworks

According to the topographic survey and google earth data, the ground level varies between +5.00 and +6.50m. Therefore, there shall be no particular risk of flooding.

For this study, the geological and geotechnical parameters are evaluated according to GUES Dansk Boringer data.

The soil layers are as follows:

- **From +4.0 to 0.00**: fill material, silt, muddy soil;
- **Below 0.00**: mainly sand, clay sand, clay.

The groundwater level is about -0.5m.

The following design hypotheses are retained for earthworks:

- Slope inclination is 2h/1v;
- Subgrade class S2 (50MPa);
- The subballast layer should be at least 1.5m above highest water level;
- The compaction of the subgrade layer will be controlled with plate load tests (Ev2). A reception criteria of Ev2>50 MPa should be ensured;
- Subballast layer of 0.20m with granular fraction 0/31.5.
As the project is in cuttings, there should be no specific constraint regarding settlements.

The superficial soil layers are probably of a poor quality. However, the complete excavation of the superficial layer is not recommended due to its significant depth (about 4m). Therefore the superstructures will probably have to be supported with deep foundations.
8.4 Option 3: Eastern Yard

**Yard presentation**

<table>
<thead>
<tr>
<th>Location</th>
<th>Next to the Selma Lagerlöfs Vej station</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yard surface</td>
<td>About 120 000 m²</td>
</tr>
<tr>
<td>Used surfaces for CMC</td>
<td>43 965 m²</td>
</tr>
<tr>
<td>Implantation constraints</td>
<td>Hospital project close to the depot yard</td>
</tr>
<tr>
<td></td>
<td>Water storage for hospital close to the depot yard</td>
</tr>
</tbody>
</table>

**LRT road**

- Main Line to service-station
- Main line to stabling (via service station) by-pass track
- Main line to maintenance building
- Service-station to maintenance building
- Service-station to stabling
- Stabling to maintenance building

**Main line connection**

- Triangle connection between Selma Lagerlöfs Vej and Servibyen stations
- Double track between the triangle connection and the CMC

**Depot Layout**
**Analysis of hydraulic risk**

The issues are pretty much the same than those described for the Western site, except that the project is not located close to the bank and will not require any rock protection of the embankment.

In case this solution is retained, additional investigations will be required at EIA stage in order to assess the impact of the embankment on the flood zone. To do so, **2D hydraulic modeling can be used in order to assess the behavior of flows.** A precise topography of the extended area will be needed.

**Soil treatment and Earthworks**

According to the topographic survey and google earth data, the ground level varies between +2.00 and +4.0m.

For this study, the geological and geotechnical parameters are evaluated according to GEUS Dansk Boringer data.

![Figure 12: Geological boring from GEUS](image)

The soil layers are as follows:

- **From +4.00 to -1.00**: Sand, silt sand silt clay
- **Below -1.00**: mainly sand

The groundwater level varies between +1.8 and +0.5m.
The following design hypotheses are retained for earthworks:

- Slope inclination is 2h/1v ;
- Subgrade class S2 (50MPa) ;
- The subballast layer should be at least 1.5m above highest water level ;
- The compaction of the subgrade (35cm) layer will be controlled with plate load tests (E_v2). A reception criteria of E_v2>50 MPa should be ensured ;
- Subballast layer of 0.20m with granular fraction 0/31.5.

![Figure 13: Principle for flooding protection](image)

![Figure 14: Layers composing the embankment](image)

The geological environment should be better compared to the other sites (Western and downtown).

The buildings could be supported either on shallow or deep foundations. No specific soil treatment is expected at this stage.
9 Cost estimates by yard

Based on the functional and technical requirements previously described, a preliminary cost estimate for each yard is proposed. These cost estimates are provided here under.

The cost estimate is decomposed in the following main items:

- Deconstruction costs for buildings and tracks;
- Costs for basic site preparation, soil treatments and earthworks;
- Building costs;
- Urbanization costs including costs for internal roads, pavement and parking lots;
- Cost for electromechanical equipment (the details of the equipment is provided in a second table hereunder);
- Costs for slab track within the site;
- Costs for catenaries within the site.

For the downtown and eastern depot locations there will be an extra cost for a track connection to the main line, whilst the connection to the main line for the western location will be part of the alignment. The extra cost for the track connection to the main line is approximately 2.1 million € for both the downtown and western location.

Please note that the costs for the substations are not counted within depot. Indeed, the substation which will be feeding the depot is not dedicated exclusively to it but will also feed part of the line. These costs are shown in the technical note "Power supply" (N°0008-02a).

The cost estimates provided below:

- Do not include land acquisition costs;
- Do not include the costs for stabling at LRT phase 2;
- Do not include the costs for design and project follow up (it shall be around 25%);
- Do not include any provision for risks (it shall be around 30% at feasibility study stage);

The costs provided are at the economic conditions of April 2014.
### Figure 15: Preliminary cost estimates for each yard

<table>
<thead>
<tr>
<th>Description</th>
<th>Western depot</th>
<th>Downtown depot</th>
<th>Eastern depot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deconstruction (building + tracks)</td>
<td>0</td>
<td>1 250 000 €</td>
<td>0</td>
</tr>
<tr>
<td>Site preparation + Soil treatments + Earthworks</td>
<td>10 400 000 €</td>
<td>6 650 000 €</td>
<td>5 400 000 €</td>
</tr>
<tr>
<td>Building Construction</td>
<td>11 700 000 €</td>
<td>11 700 000 €</td>
<td>11 700 000 €</td>
</tr>
<tr>
<td>Urbanization (internal road, pavement, parking)</td>
<td>1 000 000 €</td>
<td>1 000 000 €</td>
<td>1 000 000 €</td>
</tr>
<tr>
<td>Equipment (with installation)</td>
<td>3 760 000 €</td>
<td>3 760 000 €</td>
<td>3 760 000 €</td>
</tr>
<tr>
<td>Slab track</td>
<td>5 670 000 €</td>
<td>8 790 000 €</td>
<td>6 700 000 €</td>
</tr>
<tr>
<td>OCS</td>
<td>1 510 000 €</td>
<td>2 430 000 €</td>
<td>1 530 000 €</td>
</tr>
<tr>
<td><strong>Total cost for depot (Euros)</strong></td>
<td>34 040 000 €</td>
<td>35 580 000 €</td>
<td>30 090 000 €</td>
</tr>
</tbody>
</table>

| Total cost for depot (DKK)                  | 253 955 000 DKK | 265 445 000 DKK | 224 486 000 DKK |

### Figure 16: Detail of cost for the electromechanical equipment within depot

<table>
<thead>
<tr>
<th>Equipment (with installation)</th>
<th>Quantity</th>
<th>Unit price</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automatic washing machine</td>
<td>1</td>
<td>450 000 €</td>
<td>450 000 €</td>
</tr>
<tr>
<td>Sand filling system</td>
<td>1</td>
<td>350 000 €</td>
<td>350 000 €</td>
</tr>
<tr>
<td>Underfloor wheel lathe (with hauling device)</td>
<td>1</td>
<td>750 000 €</td>
<td>750 000 €</td>
</tr>
<tr>
<td>LRT lifting jacks set</td>
<td>1</td>
<td>250 000 €</td>
<td>250 000 €</td>
</tr>
<tr>
<td>Painting booth set</td>
<td>1</td>
<td>250 000 €</td>
<td>250 000 €</td>
</tr>
<tr>
<td>Rail road maintenance vehicle</td>
<td>1</td>
<td>500 000 €</td>
<td>500 000 €</td>
</tr>
<tr>
<td>Road cleaning</td>
<td>1</td>
<td>300 000 €</td>
<td>300 000 €</td>
</tr>
<tr>
<td>Overhead travelling crane 1,6t</td>
<td>3</td>
<td>15 000 €</td>
<td>45 000 €</td>
</tr>
<tr>
<td>Overhead travelling crane 6,4t</td>
<td>1</td>
<td>75 000 €</td>
<td>75 000 €</td>
</tr>
<tr>
<td>Other tools (platforms, benches, …)</td>
<td>1</td>
<td>300 000 €</td>
<td>300 000 €</td>
</tr>
<tr>
<td><strong>Equipment interfaces : about 15%</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td>3 760 500 €</td>
</tr>
</tbody>
</table>
10 Comparison of the yards

In this section, we compare the three different yards according to the following criteria:

- Operation
- Land use
- Environmental constraints
- Technics
- Cost

10.1 Operation

In terms of operation, we evaluate:

- The adequacy of the site position in relation to the needs at phase 1, and also to the future needs at phase 2;
- The internal layout and its consistency with the scheme of the ideal driving relations previously show;
- The accessibility to the site from main line.

Site position

Concerning the site position, the downtown yard may be considered as the best one. Indeed, it would considerably limit the deadhead kilometers for vehicles when the line is operated at phase 1. In anticipation of a LRT phase 2, the site is also ideally placed.

In comparison, the Western yard and the Eastern yard will cause deadhead kilometers since the trains will have to run the line empty so that the operation can start at the same time on both sides of the line. In prevision of the implementation of LRT phase 2, the Western yard offer some commodity in comparison with the Eastern one: it is much more closer to Velterbro bridge, what would limit the deadhead kilometers for the trains going towards North of the city.

Internal layout

The Western site is the one presenting the more constraints in terms of available space. If we compare the internal track layout with the ideal one presented at figure 6, the direct relation between service station and workshop building is missing and there is only one access to the stabling area. Thus, there will be additional manoeuvre within depot site, which will complicate the operation.

On the other yards, it is possible to create an “ideal” track layout as per figure 6.
**Accessibility**

In terms of accessibility, the Western site is the one offering the most direct access. The site is connected to the line by a double access track which does not present any particular constraints in insertion.

The downtown yard is less accessible in the sense that the access track has to insert between a new development and the existing bus depot. For this reason, it is difficult to propose more than one access track. Obviously, having only one access track creates an operational risk of closure of the depot if there is some obstacle lying on this track.

The Eastern yard has a more difficult access than the Western one, since the access tracks are presenting more curvatures in order to respect the Right of Way of the hospital project. Besides, there are no other particular constraints for the access.

**10.2 Land use**

If we look at the urban context, not all the sites are equal.

The Eastern yard is located close to the university site and the future hospital site. It is a valuable area for the Municipality in terms of land use, which could be adequate for developing knowledge based activities. Therefore, allocating this area to an industrial use could be controversial matter.

The Downtown yard and the Western yard are both already reserved for an industrial use. Therefore, implementing the depot on both those sites would be less controversial.

Hence, the Western yard area could hardly be converted to another use due to the vicinity with the sewage plant. Nevertheless, since there is a Real Estate development in project at the Eastern border with the yard, it could still be argued whether or not the site shall conserve its industrial use or shall rather be converted in a recreational area.

Regarding the Downtown yard, the issues may come from the acquisition of land use. It could demonstrate complicated since the area is currently the property of the Danish National railways.

**10.3 Environmental constraints**

In terms of environmental constraints, the Western and Eastern yard are the most problematical since there are subject to flooding.

In particular, the Western site, which is planned on an embankment, should be weighted and studied carefully at EIA stage, this in order to assess the impact of the embankment on the flood zone. Additional constraint on the Western site will come from the risk of erosion of the embankment. This risk will have to be mitigated. Finally, the Western site also faces the constraint of a salty environment and the associated corrosion risk. This risk will also have to be mitigated.
Regarding the Eastern site, it is located in a catchment area, as confirmed by the project for a water basin. Therefore, the drainage solutions around depot site will have to be studied carefully so that it does not disturb the hydraulic behavior in the area.

10.4 Technical constraints

Technically speaking, the Western and Downtown sites present some constraints.

Indeed, the Western site will require some soil treatment in order to accelerate the consolidation of the embankment and in order to limit the settlements. This is a quite classical treatment for a depot area.

Regarding the Downtown site, the constraints come from the current use of the yard. The area is already built and will call for the demolition/deconstruction of the existing buildings and tracks. Moreover, the project would present some interfaces with the operating railways which would need to be managed during construction.

10.5 Costs

In terms of costs the less expensive project would be the one settled on Eastern yard.

The Western yard presents some extra costs due to the more important amount of earthworks in comparison with other sites.

The Eastern yard presents some extra costs coming from deconstruction of the site. The potential extra costs from the land acquisition are not shown.

10.6 Conclusion

As illustrated by the recapitulation table hereunder, the Western site may be the most appropriate.

<table>
<thead>
<tr>
<th>Operation</th>
<th>Western yard</th>
<th>Downtown yard</th>
<th>Eastern yard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality buildings</td>
<td>Good accessibility</td>
<td>Optimal location</td>
<td>Promising location (deemed)</td>
</tr>
<tr>
<td>Constraints</td>
<td>Constrained internal layout</td>
<td>Constrained access</td>
<td>Fairly good access</td>
</tr>
<tr>
<td>Land use</td>
<td>Appropriate for industrial use</td>
<td>Property of National Railways</td>
<td>Valuable location</td>
</tr>
<tr>
<td>Environmental constraints</td>
<td>Salty environment</td>
<td>-</td>
<td>Salty environment</td>
</tr>
<tr>
<td>Techniques</td>
<td>Soil treatments</td>
<td>Interfaces with on-site operations</td>
<td>Demolition and deconstruction</td>
</tr>
<tr>
<td>Costs</td>
<td>14 M€</td>
<td>25 M€</td>
<td>30 M€</td>
</tr>
</tbody>
</table>

*Figure 17: Depot sites – Multicriteria analysis*

In fact, the Downtown yard presents some critical issues in terms of land use, technicity of the construction. Moreover it is the most expensive one.
On the other hand, the Eastern site is the less adequate in terms of operation and presents a real land use issue.

Contrarily to the two other yards, the Western yards – even if a complicated one – does not present significant drawbacks.