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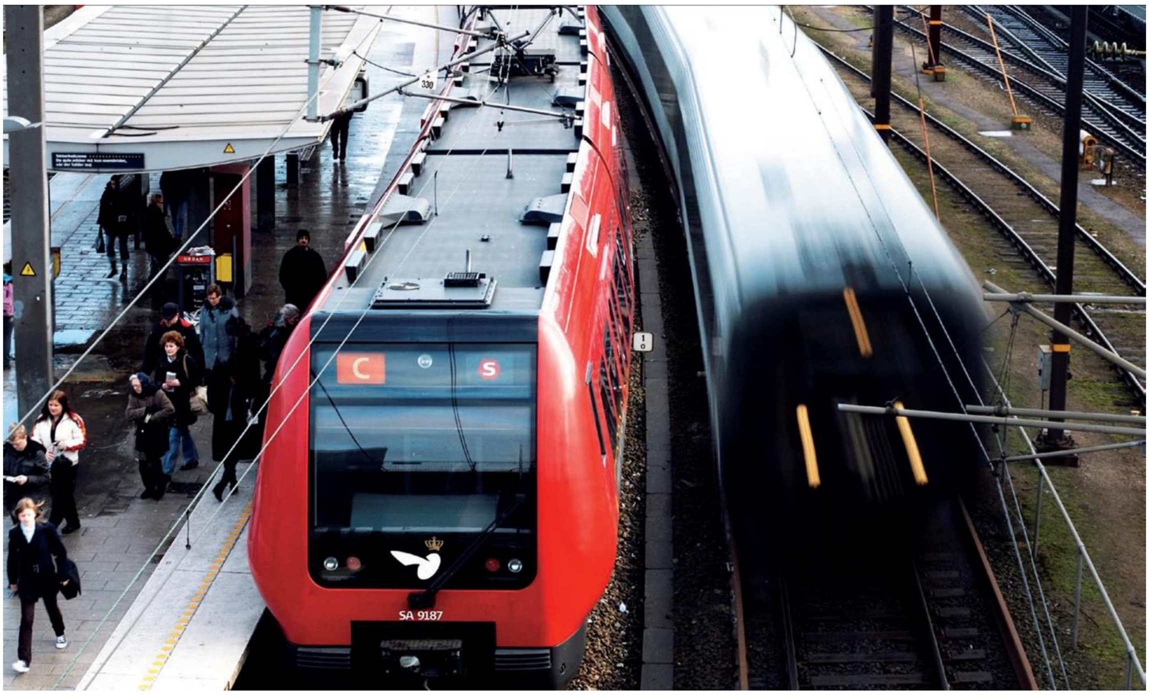
REORGANISATION OF THE S-BANE FOR DRIVERLESS OPERATION
MAIN REPORT



RAMBOLL PARSONS

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CONTENTS

1. EXECUTIVE SUMMARY

In accordance with the agreement on *metro, light rail, suburban rail lines and bicycles* of 12th of June 2014, Ramboll Denmark, as main advisor together with associated international sub-consultants, conducted an investigation on the reorganisation of the S-bane to metro operation. The purpose of the investigation has been to explore the possibilities and perspectives of reorganising the S-bane to automatic and driverless operation (metro operation) in connection with the purchase of the next generation of S-trains. The current S-trains lifespan expires in the years 2026-2036.

Automatic and driverless train operation can form the basis for a vision of better train service for less money. Automation creates the possibility to achieve higher frequency, increased punctuality, fewer cancelled trains and lower costs. A reorganisation of the S-bane to metro operation is a self-financing project, where the necessary investments associated with the reorganisation can be paid with gains in the operational costs. The project will also allow for improvement of the level of service on the S-bane, combined with a reduction of government costs for the S-bane.

A reorganisation of the S-bane to metro operation is technically feasible and can be carried out without significant risks, as automatic operation is part of the basic functionality of the Signalling Programme which is rolled out on the S-bane in these years. The reorganisation to driverless operation will only require minor adjustments to the Signalling Programme.

Forecasts for the development of the Capital Region in the next decades show that there will be significant population growth and thus also a significant increase in traffic. Traffic patterns will also change and further after the commissioning of the Cityringen and the light rail on Ring 3, which both runs across the S-bane's fingers. To reduce congestion and support green transport, the public transport system must be able to be expanded smoothly. Therefore there is a need for the S-bane to be operated in a way that will enable this development to be adapted continuously.

A reorganisation of the S-bane for automatic and driverless operation will make future S-bane investments significantly more profitable so that the expected increases in demand can be met without necessarily having to increase the state's subsidy for rail traffic. In addition, the service level may increase during the evenings, weekends and night hours, where there are no material and capacity restrictions as in daytime. Thus, the S-bane can offer round the clock service, as we know it from the metro.

In this investigation, the possibilities and perspectives of driverless operation of the S-trains has been investigated. The investigation has included operational, capacity related, technical, financial and personnel matters. The possibilities are compared with the current operation of the S-bane, where there is a driver in all trains.

1.1 Results

The investigation shows that the overall operational cost savings associated with the transition to driverless operation are expected to exceed the cost of the necessary investments associated with the project. Furthermore, it will be possible to extend the scope of operations on the S-bane, combined with a reduction of the cost of S-train traffic as compared to today.

The investigation has identified two overall scenarios for a reorganisation of the S-bane to metro operation:

- **Scenario 1**: The S-bane is automated without changing the scope of operation on the S-bane compared with today. Scenario 1 has a net revenue of DKK 1,311 million and is economically viable based upon an internal interest rate of return of 6 percent.

- **Scenario 2**: The S-bane is automated and the scope of operation on the S- bane is increased by 24 percent compared to today. In scenario 2, the annual number of travellers will increase by 11 percent. Scenario 2 has a net revenue of DKK 309 million and is economically viable based upon an internal interest rate of return of 9 percent.

The savings for each of the scenarios are based on an average life of 30 years for the investments and are calculated by discounting all investments, costs and gains to 2016 with a discount rate of 4%. A reorganisation of the S-bane to metro operation is thus a self-financing project, which in addition could also improve the S-bane service level to the benefit of passengers.

1.1.1 Investment needs

In addition to the minor adjustments of the Signalling Programme, the reorganisation of the S-bane to metro operation will require investments in infrastructure and new driverless trains. In addition, there will be additional costs for the operation and maintenance of a driverless S-bane.

The driver currently handles the arrival and departure of the S-train and ensures that the S-train can drive arrive at the station and open and close doors at arrival and departure. In case of driverless operation, a monitoring system is established that detects contaminants on the tracks and, if necessary, causes an emergency stop of a train. Experience from other railways with driverless operation shows that by establishing such a system the safety level at the platforms can be at least at the same level as for the current operations. Along the tracks between the stations fences shall be established - also on bridges.

At all stations a possibility for level free access (stepless entry) to the train will be established and the train will be equipped with a gap-filler. In this way, disabled people will be self-reliant on boarding and leaving the train, where it today requires intervention by the driver with increased dwell time as a consequence.

The analysis has shown that a combination of 3-car train sets that can be combined to up to three train sets with a maximum train length of 165 m will be most appropriate to accommodate the passenger needs. There will be no need for additional workshops or depots for any of the two scenarios.

Driverless trains are more expensive to acquire than traditionally manned trains. However, this is offset by the fact that the turnaround time at end stations for driverless S-trains is shorter than for manned trains. Thus a higher utilization rate can be achieved and the total number of trains can be reduced when the system is rendered driverless.

1.1.2 Roll-out plan

The investigations have shown that a decision to introduce driverless operation on the S-bane must be taken before the purchase of new S-trains commences to ensure that the new S-trains can be used for driverless operation without having to be changed after delivery. As it is a comprehensive project that requires changes in infrastructure, purchase of new driverless trains and the completion of a series of tests, it a decision on the project should be made no later than in 2019.

The roll-out of driverless operation on the S-bane must be carried out in a manner that affects the current operation as little as possible. To ensure this, it is proposed to complete the rollout in phases where the first phase is a pilot phase, which comprises the Ringbane (Hellerup-Ny Ellebjerg). The pilot phase shall be used to test the solution and collect experience without affecting the other lines on the S-bane. Subsequent roll-out of the project on the other lines of the

S-bane will then take place in phases where experience from the Ringbane is utilised.

If a decision is made to carry out the project has been taken not later than in 2019, the pilot phase on the Ringbane can take place in the years 2022-2026, while the roll-out of the other sections can take place in the years 2025-2030. This is a conceptual schedule, as the rollout of the project can be postponed by lifetime extension of existing S-trains, although this can be costly and impact the operating stability of the S-bane.

The technology-based technological solutions on which the project is based are all in operation on one or more existing driverless railways in urban areas. The envisaged rollout plan, in which the project will roll out over the next decade, will probably imply that new technologies in the meantime will emerge and can possibly be used for the final rollout of the project. These yet unknown technologies may potentially contribute to further improvement of the safety level and thus provide even more attractive solutions than those described - also in regards to investments and operational purposes.

1.1.3 Human resources

Remuneration of personnel directly involved in the operation of the S-bane is today a significant cost driver. With the reorganisation of the S-bane to driverless operation, the will be no need for drivers and other operational personnel, while a small number of train stewards will be required to carry out service tasks currently carried out by drivers.

It is considered possible to carry out the project without having to dismiss staff, when taking into account retirements and potential transfer of staff to the long distance and regional lines. Specific models for dealing with excess staff should be investigated in a possible later phase. The immediate human resource issue is primarily a question of maintaining the required number of employees at the S-bane during the transition period, as some employees might be expected to consider changing jobs as a result of a political decision to make the S-bane driverless. As part of the project it must be ensured that a sufficient number of drivers are available during the transition phase.

As a result of a reduction of the need for operational-oriented personnel by 90%, it will be possible for each of the proposed scenarios to increase the capacity in periods when it is not fully utilized without significant changes in operating costs. This implies that the business model for operating the S-bane with driverless operation will be significantly different from the business model for the current mode of operation, where the operating costs are highly dependent on the amount of trains operated. Thus, the driverless operation will contribute to a significant expansion of the capacity and new more flexible operational opportunities.

1.1.4 Metro-like operation and classical operation

As part of the investigation, a comparison was made of the advantages and disadvantages of classical and metro-like operations on the S-bane in connection with a conversion to driverless operation. Classical operation involves driving a mix of fast trains that stop at selected stations and trains that stop at all stations. Metro-like operation implies that all trains stop at all stations.

The studies show that the choice between the two types of operation does not significantly affect the outcome of the project. Thus, a reorganisation of the S-bane to automatic and driverless operation can be carried out independently of the choice between the two operating models. The choice between metro-like and classic operation - or possibly a combination of both - can be taken in conjunction with the timetable planning in the wake of an S-bane reorganisation to automatic and driverless operation. In today's situation, DSB switches between the two operating models during the operating day.

1.1.5 Summary - key figures

The passenger related and financial key figures for the project are shown in the tables below. The effects of the project are calculated as additional costs to a base scenario where the S-trains are replaced with new manned S-trains, and the level of service of the S-bane remains unchanged as compared with today.

Economic effects in relation to basis Present values*, DKK Mio. 2016 prices	Scenario 1	Scenario 2
Costs		
Infrastructure	1.086	1.141
- CBTC upgrade	*47*	*47*
- Stepless entry	*39*	*39*
- Platform-edge safety	*671*	*671*
- Fencing along rails	*329*	*329*
- Upgrade of traction power	*0*	*55*
Trains	-16	756
- Train needs	*-201***	*521*
- Driverless technology	*184*	*235*
Operations and maintenance	810	1.989
- Train maintenance and power supply etc.	*138*	*1.328*
- Maintenance of infrastructure	*672*	*662*
Contractor administration cost	134	262
Total costs	**2.014**	**4.149**
Revenue		
Ticket sales	-39***	1.095
Reduction of staff	3.363	3.363
Total revenue	**3.324**	**4.458**
Net revenue	**1.311**	**309**
Payback time (Break-even)	18 years	19,5 years

Note: "Summary error" is due to rounding up.
* This is the present value related to the financial cash flow, which should not be mixed up with the socio-economic present value from the socio-economic cost-benefit analysis.
** S-train demand is reduced in scenario 1, although the production volumes remain unchanged as compared with today, as driverless S-trains have shorter turnaround times and thus have a higher utilization rate.
*** Ticket sales are reduced in scenario 1, due to the marginally extended dwell times at stations (and thus travel times) as a result of on-board gap fillers (stepless boarding). This marginal change will affect the traffic model calculations, but is unlikely to make any significance in practice.

Passager-based effects in relations to basis (DKK)	Scenario 1	Scenario 2
Scope of production	15,9 mio trainkm	19,7 mio. trainkm
- Growth as compared with basis	0 %	24 %
Number of annual travellers on the S-bane	111,9 mio.	124,7 mio.
- Growth as compared with basis	0 %	11 %
Number of annual collective travellers in the capital area	373,8 mio.	378,1 mio.
- Growth as compared with basis	0 %	1 %
Economy (Internal rate of return)	6,1 %	9,6 %

2. READING GUIDE AND REPORT STRUCTURE

The study of reorganisation of the S-bane for driverless operation is documented in a main report (this paper) and a number of sub-reports.

The main report provides an overview of the study highlighting and describing conclusions and key findings within the different focus areas of the study. Each of focus areas has an attached sub-report, where a more detailed analysis and documentation of the conclusions and findings can be found. The main report is divided into 9 main sections:

1. **Executive summary**
   This section summarises the objective and conclusion of the study.
2. **Reading guide and report structure**
   This section explains the structure of the main report and links to sub-reports where a more comprehensive analysis can be found.
3. **Introduction**
   The introduction outlines the objective and background of the study and highlights its key preconditions.
4. **Methodology**
   The methodology section describes the overall approach and method applied in the study.
5. **Operational scenarios**
   This section describes the analysis, assessment and conclusions made in relation to the operational concepts and scenarios. The detailed analysis can be found in Appendix 1: Operational Plans.
6. **Infrastructure and rolling stock**
   This section concerns the different infrastructure and rolling stock focus areas of the study. Each item has its own sub-report:
   - Appendix 2: Safety (Platforms, etc.)
   - Appendix 3: Stepless Boarding
   - Appendix 4: Track Capacity in the Central Section
   - Appendix 5: Flexibility and Capacity Enhancing Infrastructure
   - Appendix 6: Driverless Rolling Stock
   - Appendix 7: Combining and Splitting or fixed Trainsets
   - Appendix 8: Depot and Workshop Facilities
   - Appendix 9: Power
   - Appendix 10: Rollout Plan
7. **Organisation**
   This section describes the organisational analysis and assessment. The detailed investigation can be found in Appendix 12: Organisation.
8. **Risk and cost estimate**
   This section describes the risk analysis. The detailed analysis can be found in appendix 11: Risk and cost estimate.
9. **Financial analysis**
   This section describes the financial analysis. The detailed investigation can be found in Appendix 13: Financial and socio economic assessment.
10. **Socio economic assessment**
    This section describes the socio economic analysis. The detailed investigation can be found in Appendix 13: Financial and socio economic assessment.
11. **Conclusion**

3. INTRODUCTION

3.1 Objective for the study

According to plan, the next generation of Rolling Stock on the S-bane in Copenhagen shall be procured within the next decade. As part of the long term preparation for that the general requirements, feasibilities and context related factors must be investigated and assessed. Technological innovation must e.g. expect to lead to potentials quite different from the mid-nineties where the existing generation of Rolling Stock were implemented. Equally, Greater Copenhagen has changed substantially during the last decade, driven by growth and prosperity, which has influenced the general traffic patterns.

In this overall context, the objective of the study is to deliver fact based pointers and feasibility assessments that can initiate the next step in a decision making process that will eventually bring the next generation of the S-bane successfully into operation.

A particular focus in the study is related to unattended train operation, i.e. mode without any driver. An increasing number of urban traffic systems worldwide have already transferred, or will in the upcoming years introduce UTO. The key questions related to that are to which extent will such solutions could fit to the Copenhagen S-bane from a technical, a financial and a service provision perspective.

Accordingly, the methodologic frame for assessment of the overall objective is to:

- Investigate a financial potential associated with UTO, documented in a formalised Business Case
- Clarify the span of feasible technical solutions that can support the business case
- Ensure that certain service requirements, defined as more or less formal precondition, can be met

3.2 Driverless potential

Driverless systems have several superior characteristics compared to a regular attended system. It’s more flexible in situations where it is necessary to recover from irregular operation, as the operation is independent of the drivers and their rosters. Also, extra trains are easier to put into operation, e.g. if additional capacity is needed due to special events. Furthermore, the absence of drivers ensures that dwells are kept within the defined dwell time. Situations with a shortage of drivers (e.g. due to illness) are also avoided in a driverless system.

However, from an optimization perspective of the overall operation, the single most powerful potential of the UTO mode emerged from the fact, that costs related to operation of one long train equals two trains of half the size and with double the frequency. Accordingly, it’s possible to satisfy a given capacity demand by smaller units operated with higher frequency for the benefit of customers. Often, the higher frequency makes official time plans redundant due to the very high availability. Equally, transfers from one line to another, or between different transportation systems are perceived as very smooth and easy. These factors therefore attract more customers and make the public transportion more competitive.

This optimized operation is usually enabled by simple network layouts, where train units and frequency can be combined very flexibly. As the S-bane merges out of several distinct lines into one central section, makes it a little more challenging. Also, the layout makes the impact of disruptions or significant delays more complex. The driverless potential needs therefore to be derived without creating bottlenecks in the inner section, or a too low frequency provision on the outer lines. That’s the fundamental objective in context.

3.3 Background

The study has its current actuality due to a number of circumstances related to the S-bane and its environment that makes it particular relevant to assess UTO mode in details now:

New signalling system on the S-bane

The new signalling system, currently being implemented, is the foundation for the future operation of the S-bane. Its functionalities support the transition from manual operation to STO, thereby permitting higher frequency and automation of a number of tasks (e.g. starting and stopping) at the same time. The implementation of the new signalling system is the enabler for further development, an upgrade rather than a new system, from STO to UTO, and without massive associated transformation required.

Procurement of 5th generation of S-trains

The current S-train fleet (4th generation) which were put into operation from 1996 to 2006, will reach the end of their lifetime from 2026 to 2036. Procurement of a new 5th generation S-train fleet thereby needs to take place around this period. The *in-any-case* procurement of new trains then opens up an opportunity to purchase rolling stock which from the beginning are designed to operate in UTO mode.

Growth in the greater Copenhagen Area

The greater Copenhagen Area has experienced a significant population growth during the last decades. This development – which is considered to continue – impacts the transportation system and creates new requirements to existing infrastructure. The S-bane will experience a higher demand, especially during the peak hours.

Previously promising results

Earlier investigation of the potential for UTO on the S-Bane has shown promising results. A Parsons report from 2010 documents a feasible transfer to UTO, including different operational solutions bringing a stronger financial result. Equally, a 2013 screening report from the Ministry of Transport, Building and Housing state a potential.

3.4 Preconditions for the investigation

The investigation is based on a number of preconditions which have been established in order to frame the investigation on a sufficiently firm foundation. The key preconditions are:

Current infrastructure and approved projects as baseline

Already initiated or approved future projects, will have an impact on the estimated passenger flow for the S-bane. The current analysis is based on incorporation of all these initiated and approved project, i.e. relevant projects with their allocated budget are taken into account. For example: New high speed line from Copenhagen to Ringsted, the Metrocityring, Ny Vinge station, etc. For a full list of incorporated projects, please refer to Appendix 1.

Remain current safety level
A major challenge for converting a system like the S-bane into a driverless system is the safety requirements and approval process. The investigation is therefore based on an approach where the safety level needs to be at least the same level going from STO to UTO operation.

Same service provision for special segments
The service provision is likewise assumed to be at least the same across needs of different user groups; in particular access for disabled people needs to be at least the same.

4. APPROACH AND METHODOLOGY

An assessment of the possibilities for introduction of UTO on the S-bane requires investigations into a wide range of operational, technical and organisational focus areas. The areas are to a wide extent mutually interdependent and the result from one focus area serve, might have an impact in the investigations in other areas. For that reason, the study has been divided into distinct focus areas making cross analysis more transparent. The areas are:

1) Best performing operational scenarios
2) Feasible and high potential technical solutions related to infrastructure and rolling stock
3) Analysis of associated organisational impact
4) Total financial and social economic assessment

The investigation of operational scenarios has been designed in order to develop a number of potential alternatives making determination of the best performing as clear and significant as possible. Through an iterative process, preferred scenarios have been defined and selected for further investigations based upon relevant key parameters covering operational and financial indicators. The basic idea has been to explore how different potential *baseline cases* defined from the particular design characteristics of the total railway network – bottlenecks in the central section, distant outer lines, existence of a ring line, etc. – can be used to optimize performance.

Subsequently, derived from that approach a considerable number of different operational scenarios, equally distributed between Classic and Metro, have been assessed. Each one of them has been investigated in order to find promising patterns, potentially ready for further in-depth financial analyses. Variations associated with any non performing baseline cases at the other hand, has been excluded. The outcome of these analyses has led to adjustment and a narrowing of competing scenarios.

For the above mentioned processes PRIME[1] has been used for technical and operational analysis, and the OTM[2] has been used for calculation of the passenger impact[3].

The technical investigations – covering safety, infrastructure and rolling stock – have included identification of alternative solutions and assessment of their suitability for the S-Bane with a clear separation between *need to have* and *nice to have* investments. For each area of investment budgets and operational budgets have been established to serve as input for the financial analysis.

Some elements of the technical investigation and investigation of operational scenarios are directly linked to driverless operation (e.g. platform safety), while others are more indirectly linked (e.g. coupling of train units). The study will highlight the distinction between elements and solutions that are directly and indirectly linked to driverless operation.

Both the investigation of operational scenarios and technical solutions end up with a number of recommendations. It is however important to emphasize that the recommendations shall be perceived as *conceptual design choices,* aiming at proof of concept for driverless operation. This implies that the recommended solutions – and their attributes and characteristics – will change along with the specification of the project and the technical development within the industry.

[1] PRIME is a simulation model developed and provided by Parsons enabling a structured investigation of travel time, dwell time, required number of rolling stock, etc. related to a given operational pattern

[2] The OTM model is based on data (matrixes of passenger patterns) from which impact on different operational models can be estimated. Existing version of OTM are based on the latest calibration from 2009. Accordingly, trends observed during the last 7 to 8 years are not explicitly captured or explained in OTM

[3] Results from PRIME and OTM have been quality assured separately and validated cross functionally in order to ensure quality assurance of the outcome

An example could be the recommended safety solution at the platform – the recommended solution is relatively specific in order to define its characteristics (cost, safely level, dwell time, etc.). It is however relatively certain that the final design of this solution will differ from the described solution, due to the technical development, etc.

When it comes to the organisation analysis, it has been based upon the current situation which serves as base for assessment and for the changes to be imposed. Based upon the operational and technical assessments, the required changes can be identified. In particular, the organisational analysis derived from the suggested roll out scenarios in setting the pace of transformation of staff, equally figures and assumptions about current relevant staff are included. The financial impact of these changes serves equally as input for the financial analysis.

The financial and economical assessment is based on the results from the three other investigations. The business case is made from a delta perspective from STO to UTO mode. The starting point for the investments in the business case is a fully implemented signalling programme and procurement of new rolling stock in any case. That has the consequence that comprehended financial impacts are isolated to any income, capex or opex that differs from STO compared to UTO. The business case is furthermore prepared in line with *Ny Anlægsbudgettering*.

Finally, approach and methodology have been customized and impacted according to international operational real life studies. Visits to Nuremberg, Munich, the Copenhagen Metro as well as visit from Stockholm, have brought in valuable consistency checks and inspiration to the definition of solutions: Recommended platform safety solution, operational handling of false alarms, coupling feasibility and operational scenarios, are examples of subjects that have been heavily influenced by these real life studies. In general, none of the suggested solutions are truly green fields. Any mentioned technology has proven its feasibility in commercial operation, only the application in the specific context, environment and layout of the S-bane is unique.

Throughout the process, results and findings have been discussed and assessed with the Ministry of Transport, Building and Housing, Banedanmark, DSB, Copenhagen Metro, Banedanmark (Rail Net Denmark) and the Danish Transport and Construction Agency, who jointly have in-depth knowledge and experience in operation of metropolitan railways.

5. OPERATIONAL SCENARIOS

5.1 Introduction

The current operation of the S-Bane is based upon trains attended by a driver. By introduction of driverless trains it will be possible to change the operation and thus improve the utilisation of the S-Bane network. Previous investigations[4] have shown that a better utilisation of the S-Bane would lead to an increased number of passengers.

In order to identify the operation solution that can provide the best possible business case, a range of scenarios has been analysed. The overall approach has been to investigate the impact of different benchmark scenarios, each with the objective to derive the maximum potential from a driverless operation in a rail network with a structure that does not have the typical driverless simplicity. Goals of the analysis have thus been to reduce the pressure on the central section, to increase frequency at some of the outermost sections, or to reduce cost by removal of lines with the fewest number of passengers. The benchmark scenarios have included:

- Use of *Ringbanen* instead of the central section by one of the northern lines
- Use of turn tracks enabling a train going back to an outer line before reaching the central section
- Alternative uses of capacity derived from use of Ringbanen or use of turn tracks

Each of the benchmark scenarios has then been combined with different operational styles, i.e. Classic and Metro, and has been assessed with alternative ranges of frequency from 30 over 36 to 39 hourly departures in the central section.

16 scenarios in total have been derived from a combination of these parameters. The tools OTM and PRIME have then been used for assessments in several steps, and increasingly more detailed, to identify the best performing scenario.

The whole analysis regarding operational scenarios can be found in appendix 1.

5.2 Conclusion

Based on the analysis it is found that the single best performing scenario consists of a flexible combination of Classic- and Metro style with 36 hourly departures in the central section, named Flex 36. This conclusion is based on the entire assessment comprehending both the financial and the socio economic analysis, while a partial assessment relying only on the financial business case makes the UTO30 as the best performing. For further details about these analyses, please refer to chapter 9 and chapter 10.

Classic style is used in peak periods, while Metro style is used outside peak periods. This is a principle that DSB, to a lesser extent, will already initiates by the end of January 2017 with metro style operation in the evenings and classic the remaining part of the day. However, in the Flex 36 the extent to which the styles are mixed is higher. The following conclusions can be derived from this, as well as from the total analysis:

1. Combined benefits from a reduction in the total required number of rolling stock units, as fewer trains are needed in a Classic style during peak hours and - at the same time - the advantages of Metro that can be exploited the remaining part of time
2. The outer lines do not have enough passengers to let a Metro style serve to the very end. Instead, it is beneficial to let half of the train's turnaround between the beginning and the

[4] See e.g. Parsons 2010 or Screening from 2013

end of each *finger,* e.g. Solrød, Ballerup, Buddinge and Holte. Only at Klampenborg and Høje Taastrup every train goes to the end
3. A frequency of 39 hourly departures in the central section does not yield significantly more passengers and the marginal extra revenue does not match the cost of additional train units. At the same time 39 trains per hour is a heavy utilisation of the central section that will cause a significant degradation of the service quality. A maximum of 36 trains per hour is therefore also recommended in the central section
4. Offloading of the central section by introducing different utilisations using the Ring line, or establishing turnarounds in order to increase train capacity does not lead to better performing scenarios
5. In general the distinction between Metro and Classic shall rather be considered as a continuous space, each concept with multiple variants, enabling the two styles to become almost identical. E.g. a train only skipping a few stations on the outer part of the network is per definition considered as 'Classic' even though it operates according to the metro definition on the remaining part of the network. This acknowledgement lead to interesting results: An optimized traffic pattern is much more about identifying and combining the potentials across the two concepts, rather than taking a binary choice. Even more interesting: That allows for a potential decision for UTO operation without requirement of a detailed defined operational pattern in parallel. The latter can easily be a part of the initial analysis after a formalized project has been initiated

The key operational characteristics for the UTO Flex 36 are shown in the table below.

Indicator	**Base STO**	**Flexible scenario - 36 trains per hour (Best Performing Scenario)**
Train km	50.918	63.249
Train sets	161	175
Passenger trips	359.111	399.714
Trips per train km	7,1	6,3

Table 1: Key operational data for base scenario and flexible, best performing scenario

5.3 Analysis

The analysis aiming at identifying the most suitable operational scenario has included a definition of number of scenarios covering metro style and classic operation. Through that process the scenarios have been compared and the most favourable have been brought forward for further analysis.

It has been a main objective for the analysis to keep a comparison between metro- and classic style. The initial pool of scenarios is therefore characterised by scenarios in pairs, i.e. metro and classic scenarios based on the same overall concept. The following concepts have been analysed in different combinations:

- 36 to 39 trains per hour in the central section
- All trains running to the terminal stations (end of the fingers) or only some of the trains
- Alternative utilisation of the S-Bane network aiming at offloading the central section incl.:
  - Additional trains from Hillerød via the Ring line to Ny Ellebjerg
  - Establishing turnaround at Enghave for some trains from Ballerup/Frederikssund and thus allowing for extra trains to/from the other fingers through the central section

5.3.1 Assumptions and preconditions for the analysis

Utilisation in the central section
The number of trains that can be operated in the central section (Dybbølsbro-Svanemøllen) has been analysed using the PRIME model. Based on recommendations by the International Union of Railways (UIC), the maximum utilisation has been derived as 40 trains in the peak period and 33 trains in the off-peak period. Consequently, operational scenarios with a high capacity utilisation of 39 trains per hour and medium capacity utilisation scenarios with 36 trains per hour in the central section have been composed. Simulations of delay propagation has subsequently led to the conclusion that 36 trains per hour is the maximum obtainable capacity, as 39 trains per hour will lead to a significant decrease in punctuality compared to the base STO scenario.

Public timetable
In the Copenhagen Metro timetables are not published. This provides additional flexibility as the train services can be easily adjusted. In turn, this added flexibility can be an incentive to reduce the running time supplements and thus provide faster travel times. Furthermore, the arrival pattern of passengers is affected by the timetable being published or not. An assessment has therefore been carried out in order to investigate whether the same flexibility can be obtained on the S-Bane if the timetable is not published.

The assessment shows that a published timetable is the preferable solution for the scenarios as the flexibility obtained by not publishing a timetable cannot offset the increased waiting time. A main factor in this is that the Copenhagen S-bane network consists of six branches of varying length which all pass the heavily utilised central section. A timetable is needed to be able to effectively utilise the central section capacity and at the same time serve different destinations. This "timetable" does not necessarily have to be published, but emphasizes the fact that the structure of the system reduces the dispatching flexibility that could otherwise be obtained (e.g. if the capacity in central section was significantly higher).

Because of low frequency at the outer stations, especially at mornings and evenings, and also because of the importance of connections to low frequency bus-services, a published timetable is clearly recommended.

Train Frequencies during the Day
To obtain a suitable balance between production and demand, i.e. the service provided and the number of passengers, the frequency is adjusted outside the peak periods. Table 2 shows the frequencies during the day based on the frequency in the central section in the morning peak. It has been the objective to achieve a good service in the off-peak periods, but also to cut cost to optimise the business case.

Time period Trains in central section	05-06	06-09	09-15	15-19	19-01
30 (base)	15	30	27	27	15
36	18	36	30	36	18
39	18	39	33	39	18

Table 2: Frequencies during the day

5.3.2 Simulations

The scenario analyses have comprised technical analyses and passenger impact analysis.

For the technical analyses Parson's PRIME tool has been used to calculate minimum running time, assess travel times, crowding and delays taking into consideration the constraints defined, gaps and necessary running time supplement, required in order to have a stable and regular operation. Furthermore, the PRIME analyses show the required number of train sets in order to perform the operation according to the timetable.

The demand in the form of the number of passengers has been calculated using the OTM. The OTM is used for traffic model calculations in the greater Copenhagen area. 2030 is used as the calculation year. All decided road- and rail projects are included in the model. The OTM calculations are based upon the results of the PRIME calculations and simulations.

5.4 Description of scenarios

For the analysis each assessed scenario has been described in details, including its characteristics, preconditions and constraints. A complete description is included in the Appendix "Operational Scenarios".

In the following the base scenario, base scenario with UTO operation (UTO 30) and the preferred classic (C.A.36) and metro (M.A.36) scenarios for a future UTO operated S-Bane are described. Subsequently, the flexible scenario based upon partly metro style operation and partly classic operation is described.

5.4.1 Base STO and UTO scenario

The base STO scenario and base UTO are based on the 2014 operational pattern with 30 trains per hour through the central section. 12 trains per hour are operated on the Ring line. On the fingers the following frequencies are used during the peak periods: 6 trains per hour for: A (inner section), B, C (inner section), and E as well as 3 trains per hour for lines A (outer section), Bx (morning only), H, and C (outer section). Running times, dwell times, and the rolling stock is adjusted to 2030 situation. As depicted in Figure 1, the base timetable is a classic, heterogeneous timetable with a mix trains stopping at all stations combined, with fast trains that skip some stations. Compared to the 2014 situation, the signalling system is updated.

The base STO scenario and the base UTO follow the same operational concept. The difference between the two is that the base UTO scenario is an unattended (driverless) version of the base scenario (where a driver is needed). The shift to UTO has a positive effect on circulation times of trains resulting in a more effective operation than without a driver. Thus, the base UTO requires fewer train sets than the base STO scenario.

Figure 1: Stop pattern for the base STO scenario and the base UTO scenario

5.4.2 Alternative scenarios

In relation to the business case, it was found optimal to operate the S-Bane with half the frequency on the outer sections of the fingers, as the number of passengers is substantially lower on these parts of the network than on the inner sections. This is similar to today's operation. Of the analysed scenarios, the short classic and short metro scenarios (C.A.36 and M.A.36) have been selected as the best. These two scenarios performed best based on a cross sectional analysis, i.e. operating economy, robustness against delays and passenger pr. train km.

Short Metro scenario M.A.36 and short Classic scenario C.A.36

The short metro and classis scenarios feature a combination of short and long lines. The short lines serve the inner parts of the network with the highest demand. Thus, the frequency on the inner and outer sections of the network is adapted to match the number of passengers. Both scenarios operate with 36 trains per hour in the central section and 30 trains per hour on the Ring line. The frequency on the outer sections is 6 trains per hour and 12 trains per hour on the the inner sections (12 trains per hour to Høje Taastrup and 6 trains per hour to Klampenborg). The main difference between the two scenarios is the origin and destination of lines and the operational style, i.e. whether the long lines skip stations on the inner part of the network, or stops at all stations. The two scenarios are depicted in Figure 2.

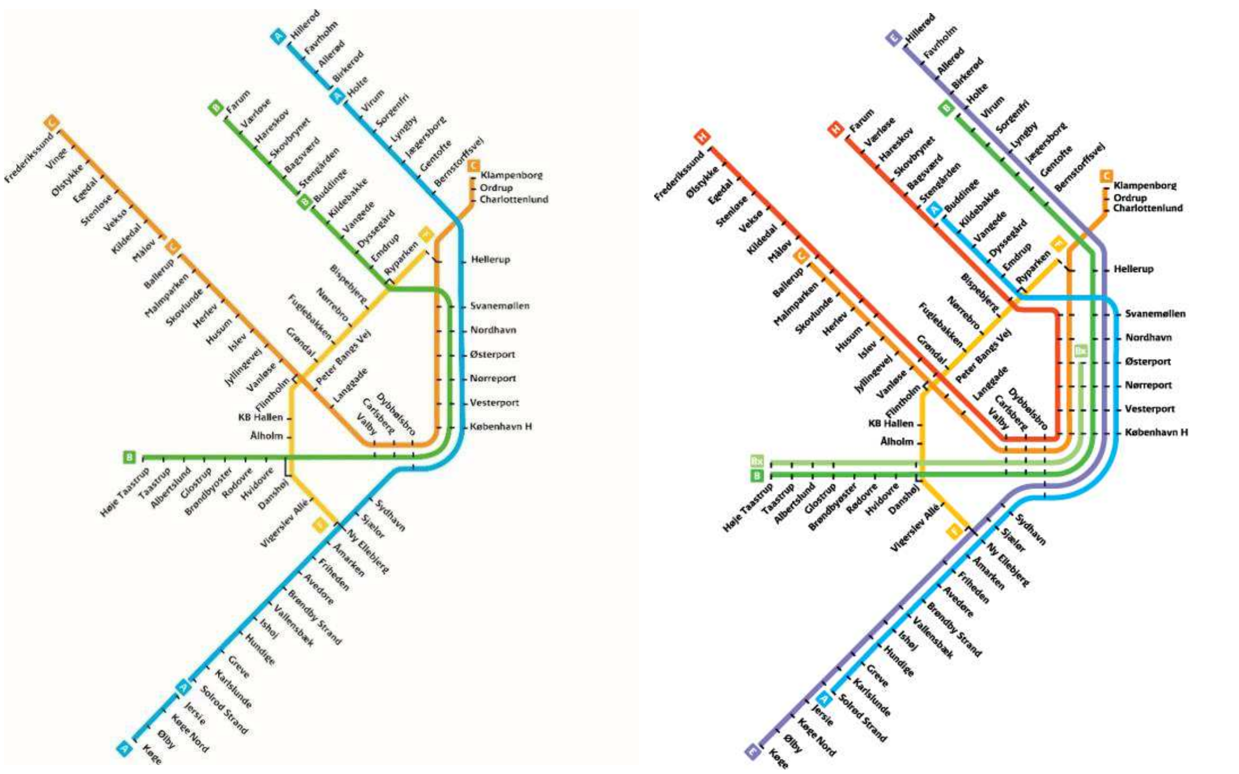

Figure 2: Stop patterns for the Short Metro scenario, M.A.36 (left), and the Short Classic scenario, C.A.36 (right)

5.4.2.1 Flexible scenario, Flex 36

Following the detailed analysis of the short classic and metro scenarios, C.A.36 and M.A.36, the following is concluded:

- The short metro scenario (M.A.36) generates the most passengers of the two, resulting in higher passenger revenue
- The short classic scenario (C.A.36) has a reduced need of rolling stock compared to the metro scenario (due to a higher average speed) and thus lower investments costs in rolling stock

The lower investment costs for the classic scenario compared with the higher passenger revenues in the metro scenario results in an almost equal operating economy for the two scenarios. To exploit the different strengths of the two scenarios, they have been combined to a single optimised scenario named the flexible scenario.

The flexible scenario is based on the classic scenario, C.A.36 (depicted in Figure 2 (right)) with the following modifications:

- Line Bx is run in metro style, i.e. Bx trains stops at all stations
- The fast train service, line E and H, stops at all stations outside the peak periods as shown in Figure 2

The operation will be Classic style during peak periods, i.e. from 5 – 9 and 15 – 19, and Metro style outside these periods. The additional 6 hourly trains compared to the base scenarios are added as an extra B line between Høje Taastrup and Østerport. The Flex 36 scenario is depicted in Figure 3.

Figure 3: Flex 36 scenario. Stop pattern in peak periods (left). Stop pattern in non-peak periods (right)

As the need for rolling stock depends on the peak period requirements, the need for rolling stock is kept low by operating a classic operation in the peak periods. Metro style operation is used outside the peak periods to attract more passengers. Studies have shown that most commuters plan their arrival at stations when the frequency is 10 minutes. Thus, commuters may benefit from a fast train services. Outside the peak periods there are fewer commuters, and the passengers arrive more randomly. As the frequency is evenly distributed with a metro style operation, it is more suitable for passengers arriving randomly and thus attractive in the off peak periods.

5.5 Future development – passengers and other projects

The exact future passenger development is surrounded with some degree of uncertainty. It is however very likely that an increase in passengers will lead to a demand of more capacity and thereby an increased number of rolling stock. The increased capacity demand can at first be handled by increasing the frequency from 36 trains pr. hour to 39 trains pr. hour and by coupling of train units (section 6.7), but at some point it will be necessary to purchase extra train units to maintain the same service level.

This issue (even therefore it is positive) is not linked in particular to the implementation of UTO on the S-bane, and a similar issue will occur in a STO scenario. A potential risk in this scenario is overpricing of the extra train units, caused by the fact that rolling stock supplier of the main delivery will have a major advantage. A way to mitigate this scenario is include a later smaller delivery in the contract with the rolling stock supplier.

A sensitivity analysis regarding the passenger numbers is included in the financial analysis (section 9.5).

Another key factor that will affect the final UTO operational concept is the development of the infrastructure – e.g. implementation of a turn track at Enghave or similar. These improvements of the infrastructure will be beneficial for the implementation of UTO and in turn it will improve the flexibility of the S-bane.

6. INFRASTRUCTURE AND ROLLING STOCK

6.1 Platform Safety

6.1.1 Introduction

Safety and punctuality are key issues for a successful operation of a railway. By a reorganisation of the S-Bane to driverless operation, it must be ensured that the current level of safety is at least maintained and the punctuality/reliability is not reduced. A cornerstone of a driverless system is thereby the technical solution that can provide the required passenger safety without decreasing the punctuality.

The investigation contains analysis of different technical safety systems in order to determine the most preferable solution for the S-bane. Platform safety can in general either be handled by an intrusion prevention system, or an intrusion detection system. Whereas an intrusion prevention system (e.g. platform screen doors) segregates the track and platform areas, an intrusion detection system detects objects in the track. The objects may be persons falling onto the tracks or other large objects (items and animals) which prevent the train operation.

The analyses leading to the proposed solution is based upon an assessment of different solutions and their safety level, reliability, maturity and cost.

The whole analysis regarding platform safety can be found in appendix 2.

6.1.2 Conclusion

For the S-Bane stations it will be sufficient – from a safety perspective – to install an intrusion detection system in the form of an object detection system (ODS). The introduction of ODS will actually improve the safety at the stations as the system will immediately detect and stop the train operation if a person falls onto the track. The ODS has furthermore a significantly lower cost than intrusion prevention systems and at the same provides the required reliability.

An ODS consists of electronic barriers and a camera system as shown in Figure 4 below. The recommended solution for the S-bane – as a design choice – contains two infrared barriers, one under the platform high above ground and one at a just above track level. In case one of the barriers identifies an object, a message is sent to the control centre for further action. In order to minimise traffic interruptions due to false alarms, cameras covering the platform train interface with video analytics shall be positioned above the platforms with a view along the tracks.

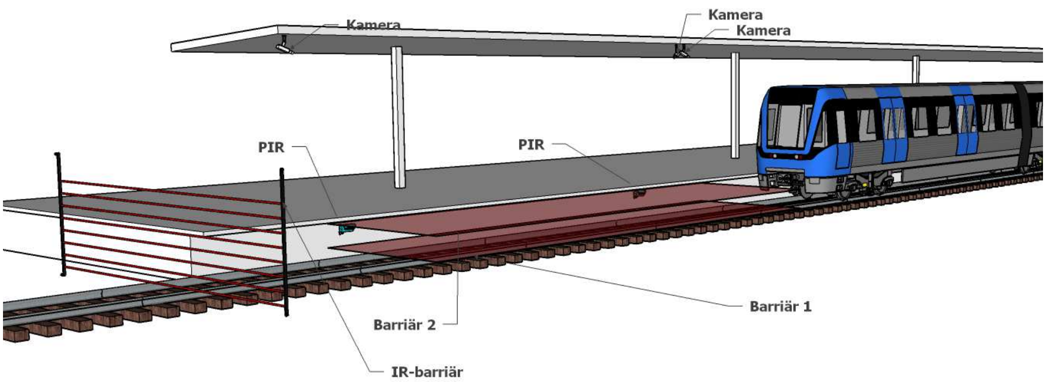

Figure 4: Obstacle Detection System (ODS)

As per Figure 4 an ODS has been tested at the Stockholm metro where two station have been equipped with different solutions for a period. This trial has demonstrated that the ODS can sense and identify events of persons and items on the track correctly and at a level required for the S-

Bane. By means of cameras with video analytics, the assessment can be improved significantly. Furthermore, tests have indicated that video analytics can detect persons being trapped in train doors.

The field trial also showed that the ODS shown an acceptable performance for outdoor stations in different weather conditions. The assessment of the Stockholm metro field trial results are furthermore supported from commercial operation in Nurnberg (where electronic barriers similar to those installed in Stockholm) confirms the system robustness.

The experiences from the Copenhagen Metro – which converted from an ODS system to automatic platform gates on the outdoor stations due to performance/reliability issues – have been part of the assessment. The technology development within sensors combined with camera technology makes it difficult to compare the two generations of ODS systems directly[5]. Which the field trail from Stockholm also supports.

The recommended ODS is based upon standard commercially available components which supports that the technology is mature. For final design of the ODS on the S-Bane, there will be a need for further studies and adaptations in order to cover curved platforms, multi-track stations and stations with platforms on the outer tracksides. These conditions are however not seen as potential showstoppers for the ODS, but known and manageable technical issues.

The technical development within the field of ODS and similar safety solutions (e.g. advanced driver assistance systems (ADAS) known from the car industry) is rapid changing technologies – improving system performance and reducing cost. The overall technical development is pointed towards higher reliability of the systems due to more accurate measurements/higher component sensitivity. The cost of the future ODS systems is of course dependent on the technical development – e.g. the development pace of video analytics combined with behavioural algorithms which can reduce the number of false alarms and improve the reaction time significantly. This development could influence the technologies on which the ODS will be based and thereby reduce its cost. It is therefore also important to let the market development be a key driver for the decision of the final ODS solution.

The introduction of the ODS system will imply a new staff organisation in order to manage disruptions. An event requiring staff intervention will cause delays and thus decrease the punctuality. The staff shall be organised in a way which allows presence at any location of the network within 10 minutes. This will limit the duration of a disruption and the socio economic costs caused by increased waiting time for the passengers.

Even though an ODS based solution can provide the needed level of safety at the lowest cost, it might be recommendable to install an intrusion prevention system at a few stations at the central section in order to achieve a higher reliability of the S-bane. It is however recommended that the ODS is first installed at all stations, and based on the in-service performance of the ODS, the need for an intrusion prevention system at specific stations can be reviewed.

The assessment of different intrusion prevention system (e.g. platform screen doors and platform gates) shows that the most promising solution for the S-bane is a Rope Vertical Platform Screen Doors (VPSD) solution.

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[5] The ODS at the Copenhagen Metro was implemented in 2002-2003 and 2007 and developed around 1990 and 2000. The first roll-out at the S-bane will take place in 2022.

Figure 5: Rope Vertical PSD at a platform

Rope VPSD is a relatively new technology which has been put into operation in Korea and Japan and been tested at the Stockholm metro (outside environment). A Rope VPSD, see Figure 5, is a wall made of rope (metal wires) with distance of app. 50 mm. The space between the ropes/wires is closed with a flexible plastic material creating a closed surface, and thereby preventing people from getting into contact with the train. The VPSD is established along the whole platform, fixed at post every 8-12 meters and with at height of app. 1,75 meter. Once a train has stopped at the platform the rope VPSD is rolled up along the train, similar to a blind in a window, thereby allowing passengers to leave and enter the train. The rope VPSD is lowered again before train departure.

The rope VPSD is not yet a fully mature technology. It is a promising technology, which has significantly lower costs than PSDs as known from the Copenhagen Metro. Furthermore, as the technology is simpler than PSD it must be envisaged that maintenance costs will be lower.

The rope VPSD and associated costs are not part of the business case due to the fact that it is a potential add-on if the ODS system performance needs to be improved at a few stations.

6.2 Safety between stations

6.2.1 Introduction

Once driverless trains are put into operation on the S-Bane, the continuous monitoring of the tracks in front of the trains which the train drivers have performed will no longer be carried out. As the tracks are currently relatively unprotected there is a need for a means which can ensure protection and prevent intrusion between the stations, and thereby ensure that the current safety level can at least be maintained.

The proposed solution for ensuring safety between stations is based upon assessment of data for trespassers and large objects on the tracks for the S-Bane, and investigations of similar protection systems for other driverless networks in operation, including the Copenhagen Metro. As part of the investigation potential suitable technical systems have been assessed.

The whole analysis regarding safety between stations can be found in appendix 2.

6.2.2 Conclusion

It is proposed to protect the tracks between the stations, including bridges crossing the tracks with fences. The fences shall comply with requirements in BOStrab[6] which is also used for the Copenhagen Metro. Whereas trespassers intrude the track area along the lines, and large objects are mainly thrown on tracks from bridges. The fence will reduce the possibility of both unauthorised access to the track area and undesirable objects on track – and thereby improve the safety of the S-bane system in general.

Figure 6: Example of fencing and bridge protection

In order to prevent unauthorised access to the track areas from platforms, infrared barriers shall be established at the end of all platforms to identify intruders.

By establishing a protection system the number of trespassers will be reduced. The level of safety between the stations will therefore be increased. Thus, a need for a costly technical system enabling continuous monitoring has not been identified.

As the numbers of reported trespassers is only a small proportion (around 10%) of the total number of trespassers, a field trial covering test of the proposed fence between two stations and continuous monitoring for collection of data of all trespassers, should be carried out. The monitoring and data collection shall be carried out by a system sensing movements along the tracks. The requirements to the fences and the platform end systems can be adjusted after evaluation of the field trial data.

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[6] [BOStrab] – German regulations for the construction and operation of light railways (also applying to metros)

The protection of the tracks can be established before the driverless operation is introduced, as it does not rely on the driverless functionality. The field trial should be carried out timely to allow for this.

6.3 Stepless Boarding

6.3.1 Introduction

Following the transition to driverless operation, it will not be possible for a driver to assist disabled people (e.g. people in wheelchairs, etc.) entering or leaving the train as is the situation today. In order to comply with existing legislation[7], disabled persons shall be able to enter and leave the driverless trains, accordingly a driverless/staff-free solution will be required.

The key issue at the S-bane is the gaps (vertical and horizontal) between the train and the platform edge. An investigation has been carried out on an analysis of the magnitude of the issue (the size of the gaps at all stations) and potential solutions.

The solution recommended is based on the requirements in the field (including BOStrab regulation which is used for the Copenhagen Metro and in the EU regulation for person with reduces mobility, TSI PRM) and that the service level requirement for disabled people should be at least the same as today.

The whole analysis regarding stepless boarding can be found in appendix 3.

6.3.2 Conclusion

The analysis shows that the gaps are manageable with known solutions. The recommended solution is:

- Horizontal gaps are managed by an onboard gap filler
- Vertical gaps are managed by construction of ramps on the platforms

The horizontal gap can be bridged by a gap filler on the train which can cover the maximum gap between a train and a platform. Gap fillers are part of standard UTO trains and can bridge the gaps on the S-bane which are between 88mm and 403mm without additional costs.

The vertical gap can be bridged through construction of two fixed ramps in each train direction on the platforms. Ramps will be required on up to 85 of the 194 platforms where the gap is more than 50mm. A fixed ramp localised at one of the door positions will allow access to a train. It will not require maintenance and not cause any increase in dwell time. Establishment of ramps on parts of the platforms complies with TSI PRM.

For a few platforms the vertical gap is negative. According to TSI PRM this is allowed, but not according to BOStrab. A solution to this issue shall be found in a dialogue with the National Safety Authority.

The analysis of stepless boarding also reveals that the current manual solution is an outdated solution seen from both a service and operational perspective. In fact, it could easily be in contradiction with the relevant UN convention not to provide an automated solution once new trains will be purchased. An improvement of the current situation – e.g. removing the vertical gab by infrastructural adjustments as mentioned above – could then be required in any case and then not a particular UTO related issue. Stepless boarding is however a *need-to-have* solution for a driverless system and it is therefore included as part of the UTO project.

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[7] UN Convention on the Rights of Persons with Disabilities

6.4 Flexibility and Capacity Enhancing Infrastructure

6.4.1 Introduction

This section describes the infrastructure investigation. The focus for the infrastructure investigation has been the infrastructure readiness going from STO to UTO, including an increase of operation from 30 to 36 trains pr. hour. This focus investigation is made from a *need-to-have* perspective.

Beside the *need-to-have* investigations, *nice-to-have* investigations have also been made in this part of the report. The operational concept for UTO will change the timetable from 30 trains/hour to 36 trains/hour in the central section in the peak hours compared to today’s timetable. Normally when a train frequency is increased, the risk of failure and operation errors will also increase. The investigation analyses is if these failures can be minimised by implementing flexibility-increasing initiatives in the S-bane infrastructure. These investigations are from a *nice-to-have* perspective.

The whole analysis regarding Flexibility and Capacity Enhancing Infrastructure can be found in appendix 5.

6.4.2 Conclusion

The most important conclusion is that the current S-bane infrastructure can handle the implementation of UTO without need for any changes. The 36 trains/hour are possible through the central section and the different fingers can also handle their frequency, inclusive turnaround movements at the end stations.

The extra frequencies will create extra passengers, but the platforms will not need to be expanded in order to handle the extra passengers. This is due to the extra frequencies will distribute the passengers more evenly on the platforms over time. The only places on the S-train network were the trains will have more passengers boarding and un-boarding pr. train are at some of the stations on the fingers. These platforms have not met their capacity limit, whereby the platforms can handle the extra passengers without a problem.

In UTO the Ring Line is scheduled to 30 trains/hour in each direction in the peak hours. With UTO the trains will have a 1 minute scheduled turnaround time compared to 6 minutes for today’s timetable. In theory, 30 trains/hour on the Ring Line should therefore be possible (giving 2 minutes turnaround time), and with the new Signalling Programme implemented, the signalling system will also be able to handle 30 trains/hour. Ny Ellebjerg station will though be the restriction for the Ring Line’s timetable due to the placement of the crossovers at the station. To improve the robustness at Ny Ellebjerg station for the Ring Line, the crossovers can be optimised by changing them into a diamond crossing. This is a robustness improvement, but not necessary in order to obtain 30 trains/hour for the Ring Line.

A reversing track at Carlsberg, Copenhagen Central or Flintholm station has also been investigated. A scenario with one of these turnaround possibilities were deselected in the earlier phases of the project due to the financial calculations.

With UTO implemented for the S-bane network, the timetable will be more robust due to the extra flexibility of turning the trains around faster than the STO timetable. This can also be used in case of a fall-back situation, where the trains can run easier with one track operation and thereby have a positive effect during disruptions. The UTO timetable therefore has not a need for extra crossovers. The recommendations are still to implement new crossovers at Hvidovre and Avedøre stations, as this will make the timetable even more robust since it will result in the possibility of crossing over to the opposite track on the S-bane network every 10 minute (20 minute pr. direction). These crossovers will benefit both the UTO operation and today’s operation.

6.5 Power Supply

6.5.1 Introduction

This section describes the investigation related to power supply focusing on the additional need for power supply in the different scenarios, and the development of power efficiency of future trains.

The whole analysis regarding Power supply can be found in appendix 9.

6.5.2 Conclusion

Banedanmark has earlier made calculations of operational scenarios comparable to the Classic and the Metro UTO solutions resulting in the report "Effektanalyse af S-banen" (Analysis of power on the S-bane). The following costs for upgrading the traction power system to the UTO project are based on this data foundation.

Scenario	Number of trains	Cost
STO – Baseline	30	11.000.000 €
UTO – Baseline	30	11.000.000 €
UTO – Classic Style	36	17.000.000 €
UTO – Metro Style	36	19.400.000 €
UTO – Flexible	36	17.000.000€ – 19.400.000€

Table 3 – Cost for implementing UTO

The costs for already planned/conducted upgrades have been taken out of the cost estimate.

There are significant costs for upgrading the traction power system when implementing UTO, both for the Classic Style and for the Metro Style. Approximately 2/3 of the costs relates to upgrades that should already have been done regardless of the UTO project. These upgrades are however not planned/approved and are therefore included in the cost estimate due to the preconditions for the investigation (only approved projects shall be taken into account).

The future power consumption of the rolling stock is difficult to predict as there are two opposite trends in the market, pulling consumptions in opposite directions. The first trend is the development for rolling stock to be more efficient and with lower weight, thereby causing lower consumption for the propulsion system. The second trend is that there are more and heavier auxiliary systems, such as air-condition and passenger services in the rolling stock, thereby causing higher consumption for the auxiliary systems.

The trends will cause the peak consumptions to be reduced but the minimum consumption to be increased. This will have a positive effect on the traction power system, as the peak consumptions normally are the ones that define the capacity of the system.

Implementing new rolling stock to the system does not cause additional costs due to power consumption. Even though the new rolling stock is assessed to be an advantage to the system, the positive effect on the cost is assessed to be negligible.

6.6 Driverless Rolling Stock

6.6.1 Introduction

Introducing driverless operation on the S-bane will require the purchase of new rolling stock, or retrofitting of existing rolling stock. This study is based on the assumption that the S-trains will need to be replaced as they reach the end of their lifetime (2026-2036)[8].

This section summarizes the investigation of driverless rolling stock – the key elements of the investigation are:

- A proposal concerning the future train unit layout, including relevant design parameters
- Equipment for driverless rolling stock and cost estimate

The whole analysis regarding driverless rolling stock can be found in appendix 6.

6.6.2 Conclusion

Train design

Both future STO and UTO rolling stock should be based on a standard vehicle platform. The marked survey has confirmed that the future rolling stock for the S-bane can be based on "metro rolling stock".

Based on passenger data from OTM, it's concluded that 3-car trains (55m long) which can be coupled up to three times (max. train length: 165m) are the most viable solution for both UTO and STO rolling stock.

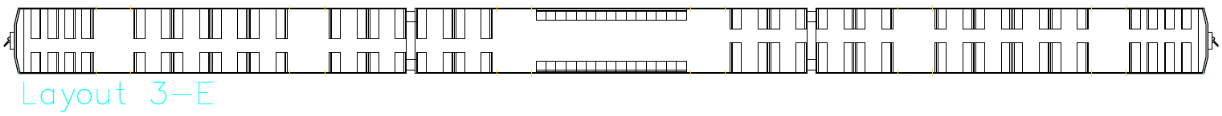

Figure 7: Proposal for interior layout of 3-sectional train set

A three car unit of 55m length provides for optimal use of the available infrastructure as three coupled units (9 cars) will utilise the full available platform length. Three carriage train sets are within the scope of the main manufacturer's standard products. Reference cases are Metro Line 1 Panama (Alstom), Downtown Line Singapore (Bombardier), Metro Oslo (Siemens) and Metro Madrid (AnsaldoBreda/ Hitachi Rail, CAF).

The concept provides:

- Adequately high seat numbers for passengers travelling longer distances on the S-Bane
- A slightly increased proportion of door width per train set, leading to an improved boarding/alighting performance
- A similar amount of multi-purpose space for mobility impaired, baby strollers, bikes, etc.
- An equal spacing of doors along the train even when operating as multiple units

The above concept recommendations complies with the train sets which the rolling stock suppliers can deliver. Further refinements will be required, but will be part of the rolling stock procurement process.

According to the assessment in section 5.1.3.2 of appendix 3 taking into account the existing infrastructure, an entrance height of 950 mm is recommended.

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[8] The lifetime is estimated to 30 years. The current 4th generation s-trains were delivered from 1996 to 2006

Rolling stock with a maximum speed of 120 km/h in UTO mode can be offered by all major manufacturers. Though 120 km/h is not common for metro platforms, major rolling stock manufacturers have indicated that upgrading of the body structure and bogies will not lead to major cost increases. For the structural design of a train, the classification of the operational environment is decisive. For the S-bane system a categorisation as C-II (rail vehicles exclusively designed for closed networks without interfaces to other traffic) according to EN 15227 is assumed (and should also be strived for in any discussions with the approval authorities).

Equipment for driverless rolling stock and cost estimate

The study includes a market survey in order to determine any additional on-board equipment requirements and cost of driverless rolling stock. The baseline for the market survey is in compliance with current legal framework for driverless operation (BOStrab[9] and FoF[10]).
The market survey shows that the following additional equipment will be needed for a UTO train:

- For the vehicle body: collision detection, derailment detection and gap fillers/detection
- For the doors: "remote control" (disabling doors) from operations control centre (OCC), "emergency release" and door control for automatic door control before departure
- For the infrastructure: Uninterrupted/continuous communication between OCC and trains at all times, including voice, video and (optional) the ability to check that the infrastructure is obstacle free. Alternatively, this can be achieved by operating the first train with a sweeper train (a train in automatic mode, but with a steward in front with the emergency control panel open and ready to push the emergency stop bottom) after a stand-still period, e.g. during the night or due to a possession

Investment estimates for the required fleet is based on recent procurements for similar rolling stock. Investment for UTO equipment is added. The investment cost is show in the following table.

Item	Cost in DKK
Cost for one 55 m STO train set Based upon procurement of new train sets for the Berlin S-Bahn which have a similar operating environment as the Copenhagen S-Bane	DKK 44 mio
Additional cost for inclusion of the UTO functionality Based upon data from the Nuremberg Metro and assessments due to increased train length and higher requirements in relation to reliability and worse accessibility for intervention	DKK 1,5 mio
Total costs per UTO trainset	DKK 45,5 mio

Table 4: investment estimates

Fleet size

The following table shows the fleet sizes for the various scenarios. Size of reserve fleet, maintenance and operational spare units, is equal to a proportion of 10% of the operationally required fleet size.

	Operational required units	Maintenance spare	Operational spare	Total fleet size
Base STO	**146 units**	13 units	2 units	**161 units**
Base UTO	**141 units**	12 units	2 units	**155 units**
Flexible + 0%	**159 units**	14 units	2 units	**175 units**
Flexible + 5%	**173 units**	15 units	3 units	**191 units**
Flexible + 10%	**184 units**	16 units	3 units	**203 units**
Flexible + 15%	**185 units**	16 units	3 units	**204 units**

Table 5: Fleet size

[9] BOStrab – German regulations for the construction and operation of light railways (also applying to metros)
[10] Fahren ohne Fahrzeugführer – operation without train drivers

6.7 Combining and Splitting of Trainsets

6.7.1 Introduction

Metro systems are in general characterised by a relatively even demand pattern throughout the day, while suburban train networks typically have a fluctuating demand pattern between lines and throughout the day. Coupling is a common procedure on S-Bane systems. Besides Copenhagen, it is carried out on all e.g. S-Bahn systems in Germany (Hamburg, Berlin, Hannover, Rhein-Ruhr, Frankfurt, Munich, Rhein-Neckar, Stuttgart, Karlsruhe), but also in other European countries (e.g. Vienna, Paris, Madrid).
The current operation on the Copenhagen S-Bane is based on around 40 or 80 meters train sets which can be coupled to form trains up to 170 meters. The study investigates if the coupling possibility shall be available in case of implementing UTO on the S-Bane.

The whole analysis regarding combining and splitting of trainsets can be found in appendix 7.

6.7.2 Conclusion

The Ramboll/Parsons study shows that operation with coupling is the most feasible solution for the S-bane. This finding and recommendation is based on assessment of the future demand/capacity and cost estimation of the two concepts: operation with or without coupling.

The figure below shows the connection between demand and required capacity of the flexible scenario.

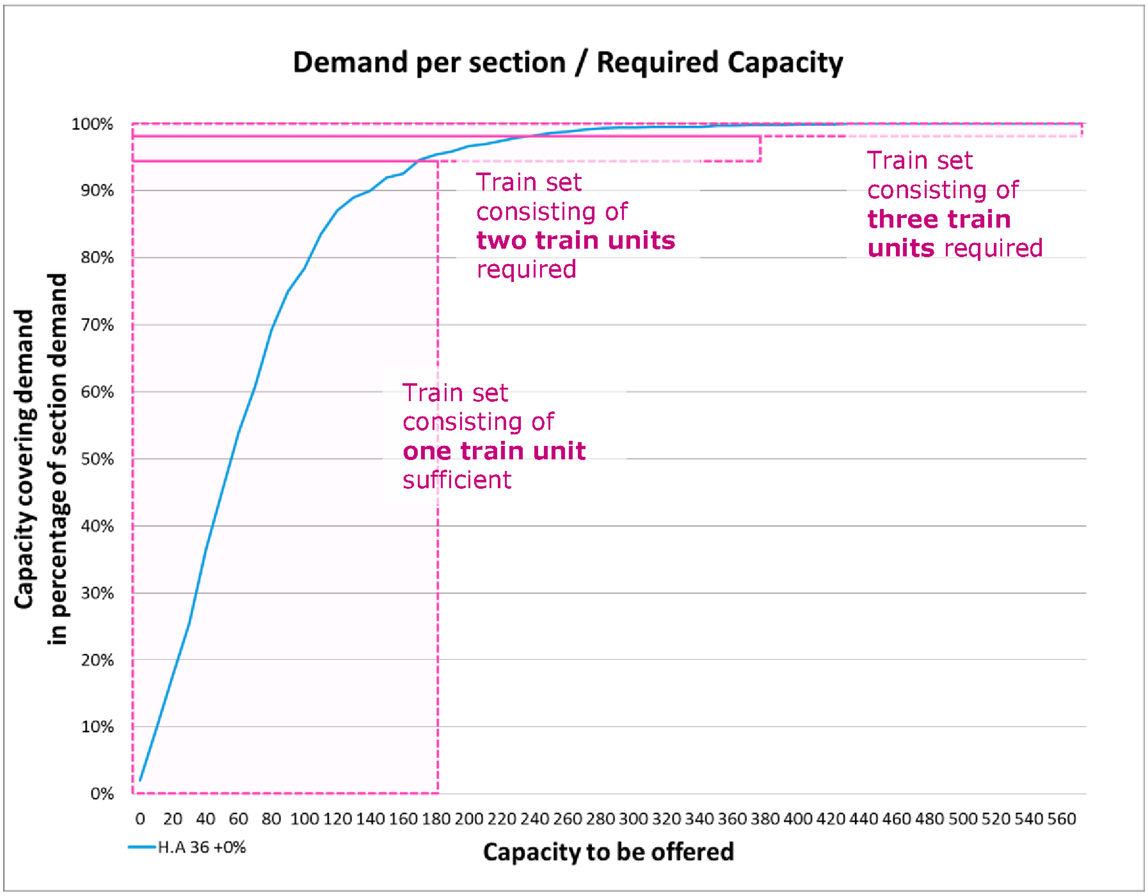

Figure 8: Distribution of section demand versus train set capacities

The financial effectiveness of coupling can be derived from the figure. It shows that more than 95% of the demand on the S-Bane could be covered with a single (three section) train set. Resulting in approximately 80% of the services could be operated as single units.

The remaining 20% of service will require trains with a larger capacity due to 5% of the section demand. If a concept without coupling is chosen, this will result in a scenario with a huge overproduction of capacity, because all trains would be dimensioned to handle the maximum demand.

As shown in the figure, a train set of 2 coupled units is sufficient for a majority exceeding 99% of services to cover the demand in the flexible scenario +0%. In case of increasing passenger numbers, it is possible at any time to operate with a full train set length of 3 units.
The cost of train sets without coupling facility in regular operations is assumed to be 5% lower than for train sets with coupling facility. Higher efforts are required for design of platform safety system if a system relying on intrusion detection is utilised.
The signalling system should be capable of coupling, as coupling takes place already today. Automated coupling can be executed at all stations and in stabling areas.

The annual operational costs for train sets with coupling facility is assessed to be at least 30% lower than for train sets without coupling facility on the S-Bane, as demand fluctuations between lines and throughout the day can be better taken into account.
A 3-sectional train design will lead to a yearly saving on 31% or 62 mio. € compared to a concept without coupling for the flexible scenario (without any increase of the OTM-figures). When allowing free bikes and subsequently increased train capacity for peak hour traffic, there will be a further increase in savings due to coupling.

If coupling should prove to be especially challenging in terms of operational reliability in bad weather periods (heavy winter conditions), it could be chosen not to uncouple the train sets (i.e. run with long trains) causing a higher operating cost in minor periods. This approach is already used by DSB today.

All manufacturers have indicated that the unattended coupling is something they either have already delivered, or will deliver in the future. Siemens has delivered unattended coupling as a feature for the Nuremberg unattended metro system.

The table below summarises pro for the two concepts (operation with or without coupling) on key parameters.

	Arguments pro short units with capability to couple	**Arguments pro longer units without capability to couple**
Vehicle procurement	• Enables procurement of only one type of train unit for the whole system, also reducing the need of different maintenance spares (both parts and rolling stock) compared to the procurement of different vehicle types • As demand fluctuates not only during the day but also throughout the network, the purchase of long unit trains would require invest without the corresponding need	• Optimization of train length in regard to existing infrastructure also for Ringbane possible • Lower invest per capacity for vehicle due to longer units and no need of coupling equipment
Service and operation	• Significant reduction in operating cost • Increasing service quality by running short units several times instead of one long unit running once - at comparable marginal costs • Increase of operation flexibility with only one type of train unit • Increased capacity according to temporary events causing higher service demand – e.g.	• Time for de-/coupling extending circulation reduces turnaround buffer which could be used for delay compensation • Combining and splitting adds uncertainties to the system, which have to be compensated by reliable technical solutions

	concerts, sports events, etc. • Rescue of broken/degraded trains – coupling makes recue of degraded trains in the network much easier thus it will be possible to transport a degraded train to the workshop by a functioning train • Higher ability to meet future demand – e.g. if the rush hour expands (which is a general tendency in metropolitan areas) it will be possible to meet this demand by increasing capacity enabled by coupling	and operational workarounds
Maintenance	• A higher share of maintenance work, which can be done during low peak periods at daytime • Lower running performance per individual unit extending fleet's life span • Vehicle length will fit into the current workshop capacity	
Stabling	• Current stabling capacity sufficient for new fleet of coupleable units but not for a fleet without coupling feature, additional invest would be required	

Table 6: Comparison of concepts with or without coupling

Taking the above into consideration the most advantageous solution for the S-Bane will be coupling of the train sets.

6.8 Depot and Workshop

6.8.1 Introduction

A procurement of new rolling stock for driverless operation on the S-bane could require an adaptation to maintenance facilities and stabling areas. The current facilities are designed and optimized for the layout of the current SA and SE units.
This section summarizes the investigations of identified adaptations.

The key elements of the investigation are:

- A proposal concerning the stabling concept and assessment of required empty running mileage
- Assessment of current maintenance facilities
- Estimation of future needs and development of a refurbishment concept for the workshops

The whole analysis regarding depots and workshops can be found in appendix 8.

6.8.2 Conclusion

Today the stabling facilities already have sufficient capacity for the future fleet size. However, some dead running will be required. To reduce this, it may be prudent to construct some additional stabling facilities. The economic benefits of doing so should be evaluated once the future operating concept has been chosen.

While some adaptations to the workshops are required, these can be accommodated largely within the footprints of the existing workshops.

Stabling areas

Referring to Appendix 6, the train unit length is assumed to be 56 m. In particular, smaller stabling areas at the terminal stations seem to be designed for a train set consisting of two SA-units. As the unit length for the proposed concept is one third this length, existing capacity can be used very efficiently. Comparatively, low capacities can be found north of the central section, in particular along the Farum- and Hillerød-fingers. At the terminal stations Holte, Buddinge, Østerport and Solrød Strand, no stabling areas are available.
The total stabling capacity on the S-bane network would be sufficient for 240 train units of 56m length. The working assumption for the elaboration of the stabling concept is that all stabling will be equipped for UTO. Exceptions are the stabling tracks and workshop in Høje Taastrup and the workshop in Hundige, where manual shunting would be required.

As the maximum fleet size including spares is 204 units in Scenario Flex 36 +15%, the need for additional stabling capacity can be avoided if some deadheading and/or capacity enhancements at the other end of the line are accepted.

Already in the Base STO scenario a significant amount of empty running is required. UTO-cases, Base UTO and Flex 36 require fewer services without corresponding demand.

The table give an overview of extra running performance:

Scenario	Operational required train units	Add. daily running performance *in train unit-km*	Additional train-km per day	Annual operating costs due to lack of stabling capacities *in mio. DKK*	Difference in annual costs to Base STO-case *in mio. DKK*
Base STO	146	1.785	1.323	**14,2**	
Base UTO	141	1.793	1.192	**14,1**	**- 0,1**
Flex 36	159	1.621	1.390	**13,2**	**- 1,0**
Flex 36 +5%	173			**18,9**	**+ 4,7**

Flex 36 +10%	184			**23,3**	**+ 9,1**
Flex 36 +15%	185	3.007	2.070	**23,7**	**+ 9,5**

A reduction of the mentioned costs can be achieved when measures to extend the current stabling capacity and the construction of new stabling areas are realized. Once the future operating concept has been chosen, a detailed analysis should assess the most economically effective actions.

Workshops
Two workshop sites near Høje Taastrup and Hundige stations provide maintenances services to the S-tog fleet. Whereas Høje provides the majority of services including heavy maintenance, Hundige is only equipped with facilities for light maintenance and exterior cleaning. As the new proposed train layout differs in various points from the existing S-tog units (two axles per bogie instead of one, two bogies per body section, increased section length, diverging train unit length), significant changes to the configuration of work stands and equipment are expected.
Depending on the scenario, fleet sizes increases by 6 to 56 train units. Maximum fleet size of 191 units represents an expansion by 40 % referring to the number of train units.

It is assumed that today three work stands are kept for exterior cleaning, 9 for light maintenance and 7 for heavy maintenance.

The new concept requires that on workshop tracks for heavy maintenance in Høje Taastrup and tracks in Hundige, where today one unit is maintained, in future two units in-line will be treated. For light maintenance facilities in Høje Taastrup, where today two units per track are processed, the elaborated concept proposes to maintain three units at once.
UTO related equipment does not require additional track capacity.

The increased number of work stands without a direct access will mean that the average occupancy per work stand could decrease. As far as possible, service and maintenance plans should therefore be adapted to counteract bottlenecks.

After refurbishment, 13 working stands would be available for heavy maintenance. Two lots in Hundige and 12 in Høje Taastrup are reserved for light maintenance. Graffiti removal and exterior washing can be done for 5 units at once. In total, 27 units could be handled for maintenance activities at once.
In total, investments of 17,3 mio. € resp. 128,7 mio. DKK are required for fitting of existing structures to the new fleet. Extensive extensions of yard and buildings will not be required.

More detailed design will have to be carried out in future project phases to confirm, or adjust any assumptions made for this assessment.

It is proposed to apply all modifications already for the Base STO-case, to exploit the potential of existing structures.

6.9 Rollout Plan

6.9.1 Introduction

The roll-out plan describes the project execution phase with special focus on the onsite installation and commissioning of the rolling stock.

The whole analysis regarding rollout plans can be found in appendix 10.

6.9.2 Conclusion

The roll-out plan is based on the conditions prescribed by the infrastructure and rolling stock choices. The expected rolling stock delivery frequency is about one unit per week, resulting in a delivery period on approximately three years. The infrastructure changes (e.g. implementation of ODS, fencing, etc.) shall in general be implemented before the new rolling stock are delivered. The implementation of infrastructure changes is estimated to take approximately one year per main line.

Another major fix point and precondition for the roll-out plan is the economic time of the existing rolling stock fleet – which will reach the end of their lifetime from 2026 to 2036. 2026 is therefore chosen as the fix point for the main rolling stock delivery. A prolongation of the lifetime of the existing fleet is possible but will of cause increase the maintenance cost.

Prior to the roll-out, there will be a tender phase, where the system specifications are defined and a contractor(s) are chosen to execute the project, and a design phase where the contractor is designing the system. The main project phases – with focus on the roll-out period – are outlined on the figure below.

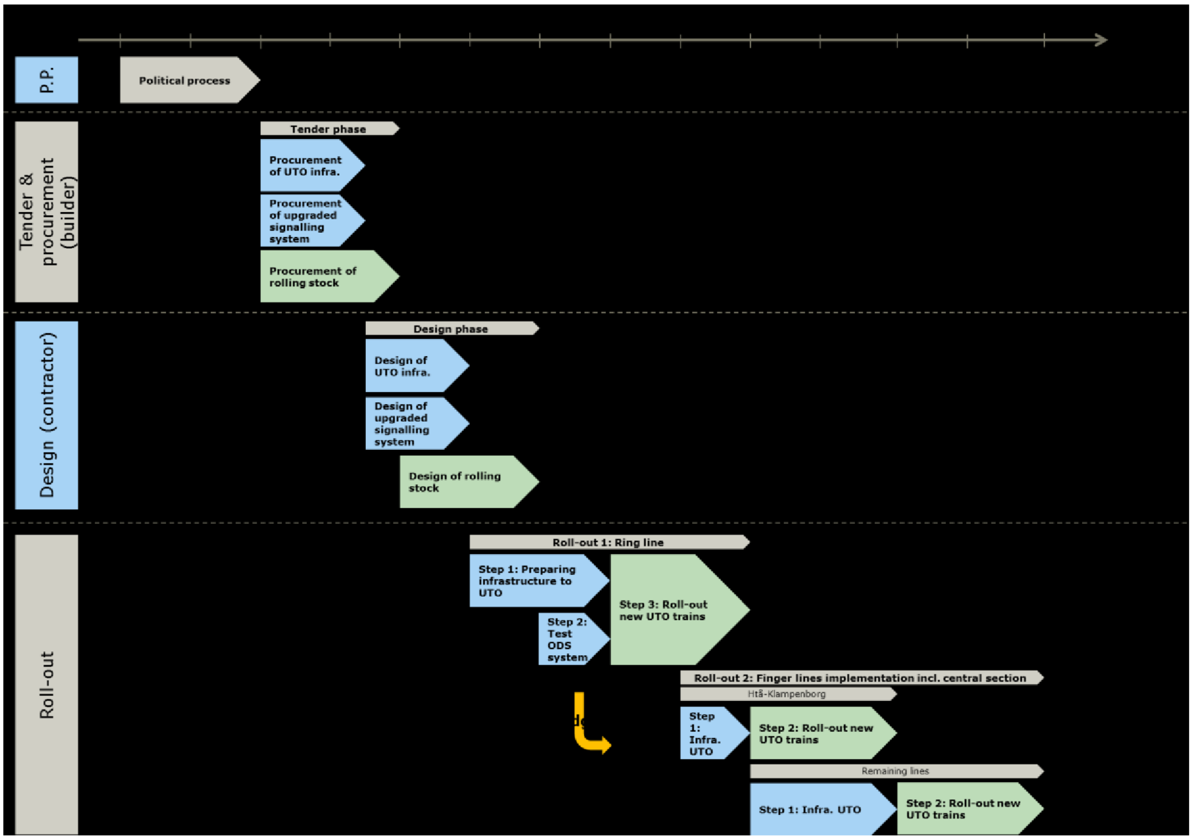

Figure 9: Overall roll-out plan

The overall roll-out plan shall be considered as a conceptual, but a robust plan. However, external projects and political processes may affect the plan – e.g. postpone the starting point of the project.

Overall approach
The proposed strategy includes the implementation of a pilot scheme using the Ring line first to acquire experience on newly installed UTO systems and to minimize risks before rolling out the new UTO systems on the rest of the S-bane. In order to use the Ring line as a valuable pilot project – and a key risk mitigation – it has to timely placed so knowledge can be transferred to the main project. It is therefore recommended, to place the pilot at the Ring line so knowledge from testing and commissioning can be taken into account in the design phase of the main project.

Furthermore, the advantage to use the Ring line is that it is not interfering with the central section and that any new timetable can be easily implemented. The roll-out on the Ring line will take place from 2022-2026.

Once the Ring line has been converted to UTO, the following step-wise rollout is recommended:

1. Migrate Høje Taastrup – Klampenborg (2025-2028)
2. Repeat the migration steps on Farum – Frederiksund (2026-2030)
3. Repeat the migration steps on Hillerød – Køge (2026-2030)

The decision on which line to be migrated first should is based on the complexity of the line (start with the most simple) and the consideration for permanent depot and workshop accessibility.

Roll-out strategy
The specific roll-out strategy for each line will take place in two main steps:

1. Preparing and testing of UTO infrastructure
   This step includes upgrading of the signalling system from STO to UTO, installation of ODS including new control-center, and fencing of the tracks. This step also includes testing of the systems and their interfaces
2. Rolling out new UTO trains including testing
   This step includes the roll-out of UTO trains on a given line. The first sub-step will include testing of train-infrastructure interface during night/non-commercial operation. Hereafter, when the test is completed, the new trains will be put into commercial operation as they are delivered.

This implementation approach implies that the new UTO trains (operated in UTO) and existing S-trains will be operated in mixed operation during the roll-out. This reduces the need for drivers, allowing smooth driver attrition and will reduce cost for Rolling stock (no temporary driver cab). This type of migration – mixed operation – has been implemented on a range of projects e.g. the RATP Paris Line 1 and Nuremberg.

The roll-out period will furthermore be used to gather data from the ODS system in order to determine if Rope VPSD are needed at some stations in order to obtain the required service level.

Procurement strategies – Time Plan
There are three types of procurements to be planned:
1. Contract change to S-Bane Siemens CBTC contract (with Banedanmark) for the upgrade of their CBTC system to UTO. This contract change can be prepared in advance and negotiated well ahead of the 2022 deadline for starting the roll-out of UTO on the F-line. We estimate that this contract change could be negotiated over a period of 6 to 12 month maximum

2. Procurements of all supporting infrastructure UTO systems: ODS, fencing, power, adjustments of platforms (stepless boarding), etc. This procurement can also start well ahead of the 2022 deadline for starting the roll-out UTO on the F-line. It is estimate that this procurement would last 1 year
3. Procurement of new UTO rolling stock. The tender phase for procuring new trains typically requires 2 years from the start of writing the specifications and contract award. The procurement should include a base order for buying new trains for the F-line with an option to be called for buying the rest of the rolling stock to be rolled out on the entire system. Equal prices for new Onboard CBTC system will be ensured by Banedanmark who will execute a contract change to the S-bane CBTC contract with Siemens

Safety approval
One of the benefits of implementing the new UTO system on the F-line is to try out the safety approval process for:

- Upgrading the CBTC system from STO to UTO
- Introducing new rolling stock in UTO mixed with STO trains
- Introducing ODS and ADAS system

The main risk that is foreseen is to obtain an approval for the operating rules for mixed traffic (STO/UTO).
Approval of UTO rolling stock is not particularly risky as it has been done before for the Metro.

Impact on the business case
The proposed rollout strategy offers several economic advantages for the business case:

- Direct introduction of the new train in UTO. This allows to avoid having a temporary cab for drivers (additional asset cost) and to start early realizing the savings by removing the drivers from operation
- By rolling out and proving the new UTO system on the F-line, this will de-risk the whole project and reduce the risk of additional development, delayed safety approvals, etc.

7. ORGANISATION

7.1 Introduction

The objective of the assessment of the organisation and staff implication is to estimate the derived input to the overall business case. Obviously, the transformation to a UTO scenario will have an impact on different functional categories that will need to be planned and managed in detail. The analysis will also provide an overview of the magnitude of this transformation.

All estimates however, are based on available data and knowledge, and assessments must for that reason be revisited and refined as soon as the new scenario develops further. As direct staff implication primarily involves DSB, the included functional categories only come from there. Although there may be minor staff consequences for BDK these are excluded due to insignificance for the business case.

The whole analysis regarding organisation can be found in appendix 12.

7.2 Conclusion

From an organisational perspective introducing driverless trains it is expected to result in a total savings of 327 mDKK, whereby 270 mDKK comes from staff reductions and 57 mDKK is a result of indirect savings. While staff reduction has a direct impact derived from reduced total payroll, the indirect savings is related to reduced associated cost like it-cost, training cost, support function cost, etc[11].

As shown in Figure 10 below, the main source of savings from staff reductions comes from removing the train drivers resulting in expected savings of 270 mDKK. Reducing the shunting personnel by 75% results in savings of 24 mDKK, while the reduction of supervisors for train drivers and coordinators amounts to a combined saving of 11 mDKK. In order to provide more service personal in exchange for task currently associated with the train driver, hire of additional 57 train stewards creates extra costs of 30 mDKK. Equally, an increase in supervisors for these new train stewards creates extra costs of 3 mDKK.

Figure 10 - Staff savings in UTO scenario (mDKK)

Note: Extra costs due to an increase in employees are illustrated with negative numbers

Figure 11 shows the indirect costs savings in the UTO scenario. As illustrated, the main savings come from training costs and the support function costs that are related to the number of employees. Together these two cost groups account for around 70% of all indirect savings. The remaining savings come from reduced VAT and payroll tax (10 mDKK), Taxi (3 mDKK) and IT (2 mDKK).

[11] As-Is operation and performance in DSB 2016 is used as bench-mark for the estimates. I.g. no potential improved efficiency in the future is talking into account.

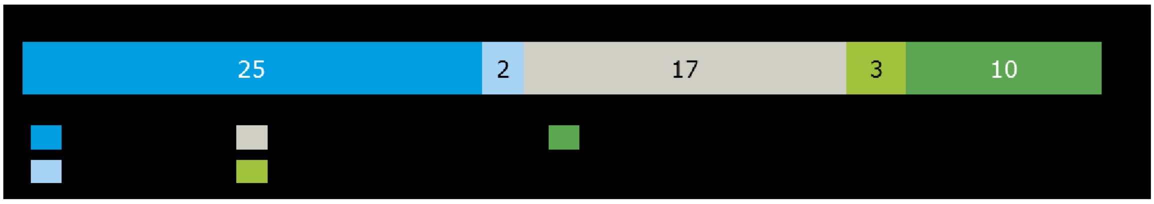

Figure 11 - Indirect costs savings in UTO scenario (mDKK)

The included staff functions and indirect cost saving in the analysis are based on assessments of the functional areas, where transformation to a driverless mode will have the most significant impact. For further elaboration of these boundaries referring to appendix [12].

7.3 Analysis

The analysis is based on cost information and employee data provided by DSB. To the extent were the levels of details in data have been insufficient for purpose, assumptions, expert statements from key stakeholders, e.g. comparable capacity figures from Metroselskabet, and extrapolation have been used. For further information about assumptions and methods refers to appendix [12].

7.3.1 Staff adjustments due to driverless operation

Table 7 below shows the estimated changes for each of the employee groups included in the business case. The most essential groups are described below while a more comprehensive explanation is provided in appendix [12].

Employee group	FTE in current scenario	FTE in UTO scenario
Train drivers (incl. trainees)	526	0
Ticket inspectors*	123	180
Supervisors – train drivers	11	0
Supervisors – train inspectors	12	20
Coordinators	8	3
Maintenance personnel	211	211 (236)
Shunting personnel	63	16

**Ticket inspectors will be converted to train stewards*

Table 7 - Expected changes in staff composition in current and UTO scenario

Since driverless trains will make the driver position obsolete, the train drivers will be reduced to zero from the current 526 FTE’s. Thus, the reduction of this group represents by far the largest savings in the business case.

The ticket inspectors are still needed in the new scenario, although their role and tasks will change to some degree. The new key front staff will be train stewards who will be on the system for service and fall back, information and ticket inspection. Hence the ticket inspector job role will be absorbed by the train steward role. To ease the transition, it is suggested that their current employee terms are kept intact, since they will still be on the same collective agreement. The average payroll expenses are expected to decrease over time as current train inspectors on perhaps more favourable conditions or higher seniority will retire. It is estimated that 180 train stewards are needed in the new scenario, which equals an increase of around 46%. Supported by 20 supervisors, in total 200 employees will in the UTO scenario be engaged as Service Stewards.

Currently the shunting personnel on the depot tracks uses 75% of their time on tasks related to moving trains (depot tracks are parking tracks close to the operating railway and will be fully equipped with UTO). In an UTO scenario, this task will be almost entirely automated, with the only exception being when trains are moved to maintenance areas, where the movement of trains will be manual. Thus, the current 63 FTE's are reduced to 16.

Smaller changes will happen to the remaining part of the observed population.

7.3.2 Transition period

The roll-out phase is set to be 2024-2030 as defined in chapter [6.9], and with the driverless operations being fully functional from 2030. Thus, staff reductions are assumed to take place gradually in the years 2024-29, following the pace for introduction of new material as shown in the table below.

2024	2025	2026	2027	2028	2029	2030
5%	5%	15%	15%	30%	30%	0%

Table 8 - Expected roll-out pattern from 2026-2030

Distributed into actual numbers and staff categories, the adjustments are expected to follow the pattern illustrated in the table below.

Year	2024	2025	2026	2027	2028	2029	2030	Total
% roll-out	5%	5%	15%	15%	30%	30%	0%	
Shunting personnel	-2	-2	-7	-7	-14	-14	0	-47
Supervisors - train drivers	-1	-1	-2	-2	-3	-3	0	-11
Supervisors - train stewards	0	0	1	1	2	2	0	8
Coordinators	0	0	-1	-1	-2	-2	0	-5
Maintenance personnel	0	0	0	0	0	0	0	0
Train drivers	-26	-26	-79	-79	-158	-158	0	-526
Train stewards	3	3	9	9	17	17	0	57
Total personnel change due to UTO	**-26**	**-26**	**-79**	**-79**	**-157**	**-157**	**0**	**-524**

Table 9 - expected personnel change due to UTO, 2024-2030

Based on the employee adjustments described above, all savings are expected to be achieved in 2030. The expected realization of savings for each year is shown in Table 10 below.

Year	2024	2025	2026	2027	2028	2029	2030	Total
% roll-out	5%	5%	15%	15%	30%	30%	0%	
Savings from staff reductions	13.480.407	13.480.407	40.441.220	40.441.220	80.882.439	80.882.439	-	**269.608.130**
Indirect savings	2.874.401	2.874.401	8.623.204	8.623.204	17.246.407	17.246.407	-	**57.488.025**
Total savings	**16.354.808**	**16.354.808**	**49.064.423**	**49.064.423**	**98.128.846**	**98.128.846**	-	**327.096.155**

Table 10 - Expected realization of savings

7.4 Natural staff reduction

A key question of interest for the business case will be estimates around the transformational staff profile from current to future state. For that reason, the natural staff reduction defined as the total sum of retirement and resignation (e.g. new job) has been estimated. Equally, as the cost and conditions for employees differs according to different employment terms the figures are divided into regular employees and public servants as illustrated in the table below.

Year	2024	2025	2026	2027	2028	2029	Total
Attrition - retirement	**16**	**16**	**16**	**16**	**16**	**16**	**96**
Regular employees	8	8	8	8	8	8	46
Civil servants	8	8	8	8	8	8	50
Attrition - other reasons	**20**	**19**	**19**	**18**	**17**	**17**	**110**
Regular employees	20	19	19	18	17	17	110
Civil servants	0	0	0	0	0	0	0
Total attrition	**36**	**35**	**35**	**34**	**33**	**33**	**206**

*Note: retirement numbers add up differently due to rounding (7.6*6=45.6 ~ 46 and 8.4*6=50.4 ~ 50)*

Table 11 - Expected attrition for S-train drivers, 2024-2029

A total of 96 train drivers are expected to retire within the period of 2024-2029. When it comes to depletion due to other reasons, and estimate of 4% p.a., derived from historical evidence, a total number of 110 train drivers will leave in the period of 2024-2029. Due to the attractive employment terms, it is assumed that no civil servants will leave DSB due to other reasons, other than retirement.

Thus, the annual attrition, both due to retirement and other reasons, is estimated to 35 S-train drivers per year on average, equalling a total number of 206 train drivers for the period 2024-2030.

7.4.1 Civil servants

Currently DSB has 150 civil servants employed as train drivers. Since this employee group have special employment terms, it is relevant to estimate how this employee group is expected to change due to attrition towards the full implementation of driverless trains in 2030. A total number of 93 train drivers employed as civil servants are expected to retire from 2016-2029.

Although the introduction of driverless trains will not take place until 2026, the attrition will be ongoing and gradually reduce the number of civil servants. More specifically, from 2016-2024 the number of civil servants will be reduced due to attrition, and employees on regular employment conditions will be hired to refill their positions. From 2024-2029, the positions will no longer be reoccupied. Figure 12 illustrates this trend, by showing the composition of S-train drivers for the entire period, including only the natural attrition and excluding the planned staff reductions from 2024-2029.

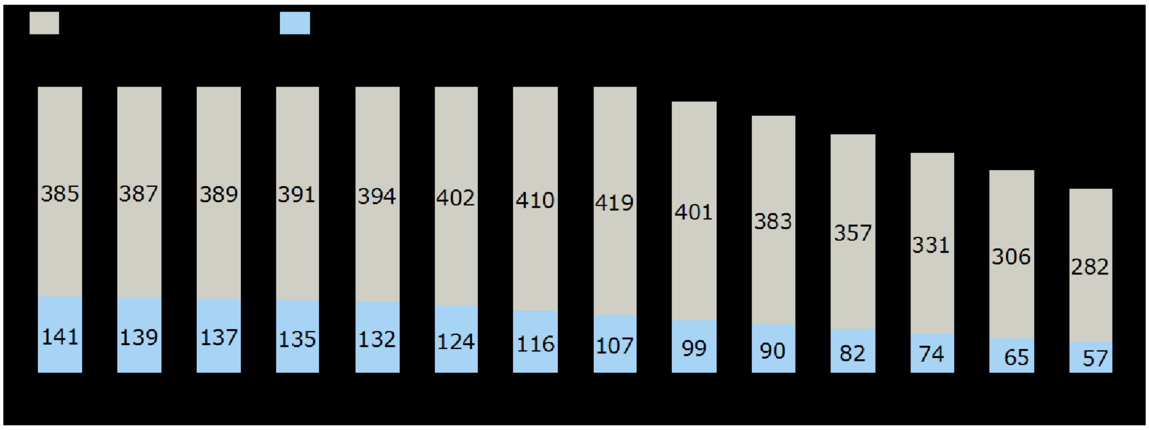

Figure 12 - Composition of S-train drivers without planned reductions, 2016-2029

From 2016-2024, it is estimated that 51 civil servants will retire and be replaced with train drivers on regular employment conditions. From 2024-2029 another 42 will retire, but these will not be replaced. This leaves a remainder of 57 out of 150 civil servants.

7.4.2 Handling of excess employees

Although the substantial natural staff reduction, it will not be sufficient to absorb the entire work force. As shown in Table 12, a total of 339 train drivers will be in excess and will have to be terminated or employed elsewhere in the organization. Out of these, 57 are estimated to be civil servants, of which many are expected to retire in the following years. This number may in reality be lower, assuming that some train drivers may retire before the age of 65.

	2026	2026	2026	2027	2028	2029	Total
Needed employee reduction	26	26	79	79	158	158	526
Natural attrition	-36	-35	-35	-34	-33	-33	-206
Excess employees	**0**	**0**	**44**	**45**	**125**	**125**	**339**

Note: in 2024 and 2025, the natural attrition is higher than the needed employee reduction. Since this "deficit" of employees cannot be transferred to the following years, the number of excess employees is set to be 0 rather than -10 and -9 respectively

Table 12 - Excess train drivers, 2024-2029

An opportunity to reduce the number of excess train drivers would be a transfer to regional or long distance trains (fjernbanen), although this would require an additional 6.5 month training period[12]. It's estimated that around 1000 train drivers are employed within this area at DSB. Assuming similar characteristics with the S-trains, the annual attrition is expected to be around 78 train drivers, equalling a total number of 310 for the entire period, since no train drivers are transferred in 2024 and 2025.

Based on the estimated numbers and experience from the signalling program, the most significant challenge for DSB may then in reality be retention rather than handling of excess employees. With 339 train drivers in excess and an estimated absorption capacity from intercity and regional trains of 310 as well as other opportunities for reemployment, there may be very few problems with excess employees. Rather it would be important to ensure that enough train drivers stay on board to secure operations until a full transition to UTO, since many may be expected to start seeking opportunities elsewhere as soon as the plans are revealed.

It's recommended that dedicated strategies and formulated initiatives supporting a smooth organisational change management process are incorporated in a potential future transformation.

[12] A 14 month training period is required for being a regional train driver. S-train drivers need a 6.5 month training upgrade (including litra training) when making the transition from S-train drivers to regional train drivers

8. RISKS AND COST ESTIMATE

Any new infrastructure project must be based on a formalised risk assessment covering identification of potential risks, assessment of their probability and impact which defines the projet's risk profile. It is part of the initial decision process and leads to an evaluation of the project's reliability. During the later preparation and implementations steps it is an associated management process defining risk ownership, mitigation and follow-up activities continuously.

From an initial perspective the UTO does have a particular risk profile.

Many elements pull the entire project in a very promising direction: UTO is a well proven operational mode, infrastructural detecting systems on platforms and in between station have been successfully in operation for years, and several types of driverless rolling stock has been in operation worldwide during the last decades. Only to add on top, that technical stability and refinements are continuously improving each of these elements. Easier, cheaper, more well-functioning and more reliable solutions have emerged during the last decade and improved solutions compared to what mentioned in this report will definitely be available when UTO potentially shall be implemented at the S-bane.

The other way around: UTO with the particular characteristics of the S-bane is not in function anywhere. The size and complexity of the total S-bane, almost entirely above ground and high speed compared too many rail metro systems are all well-known elements, however not in combination. The general risk assessment must be related to this fact. In the following sections a further analysis is conducted.

The whole analysis regarding risk assessment can be found in appendix 11.

8.1 Overall Assessment

As an introduction to a traditional event based risk assessment it is relevant to reflect on the overall risk level associated with the project as a whole. Looking into this focusing on the development and transformation, leaving the future operation excluded, two main sources of risk shall be mentioned.

The first source is related to the fact that the feasibility of the project relies heavily on external infrastructural factors outside the UTOs span of control: CBTC signalling technology upgrade enabled by the Signalling Programme is required and a firm precondition for further development into fully driverless operation. Equally, the ability not only to operate driverless, but also to increase the frequency in the central section of the network will rely on the same external factor. The UTO project relies on a future infrastructural state which neither a reality nor in control of the UTO project to obtain.

The second main source is related to the *combination* of various well proven technologies and standardised solutions, that, when brought together in context, might cause a risk per se due to the increased complexity of the total system. All suggested solutions related to rolling stock, platform edge safety, coupling, etc. are in commercial operation today. Also, driverless concept is very well functioning in several above ground cases, required max. speed is standard delivered by manufactures, etc. However, some of these elements will be combined in new patterns and concepts that have not been tested elsewhere in a similar configuration. In that aspect driverless operation at the S-bane does bring a new situation, which as circumstance will introduce a risk.

Based on these two risk sources, it's the assessment that the specific UTO project can be associated to an overall risk level characterized as medium at the current state of preparations. The likelihood of actual occurrence of events, that might have a substantial impact on ability to deliver as planned shall not be underestimated or neglected. Thus, continued careful risk assessment shall be carried out and cover all parts of the project throughout the continued project formulation process. Mitigation of all identified events identified through this process shall be incorporated in the project. This process shall continue during the subsequent tendering and implementation phases.

On the basis of the project analysis carried out the risk assessment, it indicates an overall score of 35-50 in a range from zero to 100, thus the overall risk assessment for that reason can be classified as medium. This assessment shall be seen in the light of the fact that much more evidence about the mentioned external infrastructural development and its performance, i.e. the proof of the CBTC concept, will be available before crucial UTO decision is required. This proof and reliable information about the performance of the CBTC system will be based upon operational experience and be in place way before decisive choices must be made in a potential UTO project.

8.2 Event based Risk overview

The distinct most substantial risks for implementation of UTO are described in further details below.

Risk	Mitigation	Evaluation
Organisational resistance Resistance from train drivers and Unions becomes too strong and that results in skilled personnel may leave DSB due to uncertain future and make train operation unstable in transition period and increased price due to mitigating actions or unexpected negotiated incentives	• Well-balanced roll-out plan based upon staff parameters e.g. age, potential transfers from S-bane to Fjernbane, etc.	Probability: 35-60% Impact: 1-5%
Procurement strategy A procurement strategy which does not reflect the project context and objectives can lead higher prices than expected	• The procurement strategy shall ensure a "correct" division of deliveries – e.g. separation of the CBTC system (client delivery) and the rolling stock (supplier delivery)	Probability: 1-10% Impact: >25%
Procurement of rolling stock The requirement specification leads to over- or under-specified which results in higher prices than expected or a low quality product	• Use the Ringbanen as a pilot project including a lesson-learn period in order to implement the key findings for the rest of the rolling stock procurement	Probability: 1-10% Impact: >25%
Organisational and technical changes Parallel implementation of organisational and technical change projects can result in project chaos	• Ensure separation of the two projects – the potential organisational change is completed before or after the technical change	Probability: 10-35% Impact: 15-25%
Complexity and interfaces The combination of the following three factors makes the S-bane	• Use the Ringbanen as a pilot project including a lesson-learn period in order to implement	Probability: 35-60%

unique: 1. The size of the S-bane 2. It is above the ground 3. The solution is driverless (UTO) This complexity can cause events to which there are no prior experiences about, e.g. too costly changes to existing infrastructure	the key findings for the rest of the project	Impact: 15-25%
"Brown field" project The S-bane is not designed for a driverless system – changing an existing railway will cause unforeseen challenges	• Involve stakeholders in project formulation and preparation in order to ensure compliance with actual conditions and minimising disruption of ongoing operation	Probability: 35-60% Impact: 5-15%
Future transportation needs Uncertainty about future technology and transportation patterns make decided concepts outdated	• Continue collection of technology experience worldwide and assess them • Regular update of traffic forecasts using Ørestadmodellen	Probability: 1-10% Impact: 1-5%
Delay or quality degradations of the Signalling Programme The UTO project relies on the signalling programme. Additional delays or quality degradation of the signalling programme will have directly impact on scope of the UTO project – e.g. delays of the signalling programme will in case of further delays also create delays of the UTO project. Potential quality reductions of the final STO signalling system will cause a need for extension of the scope of the UTO project in order to obtain the necessary functionalities	• Follow the Signalling Programme development and raise concerns towards the Signalling Programme in case of timing, quality, performance or functionality changes for the CBTC system in order to ensure that UTO project preconditions will be fulfilled with respect to the CBTC system	Probability: 10-35% Impact: 5-15%
Automatically coupling The automatically coupling does not work as assumed	• Use the Ringbanen as a pilot project including a lesson-learn period in order to implement the key findings for the rest of the project • If the difficulties are limited to periods with bad weather conditions it can be managed with running full configuration (coupled units)	Probability: 10-35% Impact: 5-15%
Platform safety The chosen platform safety solution – ODS – does not work as	• Use the Ringbanen as a pilot project including a lesson-learn period in order to implement	Probability: 1-10%

assumed – e.g. detects too many false events (birds, papers, etc.) which results in reduced reliability or does not work in the outdoor conditions	the key findings for the rest of the project • Base the chosen solution on proven concepts/international experience from implementation in comparable environment	Impact: 15-25%
Safety approval (CSM) The safety approval process is underestimated which results in delays and cost overruns	• Use the Ringbanen as a pilot project including a lesson-learn period in order to implement the key findings for the rest of the project • Early involvement of the approval authority throughout the project	Probability: 10-35% Impact: 15-25%
Infrastructure works The infrastructure works need to be executed at night or during line closures resulting in delays or cost overruns	• Use the Ringbanen as a pilot project including a lesson-learn period in order to implement the key findings for the rest of the project	Probability: 35-60% Impact: 1-5%
Power supply Power supply upgrades are postponed after political approval of the UTO project which leads to additional costs		Probability: 10-35% Impact: 1-5%
Poor data basis Poor infrastructure data leads to underestimated sub-projects (e.g. stepless boarding, fencing need, etc.)	• Sample check of available data in order to assess quality of data during project formulation and preparation before project approval	Probability: 10-35% Impact: 1-5%
Stepless boarding – onboard gap-fillers The onboard gap-fillers cannot stand the weather conditions and daily use. This has been a risk in other projects	• Clear specifications related to the gap-fillers in the rolling stock tender material • Testing in the right weather conditions – also by supplier	Probability: 10-35% Impact: 5-15%
Project implementation The complexity of the project with more parties involved, many stakeholders and project interfaces may cause unexpected amendments or changes to the project and call for more resources on the Client's side. This will endanger the project costs and the time schedule	• Careful project formulation and preparation involving all key project parties and stakeholders • Continued involvement of all project parties and key stakeholders during project implementation after contracting	Probability: 10-35% Impact: 5-10%

The total risk add-on is calculated to approximately 780 million DKK which constitutes about 39% of the budget for Flex36 (2 billion DKK).

The overall risk evaluation is shown on the figure below.

	Impact				
	<1%	1-5%	5-15%	15-25%	>25%
Probability	10000000 DKK	60000000 DKK	200000000 DKK	400000000 DKK	1500000000 DKK
>60%					
35-60%		2	1	1	
10-35%		3	2	2	
1-10%		1		2	1
<1%					

Figure 13: Risk evaluation

The most severely (red) risks are:

- Complexity and interfaces (contributing with a risk add-on cost of 190 mio. DKK)
- "Brown field" project (contributing with a risk add-on cost of 95 mio. DKK)
- Organisational and technical changes (contributing with a risk add-on cost of 90 mio. DKK)
- Safety approval (contributing with a risk add-on cost of 90 mio. DKK)
- Procurement strategy (contributing with a risk add-on cost of 82 mio. DKK)

These risks and the evaluations reflect that the project is first of its kind in Denmark (first mover project). The Metro in Copenhagen was designed as a driverless system from the beginning. Especially, the "Complexity and interfaces" and "Brown field project" risks describe and capture the challenge of transforming an existing railway system into a driverless system.

The most important mitigation – across a broad number of risks – is the use of Ringbanen as pilot project. The main purpose of the pilot project is first of all to test the technical solution and make sure it is feasible (adjust the scope – e.g. technical modifications) before it is implemented at the rest of the S-bane.

The different scenarios have been taken into consideration by the risk evaluation. There are however not identified major differences between the scenarios from a risk perspective:

- The difference between "Classic style" and "Metro style" is basically a time table question and it does not affect the investments in infrastructure or rolling stock differently. Thus, it does not influence the above risk assessment
- The difference between "36" and "39" is likewise mostly a time table question – however it is highlighted that the 39 scenarios are close to technical limitations of the signalling system and thus an operational risk related to the 39 scenarios. This operational risk has been taken into consideration in the scenario selection and was one of the reasons to deselect the 39 scenarios
- The difference between UTO30 and Flex36 is primary the required number of rolling stock units and time table. The risk assessment will however contain the same overall risks and evaluations

9. FINANCIAL ANALYSIS

9.1 Summary

The purpose of the financial analysis is to provide a comparison of the feasibility of each alternative based on a consolidated examination of all costs and revenues related to the investments in and operations of the new driverless trains. The analysis includes two different alternatives to the baseline scenario, namely the Base UTO 30 and Flexible UTO 36.

The Base UTO 30 has a 2016 NPV of 1.311 mill. DKK, whilst the Flexible UTO 36 scenario results in an NPV of 309 mill. DKK. Based on the NPV calculations, therefore, both scenarios are financially beneficial compared to the baseline, although the former proves significantly stronger. This is further backed up by the breakeven analysis, which shows that the Base UTO breaks even primo 2038, meaning that the project pays back within 18 years after the first project costs are held. The Flex 36 scenario breaks even 18 months later in mid-2039, slightly later than the Base STO, which breaks even ultimo 2038.

The main driver of the business case in favour of UTO is the savings of staff operating costs. The transition to driverless operation saves 3.363 mill. DKK in NPV, equivalent to an annual saving of 327 mill. DKK after 2030. The difference in NPVs between the two UTO is roughly 1.000 mill. DKK, and it is primarily driven by higher rolling stock investments, as well as higher train set operating costs, the latter of which mainly covers train maintenance and energy consumption. Thus, the larger passenger base and resulting 1.095 mill. DKK larger revenue base in the Flex 36 is outweighed by the higher costs base.

The sensitivity analysis assesses the sensitivity of the UTO business case to changes in key parameters; namely, passenger revenues, rolling stock investments, infrastructure investments and savings on staff operating costs. The business case for the UTO scenario proved highly robust to changes in the key parameters, whilst the Flex 36 show less leeway in terms of changes in the size of key parameters. This scenario is especially sensitive to changes in the savings on staff operating costs, as well as the price of new rolling stock.

Conclusively, there is a strong business case for introducing driverless operation in the S-train network. However, a simultaneous increase in train frequency to 36 trains does not improve on the business case, and the current frequency of 30 trains is therefore suggested as the best option from a purely financial perspective. Confer Appendix 13 for more detailed information about the calculations behind the financial analysis.

9.2 Introduction

The overall objective of this project is to investigate the financial costs and benefits of implementing unattended train operation (UTO) on the S-bane compared to the current semi unattended train operation (STO). The STO will be fully implemented after the implementation of the signalling programme.

The financial analysis measures all costs and benefits in financial terms by addressing whether or not UTO provides increased revenue (more passengers), reduced costs (CAPEX or OPEX[13]), or any combination of these that brings a better financial result compared to the existing operational setup. Specifically, the performance of the UTO alternatives compared to the baseline is constrained based on preconditions that should satisfy the following: 1) At least same overall safety level should be kept, 2) Equally special segments of passengers should be provided with same service level, e.g. disabled people shall have at least the same level of access, despite the lack of driver support. 3) Other service intensions, on the other hand, are less strict: No explicit

[13] CAPEX = Capital expenses, OPEX = Operating expenses.

requirements are associated to for example availability, reliability or comfort. Such parameters are assumed to fulfil a sufficient level, as long as it does not damage the financial result.

In practice, the financial analysis provides a financial examination of the costs and revenues related to the project of transforming the S-train network to unattended train operation. The analysis is conducted in accordance with the principles in the Ministry of Transport, Building and Housing's *"Manual for samfundsøkonomisk analyse på transportområdet"* [14]*.* The results of the financial analysis are based on figures and values provided by other working groups, as well as underlying assumptions related hereto. The project calculation period spans from 2020, where the first project costs are held, to 2053, where the lifetime of all capital investments end. The following section provides a short discussion on the timeline of the project and the calculation and timing of costs and benefits. For a more detailed description of the assumptions and methods underlying the analysis, please refer to Appendix 13.

9.3 Project timeline and discount rate

According to TRM, the project timeline shall follow the lifetime of the acquired rolling stock[15]. This is based on the fact that it does not seem feasible to extend the timeline beyond the lifetime of the rolling stock, as the main interest lies with the analysis of the operations of the new rolling stock.

In the screening report from 2013, the lifetime of the new driverless rolling stock was estimated to 25-30 years[16]. This is consistent with the lifetime of the current rolling stock, which is 30 years (cf. section 6.6 on rolling stock). As a result, a lifetime of *maximum* of 30 years is applied in the financial analysis.

In practice, the project timeline consists of two phases; 1) a construction phase and 2) an operational phase. The construction phase spans from 2020 to 2029, both years included. Effectively, this phase begins when the first project costs are held in 2020 (cf. section 9.4.2 on details about the project costs), and ends when the last UTO trains have been rolled out on the lines Farum – Frederikssund and Hillerød – Køge. For details on the rollout of the new trains, see section 6.9.

The operational phase spans from 2030 to 2053. Technically, however, the operational phase overlaps the construction phase, as the first trains are rolled out on the Ring line already from 2024-2026, after which the operations hereof starts in 2027. The operations of the new UTO trains on the rest of the lines begin in 2030, as the operations of hereof are rolled out later than on the Ring line.

In accordance with the rollout plan in section 6.9, the first trains to operate on the Ring line are acquired in 2024, and it is the lifetime of these trains, which determines the length of the project timeline. As this is assumed to be maximum 30 years, the timeline of the project ends in 2053. In practice, however, this means that trains acquired at a later date are yet to exhaust their lifetime at the end of the calculation period. However, no terminal value is included at the end of the period due to the fact that the average lifetime of new driverless rolling stock is defined to be between 25 and 30 years. As a result, some trains may in fact have shorter effective lifetimes than the 30 years assumed. This applies both to the project alternatives and the baseline scenario, however. Thus, as the business case calculations are based on the difference (delta) between the alternatives and the base scenario, on average there is no effect of this assumption on the overall results of the analysis.

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[14] Transportministeriet (2015). Manual for samfundsøkonomisk metode på transportområdet.

[15] Transportministeriet (2015). Manual for samfundsøkonomisk metode på transportområdet, p. 17.

[16] Transportministeriet: Rapport om mulighederne for automatisk S-bane drift (2013).

The Ministry of Finance and the Ministry of Transport, Building and Housing sets the official discount rate (the rate at which all future costs and benefits are discounted back to 2016 present values (PV)) for projects not exceeding 35 years at **4 percent.**[17] Hence a discount rate of 4 percent is applied in both the financial and socio-economic analyses.

9.4 Detailed results

Table 13 below displays the results in delta figures (Alternative – Base), i.e. as the differences between Base UTO/Flex 36 and Base STO, respectively. The following paragraphs provide short descriptions of each of the accounts displayed below, along with explanations as to why they differ between the two alternatives.

ALL ACCOUNTS – DELTA FIGURES	NPV mill. DKK 2016	
	Base UTO	**Flex 36**
Procurement of new rolling stock	201	-521
Additional costs for UTO functionality	-140	-158
Upgrade of the on-board unit (CBTC)	-44	-77
TOTAL OPERATIONAL RELATED CAPITAL EXPENDITURE	16	-756
Platform Edge Safety	-671	-671
Safety between stations	-329	-329
Traction Power	-	-55
Track	-	-
Stepless boarding	-39	-39
Upgrade of maintenance facilities (workshops)	-	-
Upgrade of the signalling system (CBTC)	-47	-47
TOTAL INFRASTRUCTURE COSTS	-1.086	-1.141
TOTAL INVESTMENT CAPITAL EXPENDITURE (CAPEX)	-1.070	-1.898
PROJECT COSTS	-134	-262
SAVINGS ON STAFF OPERATING COSTS	3.363	3.363
Rail access fees	-	-198
Insurance costs	1	-97
Train set operating costs (maintenance and energy)	-139	-1.033
TOTAL OPERATIONAL COSTS	-137	-1.328
Safety between Stations	-172	-172
Platform Safety	-501	-501
Costs for stabling areas	2	12
TOTAL INFRASTRUCTURE MAINTENANCE COSTS	-672	-662
TOTAL OPERATION AND MAINTENANCE COSTS (OPEX)	-810	-1.989
TOTAL PASSENGER REVENUE	-39	1.095
TOTAL OPERATING SURPLUS		
TOTAL COSTS	-2.014	-4.149
TOTAL SAVINGS ON STAFF OPERATING COSTS	3.363	3.363
TOTAL REVENUE	-39	1.095
NET RESULT	1.311	309

Table 13: Results of the financial analysis, 2016 NPV mill. DKK

[17] Transportministeriet (2015). Manual for samfundsøkonomisk metode på transportområdet

9.4.1 Investment capital expenditure

Figure 14 below shows the total investment capital expenditure held during the production period from 2022-2029. For more information about the rollout plan, cf. chapter 6.9.

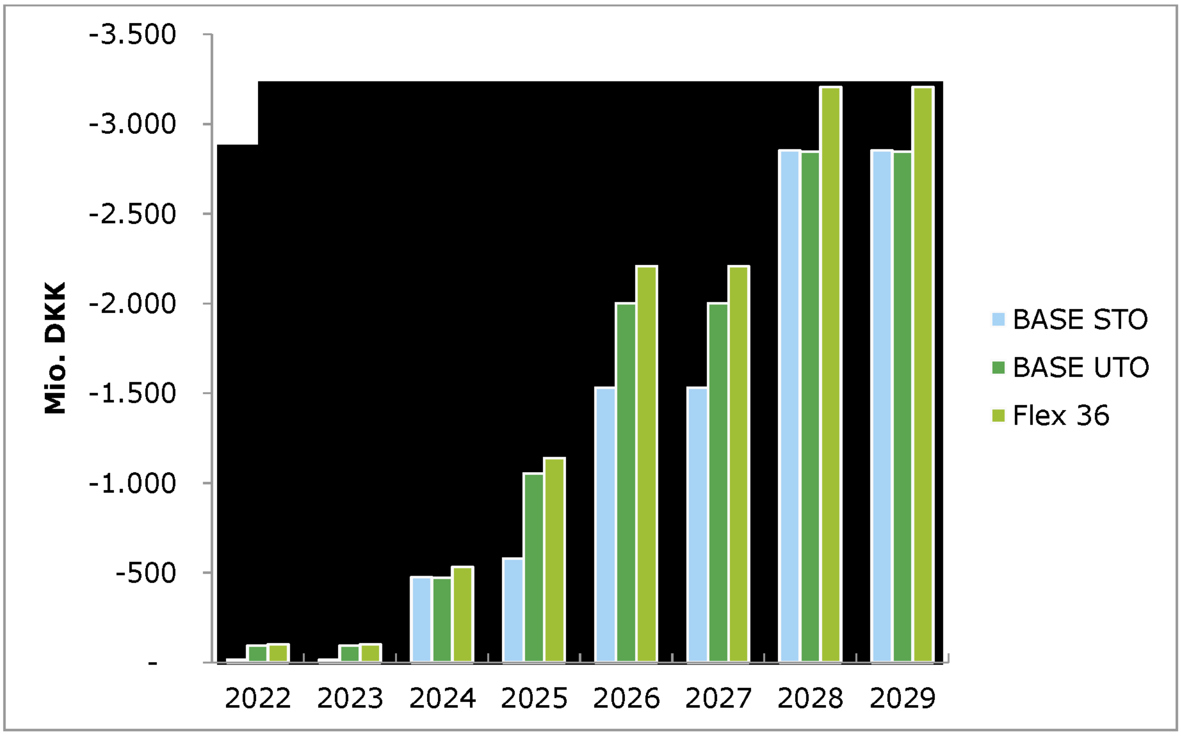

Figure 14: Investment CAPEX, 2022-2029

The values above include both operational related capital expenditures, i.e. the costs for investing in new rolling stock, as well as infrastructure capital expenditures.

9.4.1.1 New Capital Budgeting (NAB) and uncertainty correction

In large infrastructure projects, there will always be some uncertainty in the estimation of capital expenditures in the early phases of the project. To account for this uncertainty, the Ministry of Transport, Building and Housing issued official guidelines in 2007, namely the principles of New Capital Budgetting (Ny Anlægsbudgettering).[18] The guidelines propose to divide any infrastructure project into five separate phases in their so-called "phase-model". The first phase is the design phase, in which uncertainty is highest. In this phase, all estimated infrastructure investments are subject to a risk add-on of 50 percent. Since the project in this analysis is still in its design/preliminary phase, the estimation of infrastructure investments costs is governed by the principles of New Capital Budgeting (NAB), and is therefore subject to an uncertainty correction of 50 percent.

The NAB principles do not, however, suggest to correct the uncertainty related to the purchase of new rolling stock, as TRM does not categorize rolling stock investments as *construction costs* per se. Still, however, it is argued that there is a risk in estimating costs for rolling stock, as evident from experiences from similar procurement projects in the past.

[18] https://www.trm.dk/da/ministeriet/ny-anlaegsbudgettering

30 percent is there for used in a balance between practice and expert assessment. The early phase of assessment and few historical very challenging projects argues for a high factor. At the other hand, Rolling Stock does typically implies less risk imposing external stakeholder engagement (noise, resistance, complains, legislations etc.) than huge construction- or installation projects. Equally the rolling stock will based on standardized platforms wherever possible. From these weighted considerations a 30 percent risk factor seems reasonable for Rolling Stock purchase

9.4.1.2 Operational related capital expenditures (rolling stock)

The operational related capital expenditures include all investments related to the acquisition of new rolling stock, and they are held in accordance with the rollout period. They are divided in 1) procurement of new rolling stock, 2) additional costs for UTO functionality and 3) upgrades of the on-board signalling systems (CTBC).

The main cost driver of all three sub-accounts above is the number of new trains purchased; cf. chapter 6.6 and appendix 6 for more information on rolling stock. More trains are purchased in the flexible scenario, as the train frequency is increased to operations with 36 trains, which results in higher costs. Furthermore, the additional costs for UTO functionality are driven by the price difference between STO and UTO trains, as there are extra costs related to the UTO specific functionality of new S-trains. The upgrades to the signalling systems (CTBC) cost 2 million DKK pr. train in the UTO scenarios, and 1.6 million DKK pr. train in the STO scenario.

9.4.1.3 Infrastructure capital expenditures

The infrastructure capital expenditures include the following two groups of investments (notice that the figures provided are excl. NAB[19]):

1) *UTO specific investments:*

- Platform Edge Safety covers costs for safety systems such as IR-barriers at the stations. Total investment is 652 mill. DKK throughout the rollout period in both UTO scenarios.
- Safety between Stations includes a total investment of 320 mill. DKK in both UTO scenarios.
- Stepless boarding accounts for investments of 38.25 mill. DKK for technology improvements to enable stepless boarding solutions.
- Upgrades of the signalling systems (CBTC) covers investments of 45.5 mill. DKK across the rollout period to adapt the current signalling systems to UTO trains.

2) *Necessary investments for both STO and UTO:*

- Traction Power upgrades includes investments to increase the capacity of the power supply in the S-train network, as a result of the increase power demand from a higher number of operating trains. Investments are identical in the Base STO and Base UTO scenarios at 82 mill. DKK, but 65 percent higher in the Flex 36 scenario at 136 mill. DKK, as the power system needs to generate power for a larger number of operating trains.
- Track investments are identical across all scenarios and include total investments of 22 mill. DKK.
- Upgrades of maintenance facilities (workshops) are identical across scenarios and include total investments of 129 mill. DKK across the rollout period. This account covers the costs for upgrading the current workshops to be adaptable to servicing the new rolling stock.

9.4.2 Project costs

Project costs cover expenses for project management and administration, safety approvals, testing and commissioning, mobilization prior to trial operation, as well as revenue operation. They are calculated as 18 percent of the total CAPEX of rolling stock and infrastructure excl. of NAB. Figure

[19] The net present values provided earlier in table 14 are inclusive of the NAB uncertainty correction.

15 below illustrates the timing of the project costs across the three scenarios. It is evident that project costs are largest in the middle of the rollout period, in which the first rolling stock investments are made on the Ring line.

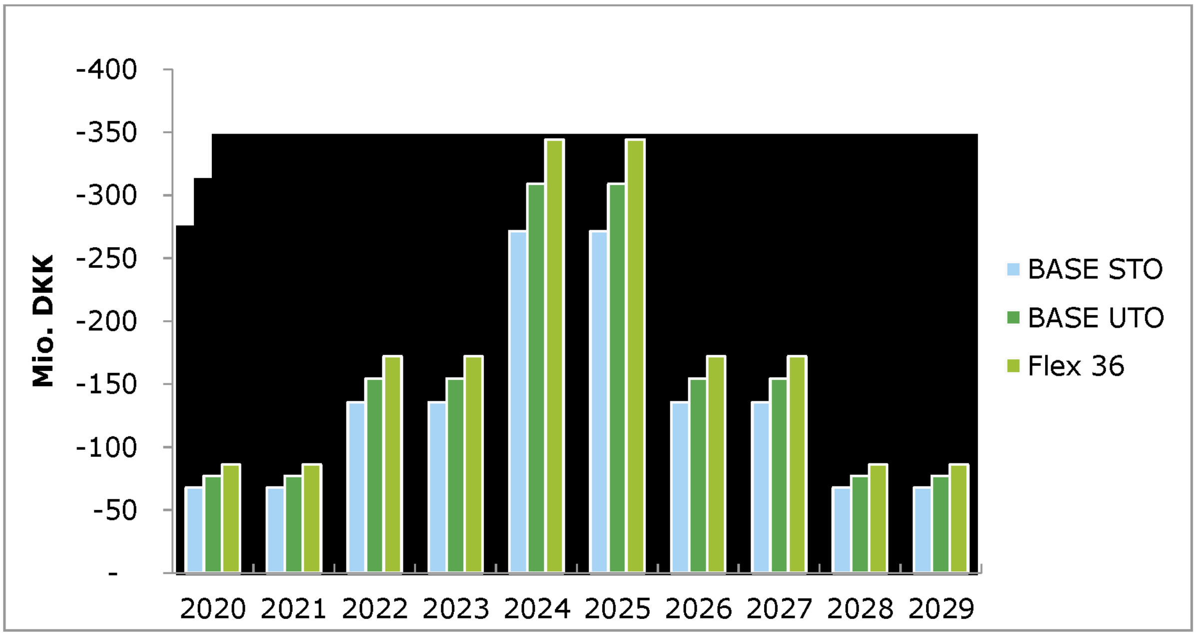

Figure 15: Project costs, mill. DKK

As illustrated previously in table 14, project costs for the Base UTO and Flex 36 scenarios are 134 mill. DKK and 262 mill. DKK higher compared to the Base STO. This means that the project costs are almost twice as large in the Flex 36 scenario compared to the Base UTO, in net (delta) terms of the Base STO. As noted above, the cost driver of the project costs is total capital expenditures. These costs are obviously much higher in the Flex 36 scenario, since a larger number of new trains are acquired (175) compared to the Base UTO (155). However, the difference in the level of project costs implies that purchasing 20 extra trains effectively doubles the costs for administering the Flex 36 project, compared to the Base UTO. Arguably, this may represent an unfair disadvantage for the flexible scenario. In practice, the new UTO trains are likely to be administered within the same purchase order, which means that the administration (project) costs of the purchase should be independent of the number of trains acquired. Hence, the project costs in Flex 36 may be viewed as a conservative measure, and thus represents an upper limit. In reality, however, the project costs are likely to be more similar in size in the two UTO scenarios.

9.4.3 Operational and maintenance costs

Operating and maintenance costs consist of operational costs of the rolling stock and infrastructure maintenance costs. The development of these costs is illustrated in Figure 16 below.

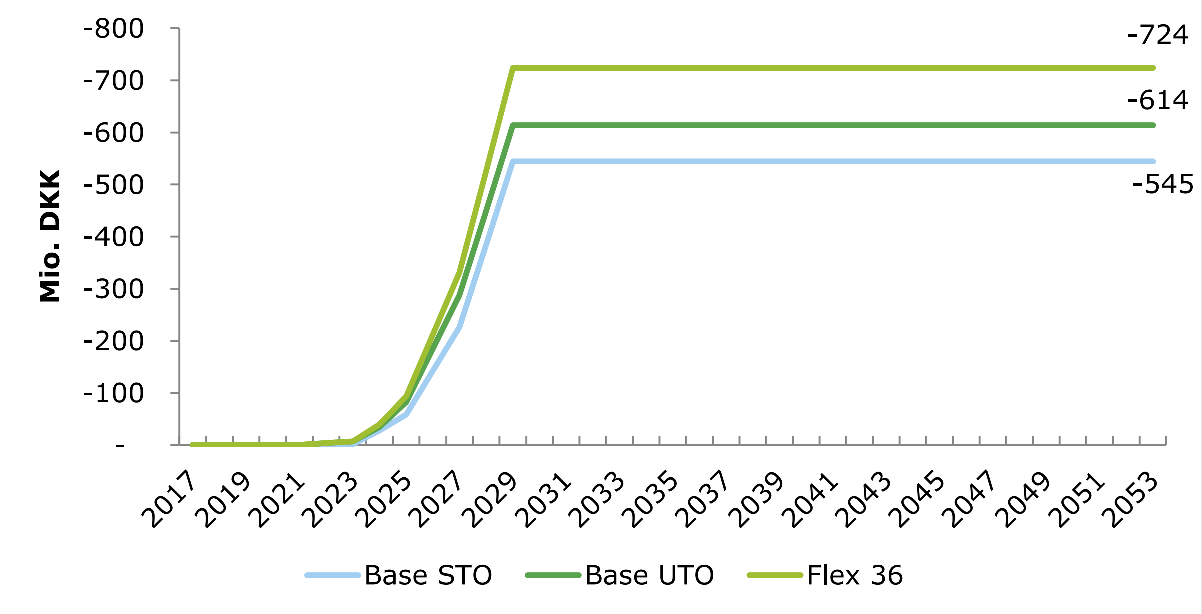

Figure 16: Operational and maintenance costs, mill. DKK

As Figure 16 above shows, the operating and maintenance costs are significantly higher in the Flex 36 scenario at an annual cost of 724 mill. DKK from 2030 to 2053.

9.4.3.1 Operational costs

The operational costs are divided into 1) rail access fees, 2) insurance costs, and 3) train set operating costs.

1) Rail access fees account for the cost, which the train operator pays to Bane Danmark for access to the infrastructure and rails. Based on "Netredegørelsen 2018", the current access fee (infrastructure charge) is calculated to 4.8 DKK pr. train km in 2016 prices.[20] Thus, the higher the number of train kms driven, the higher will be the costs for access fees (cf. the larger costs in the Flex 36 scenario of 198 mill. DKK).

2) Insurance costs (ansvar, kasko, forsikringsdækning af passagerer) are calculated based on unit costs provided by Niras in *"Enhedsomkostninger ved persontogsdrift"*. Here, the unit cost of insurance is estimated at 0.38 mill. DKK pr. S-train unit[21]. The unit costs in 2016 prices were obtained by extrapolation using the Consumer Price Index (Forbrugerprisindekset). This resulted in unit costs of 0.44 mill. DKK and 0.46 mill. DKK pr. STO and UTO train unit, respectively. The difference in unit prices is based on the fact that the price of a new UTO train is 3.4 percent higher than a new STO train (cf. appendix 13 for more details).

3) Train set operating costs account for the largest part of the operational costs, and they cover costs for rolling stock maintenance and energy. They are calculated as 21.1 DKK pr. STO train unit km, and 21.8 DKK pr. UTO train unit km. Operating costs are thus higher in the Flex 36 scenario, as they are driven by a larger number of train unit kms.

[20] BaneDanmark "Netredegørelse 2018" can be found at http://www.bane.dk/db/filarkiv/21502/Netredeg%F8relse%202018%20endelig%20version%20v2.pdf and current infrastructure charges can be found at https://www.retsinformation.dk/forms/R0710.aspx?id=175591#id42ce8ed4-7bfd-4cf5-b0d3-ffe853f183b3

[21] http://www.radikale.net/Files/379/niras-enhedsomkostninger-ved-togdrift-samlet-afrapportering-071025-endelig-1.pdf

9.4.3.2 Infrastructure maintenance costs

Maintenance costs for infrastructure are held in accordance with the rollout plan for the related infrastructure investments, and they cover maintenance costs for platform edge safety, which amounts to 1.047 mill. DKK and 2) safety between stations, which totals 360 mill. DKK. These are UTO specific maintenance costs (as they relate to UTO specific investments), and they are identical for both UTO scenarios. Finally, infrastructure maintenance costs include annual costs for stabling areas, which amount to 14.2 mill. DKK for Base STO, 14.1 mill. DKK for Base UTO and 13.2 mill. DKK for the Flex 36 scenario. See chapter 6 for more details.

9.4.4 Savings on staff operating costs

The savings on staff operating costs from introduced driverless operation accounts for by far the largest benefit in the business case at an NPV of 3.363 mill. DKK in both UTO scenarios. Confer chapter 7 "Organisation" for a more detailed description of the consequences of UTO operation on personnel.

Figure 17 below illustrates the annual savings on staff operating costs. Note that the annual savings on staff costs is lower in 2030, as a so-called "stay bonus" of 27 mill. DKK is included as a lump sum in both UTO scenarios. The bonus covers the extra costs estimated for retaining relevant train drivers until the end of the transition phase, as there is a risk that some personnel is not willing to stay until the end of the rollout period, knowing that they will either need to find another job or face reallocation.

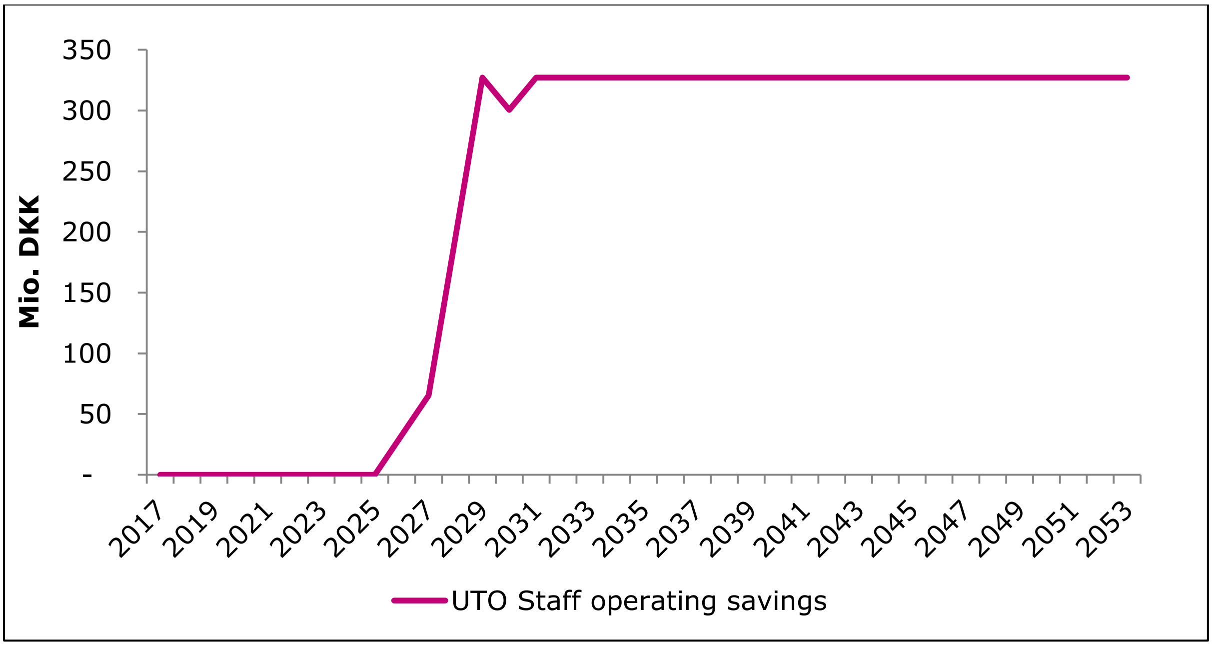

Figure 17: Savings on staff operating costs, mill. DKK

9.4.5 Passenger revenue

Passenger revenue is calculated by multiplying the number of passenger trips, according to OTM data, by the estimated average tariff per trip. In the financial analysis, the average trip tariff is calculated based on the average number of zone crossings pr. trip, in order to obtain the most reliable estimate possible. The average number of zone crossings differs between the different scenarios (Base UTO and Flex 36), as do therefore the calculated average tariffs. Cf. appendix 13 for detailed descriptions on the calculation methods.

The average tariffs pr. passenger trip are hence calculated as:

- Base STO (current situation): 12.88 DKK
- Base UTO : 12.87 DKK
- Flex 36: 12.52 DKK

The number of zone crossings is shorter in the flexible scenario, as the metro operation results in shorter average trips, which lead to a lower average tariff.

The number of passenger trips is assumed to grow 0.5 percent annually from 2030-2053. This is based on the forecasted population growth for the period 2030-2040 in the Greater Copenhagen municipalities, in which S-trains currently operate. This growth rate follows the recommendations provided by key stakeholders in the project, and is therefore deemed a reasonable estimate of future passenger growth.

It was considered to apply a higher growth rate in the project, based on the average passenger growth rate the last 10 years of 2.4 percent[22]. However, this past growth arguably mainly stems from the decision to allow free bikes on S-trains in 2010[23]. Evidently, in the 10-year period prior to the decision of free bikes allowance, average annual growth rate was 0.1 percent. This suggests that applying the average growth since 2005 is overly optimistic, thus validating the assumption of a 0.5 percent passenger growth rate from 2030 and onwards[24].

As evident from figure 15 below, annual passenger revenues are roughly at the same level across all three scenarios until 2030, after which the larger passenger base in the Flex 36 scenario leads to higher passenger revenues compared to the Base STO and Base UTO scenarios.

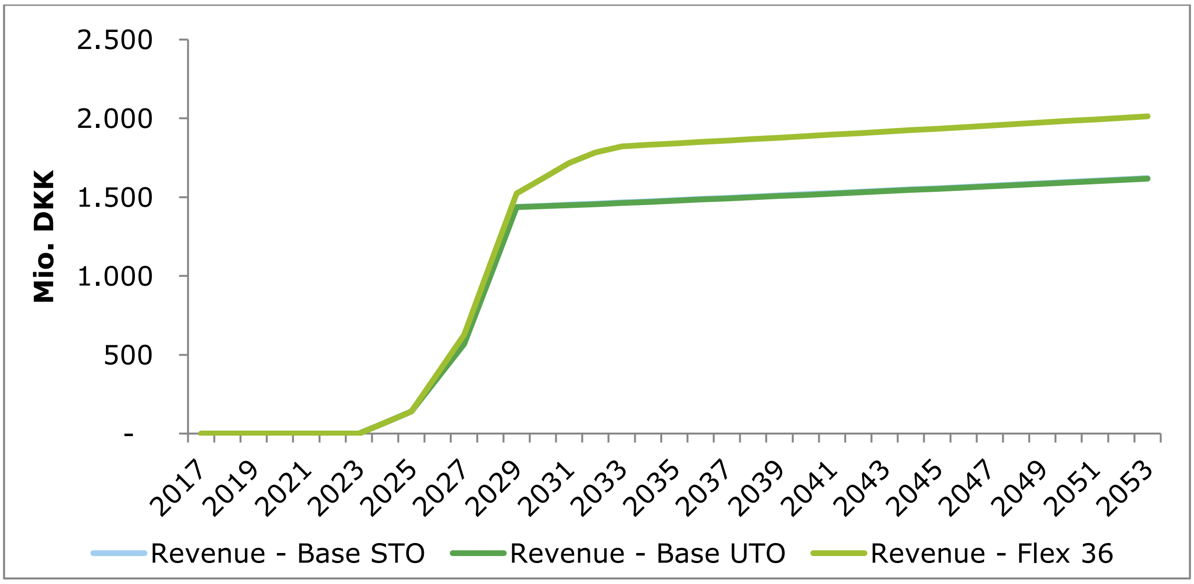

Figure 18: Annual passenger revenues, mill. DKK

For a detailed description of the underlying calculations, please see appendix 13.

[22] The 2.4 percent average growth is calculated as the Compound Annual Growth Rate (CAGR) for the number of S-train passengers in the period 2005-2015. Source: Statistics Denmark

[23] https://www.dsb.dk/Om-DSB/Presse/Nyheder/Tag-cyklen-gratis-med-i-S-toget/

[24] Additionally, one may consider the fact that increased passenger demand in the S-train network (from the 0.5 percent annual increase) may at some point in the future result in overcrowding and thus may create the need for additional rolling stock acquisitions. However, as this would be true for the Base STO scenario as well, the delta effect of this consideration is deemed insignificant and therefore excluded from the analysis. Additionally, the amount of overcrowding greatly depends on the distribution of these passenger increases across the day; an increase in non-peak hours is thus less likely to result in overcrowding, compared to an increase in peak-hours. Based on these considerations, therefore, the 0.5 percent estimate involves some underlying uncertainty. This is acknowledged and addressed in the sensitivity analysis in section 9.6.1.

As a result of the combination of classic operation during peak hours and metro operation during non-peak hours, the flexible scenario offers more passenger trips compared to both the Base STO and Base UTO. This translates into higher passenger revenues even though the average tariff pr. trip is smaller in Flex 36.

9.5 Break Even Analysis and Payback periods

Figure 19 below illustrates the accumulated net cash flows, or the liquidity development, across scenarios throughout the analysis period. Base UTO breaks even in primo 2038 and hence has the shortest payback time at 18 years after the first project costs is held in 2020. The flexible scenario pays back 18 months later in mid-2039, whilst Base STO breaks even in ultimo-2038. The estimated payback periods are consistent with the screening report from 2013, in which the payback period was estimated at 19 years.

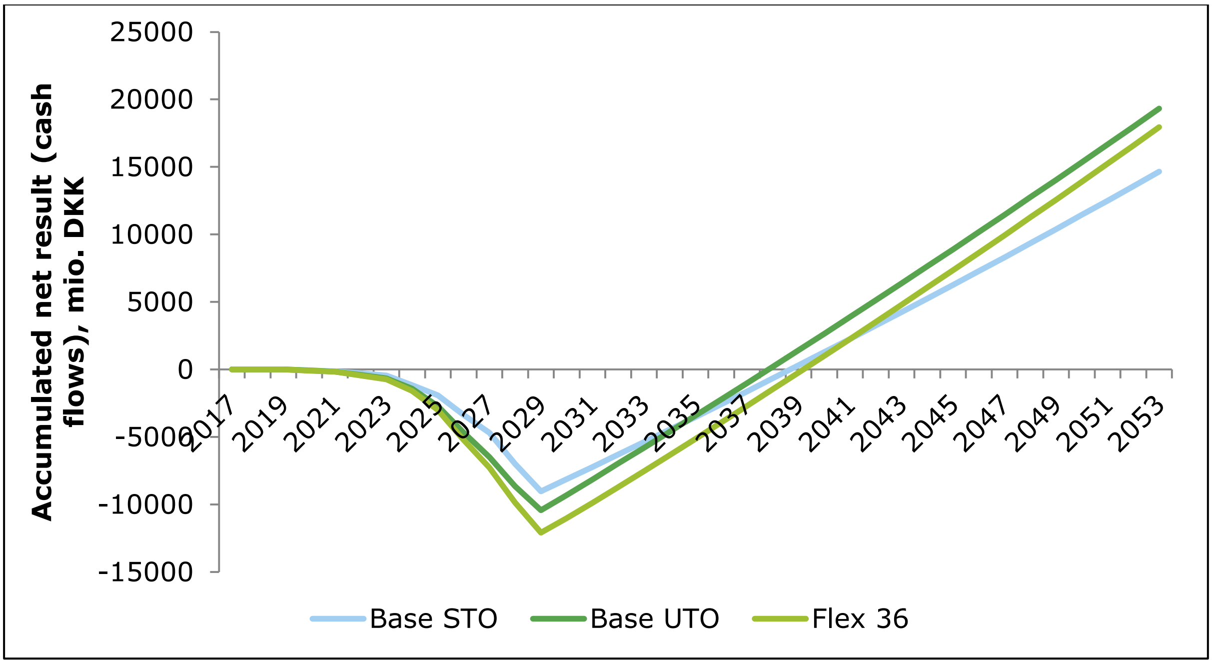

Figure 19: Accumulated net cash flows (net result), mill. DKK

The break-even times of the three scenarios thus fall within a short interval. Additionally, it is interesting to notice that the flexible scenario only outperforms the base STO after 2042. Conversely, the base UTO already outperforms the baseline after 2036, based on accumulated cash flows. This is directly related to the large extra investments made at the beginning of the period in the flexible scenario. As is evident from the fact that the Base UTO has the highest NPV (cf. 7) and the shortest payback period, the flexible scenario never makes up for the extra investments related to increasing the frequency to 36 trains.

9.6 Sensitivity analysis

The purpose of the sensitivity analysis is to examine how the results are affected when key parameters are changed. In the financial analysis, the following four parameters are key determinants for the overall results, and they will be the subject of the following sensitivities.

1. Passenger revenue
2. Operational related CAPEX (rolling stock investments)
3. Infrastructure CAPEX
4. Savings on staff operations

9.6.1 Passenger revenue

The calculation of passenger revenue is based on traffic simulations on the number of passengers from the OTM-model, and they are as such not the subject in a financial sensitivity analysis. Instead, the assumed passenger growth rate is the subject of interest.

It is assumed that the passenger base will increase by 0.5 percent per year from 2030-2053. The growth rate is an important parameter in the financial analysis, and it may be argued that letting the number of passengers increase linearly over the period and simultaneously keeping the number of operating trains constant is in contrast with reality. Hence, it may be contested that the capacity of the trains acquired during the rollout period is sufficient in relation to the assumed future passenger growth. Testing this assumption is therefore of high importance. The table below shows the how the result of the business case changes when the passenger growth rate is altered.

Sensitivity scenarios, annual growth rates	Delta NPVs, million DKK 2016 prices	
	Base UTO	**Flex 36**
Worst case: 0 percent	1.312	257
Current case: 0.5 percent	1.311	309
Best case: 1 percent	1.309	365
Converging rate: 6.3 percent	1.277	1.277

Table 14: Passenger growth rate sensitivities

The analysis suggests that the results of the business case are robust to changes in the passenger growth rate. Both UTO scenarios are financially viable compared to the base case at zero growth in passengers. Furthermore, the analysis illustrates that the two scenarios converge when the growth in passengers is very high at 6.3 percent, which in reality seems quite unrealistic. This supports the conclusion that the Base UTO scenario is the strongest, and equally importantly that the transition to driverless operation in the S-train network is in fact financially viable.

9.6.2 Operational related capital expenditure (rolling stock investments)

The size of the rolling stock investments is a key factor in the business case, especially evident from the large cost in the Flex 36 alternative, where a higher number of trains are purchased.

Although the uncertainty related to the operational related capital expenditures is already partially accounted for in the analysis through the 30 percent risk add-on, a sensitivity analysis is still deemed highly informative.

The table below shows the sensitivity of the business case to changes in the operational related capital expenditure in both the baseline and the project alternatives. It distinguishes between changes to the estimated unit price of a new rolling stock (cf. section 6.9), as well as changes to the quantity of new trains purchased.

Sensitivity scenarios, rolling stock capital expenditure	Delta NPVs, million DKK 2016 prices	
	Base UTO	**Flex 36**
Current price and quantity	1.311	309
- Price sensitivity:		
- 10 percent higher price	1.317	231

- 20 percent higher price	1.324	152
Quantity sensitivity:		
- 10 percent more trains	1.313	212
- 20 percent more trains	1.315	105

Table 15: Operational related CAPEX sensitivities

The table shows that both alternatives still have a positive NPV when the price and number of rolling stock is changed. Furthermore the table shows that the Base UTO has a higher NPV than that Flex 36 in all cases.

9.6.3 Infrastructure capital expenditures

Changes to investments that are identical across all three scenarios are not relevant to test, as they will affect the three scenarios in the same way and hence be irrelevant.

Therefore, in this sensitivity analysis, only infrastructure investments that differ in size between the Base STO and the UTO scenarios have been altered. The table below shows the results of the sensitivity analysis.

Sensitivity scenarios, infrastructure CAPEX	Delta NPVs, million DKK 2016 prices	
	Base UTO	**Flex 36**
Current level	1.311	309
- 10 percent increase	1.188	181
- 20 percent increase	1.066	52

Table 16: Infrastructure CAPEX sensitivities

As the table show, changing the level of infrastructure investments does not alter the overall conclusion; there is a positive business case for the introduction of UTO in the S-train network, and the Base UTO still outperforms the Flex 36.

Looking at the specific numbers, a 10 percent increase in investment costs results in a decrease in NPV of 123 mill. DKK for Base UTO, whilst the NPV of the Flex 36 decreases by 128 mill. DKK. The small difference stems from the fact that the only investment costs, which differ between the two UTO scenarios are the costs for upgrading the Traction Power System. This cost is initially 82 mill. DKK and 136 mill. DKK in the Base UTO and Flex 36, respectively. All other infrastructure investments are the same between the two project alternatives, cf. section 9.4.1.3.
At a 20 percent increase, the Flex 36 alternative results in an NPV of 52 mill. DKK, while the Base UTO still significantly outperforms the Base STO at an NPV of 1.066 mill. DKK.

9.6.4 Savings on staff operating costs

The savings on staff operating costs is the main driver of the positive business case for driverless operation. For this reason, this probably prevails as the most significant parameter to test in a sensitivity analysis. The table below shows the effect of altering the annual savings on staff operating costs, which was initially estimated at 327 mill. DKK, contributing with an NPV of 3.3 bill. DKK in both UTO scenarios.

Sensitivity scenarios,	Delta NPVs, million DKK 2016 prices

savings on staff costs	**Base UTO**	**Flex 36**
Current level	1.311	309
- 7.05 percent decrease	1.001	0
- 10 percent decrease	973	-29
- 20 percent decrease	635	-367
- 30 percent decrease	297	-704
- 38.78 percent decrease	0	-1.001

Table 17: Savings on operating staff costs sensitivities

Each 10 percent decrease in the annual savings on staff operating costs amount to a decrease in the NPV of both scenarios of 338 mill. DKK. This effectively means that the Flex 36 already becomes unprofitable compared to the Base STO at a decrease in annual staff savings of about 7 percent, whilst it takes a significant decrease of 38.78 percent before the Base UTO converges to the level of the Base STO result.

10. SOCIO ECONOMIC ANALYSIS

10.1 Introduction

The socio-economic analysis describes the costs and benefits for the Danish society when replacing the existing S-trains with driverless trains. The analysis is conducted using the principles from the manual for socio-economic analysis within transportation[25] published by the Danish Ministry of Transport, Building and Housing. The calculations are performed using the TERESA model administered by same authority.

The socio-economic analysis is based on the assumptions provided by the other working groups as well as the financial analysis conducted by working group 3. This includes fundamental parameters such as project investments, operational and maintenance costs. User benefits including time and distance savings are based on the results from the OTM- and PRIME-models. Furthermore, the derived effects (for example externalities and tax distortions) as consequences of the changed consumption patterns are included in the analysis as well.

10.2 Conclusion and results

Table 18 shows the socio-economic results divided in categories project investments, operational and maintenance costs, user effects, external effects and other effects.

Entry	Alternative 1 – Base UTO	Alternative 2 – Flex36
Project investments	-1.595	-2.861
Operational and maintenance costs	2.235	1.595
User benefits	-295	4.746
Externalities	-8	-180
Other effects	257	-185
Total net present value	**594**	**3.114**
Internal rate of return	6,1%	9,6%
Benefit-cost ratio	1,22	1,67
NPV per DKK project investment	0,37	1,09

Table 18: Net present value, 2016 price level in market prices (mDKK)

Both alternatives have a positive net present value indicating that both alternatives are profitable in a socio-economic perspective, cf. Table 18. However, alternative Flex36 has the most favorable socio-economic result when comparing the two alternatives. The difference between the two alternatives is primarily due to the large user benefits generated by the Flex36 alternative, even though both operational costs and investments are significantly higher.

The internal rate of return and the Cost-benefit ratio resolve in the same conclusion for both alternatives. Hence for both alternatives, the internal rate of return is higher than 4 pct. which is expected for this type of project. Furthermore, for both alternatives the benefit-cost ratio is higher than 1. The 'NPV per DKK project investment' is calculated as 'total net present value' divided by the absolute value of 'project investments' and indicates that for each DKK spend on project investment the state can expect a positive net present return in either alternative.

In the following sections the different cost categories are described in more detail. For a comprehensive explanation of each cost category the reader is referred to the appendix 13 describing the socio-economic analysis in more detail.

[25] "Manual for samfundsøkonomisk analyse på transportområdet" fra Transportministeriet

10.2.1 Project investments (CAPEX)

The investment costs included in the socio-economic analysis is based on the investments described in the financial analysis. Since the investments are established in factor prices a tax factor[26] (henceforth NAF) is added to the price to convert the prices into market prices. The NAF factor is assumed to be 1,325 which correspond to the assumptions in the manual for socio-economic analysis within transportation. NAF can be seen as an estimate of the average tax burden for private expenditures and is used to make private, public and citizen expenditures comparable.

As the lifespan of the conducted investments, including rolling stock, are equal to the length of the analysis no terminal values are included in the socio-economic analysis. This corresponds to the assumptions in the financial analysis.

Table 19 gives an overview of the included investments in capital separated into subgroups. The results are after including the NAF tax factor.

Entry	Alternative 1 – Base UTO	Alternative 2 – Flex36
Operational related investments (rolling stock)	21	-1.002
Investment in infrastructure costs	-1.439	-1.512
Project administration costs	-178	-347
Total net project investments	**-1.595**	**-2.861**

Table 19: Project investments (NPV in mDKK)

During the constructing period certain inconveniences due to noise, dust, emissions and other disturbances are expected to occur. These inconveniences can be expected to affect individuals in close proximity to the construction area. None of these inconveniences caused in the construction period are included in the analysis as these are hard to quantify and are considered to have minor impact. This results in a very minor overestimation of the benefits of the project.

10.2.2 Operational and maintenance costs (OPEX)

The operational and maintenance costs of the project are based on the financial analysis. Some of the operational costs results from acquisition of product and services which are estimated in factor prices. These costs are converted into market prices by the use of the NAF tax factor as specified by the manual for socio-economic analysis within transportation.

Passenger revenue has been calculated using the OTM-model based on the train timetable and expected number of passengers within the TERESA-model to take into consideration the loss in revenues from other public transportation modes. Some train passengers are expected to change from bus to train and from a socio-economic view this is simply a reallocation between public transportation modes. This is different from the financial analysis since the socio-economic analysis takes the society as a whole into consideration. The financial analysis directs its attention to the business case of the train operation whereas the socio-economic analysis looks at a broader picture.

Table 20 shows the included operational and maintenance costs after adding the NAF tax where applicable.

[26] Nettoafgiftsfaktor (NAF) jf. "Manual for samfundsøkonomisk analyse på transportområdet" fra Transportministeriet

Entry	Alternative 1 – Base UTO	Alternative 2 – Flex36
Operational costs	-182	-1.759
Infrastructure maintenance costs	-890	-877
Passenger revenue	-40	882
Staff operating costs	3.348	3.348
Total net operational and maintenance costs	**2.235**	**1.595**

Table 20: Operational and maintenance costs (NPV in mDKK)

10.2.3 User benefits

When implementing either of the two alternatives the transportation consumption pattern changes which result in either a benefit or a cost for the individual consumer. The user benefits or costs are based on the time and distance change determined by the OTM- and PRIME-model results[27]. The OTM and PRIME results describe how much more/less time passengers spend in either public or private traffic and how many more/less kilometers they drive in private transportation. These changes are valued through the use of transportation unit prices as defined by the Ministry of Transport, Building and Housing and their unit price catalog[28]. A unit price thereby indicates a value for society in relation to individuals saving or spending more time in traffic. E.g. when an individual saves one leisure hour in public transportation this generates a value of approximately 85 DKK. Had this hour been saved in a working relation the monetary value would have been approximately 406 DKK.

The analysis includes changes in how individuals use public transportation and road transportation and estimate the monetary value incurred compared to the base scenario. If individuals spend less time in traffic or drive fewer kilometers when an alternative is implemented then this count as a positive value from a socio-economic perspective. The opposite apply when more kilometers are driven and more time is spent in traffic.

Public transportation includes bus and train transportation. The value of time savings are separated into four categories for public transportation: Traveling time saved, waiting time saved, time saved traveling to and from mode of transportation and time saved changing mode of transportation. Table 21 indicates that most of the 'benefits' occur from time savings in public transportation. The TERESA-model does not differ between modes of transportation within public transportation. This means that the result is only highlighted as one source of benefit and not separated into bus and train transportation[29]. From Table 21 it can be seen that the Base UTO alternative result in more time spend in public transportation which result in a negative socio-economic value. On the other hand, Flex36 creates large time savings within public transportation which results in a large positive value for society as a whole.

Time and distance changes for road transportation are separated into three types: Cars, commercial vehicles and trucks. From Table 21 it can be seen that Base UTO result in more time being spend in road transportation and more kilometres are driven resulting in a negative socio-economic value. The opposite apply for the Flex36 alternative where hours are spend in road traffic and less kilometres are driven.

Table 21 shows that the individual passenger saves money in ticket expenditures when comparing the base case with the two project alternatives. This is due to the fact that each individual generally travels a shorter distance and thereby travels through fewer zones on an average. As

[27] See the appendix section 11 for a review of the OTM- and PRIME-model results

[28] Transportministeriets nøgletalskatalog

[29] From Appendix 1 section 6.1 we know that Flex 36 provides 11% more passenger trips per weekday compared to the base scenarios. Approximate 10.000 of these trips originate from trips that were previously done by car, foot or bike. 3 500 trips are new and the remaining 26 000 are trips that were previously taken by bus, metro or other public transport modes.

ticket prices are determined through the number of zones the passenger travels through this means that the lower distance results in lower ticket expenditures in general. This means that even though ticket revenues are rising in business case as more individuals are travelling by public transportation each individual are saving money on public transportation.

As the project is implemented in steps the user benefits are as well. In the phase-in period only part of the benefit effect is initiated. A phase-in period is assumed for each line opening. The first line – the Ring Line – initiates at 2026 with 40 pct. of the potential passenger benefit for this line and is increased each year in the sequence 70, 90 and 100 pct. in 2027, 2028 and 2029 respectively. The initiation of the "fingers" uses the same percentages with start in 2030. Hence, the phase-in period resembles the assumed phase-in period for the passengers in the financial analysis.

The user benefits from time and distance changes for each category can be seen from Table 21.

Entry	**Alternative 1 – Base UTO**	**Alternative 2 – Flex36**
Time savings, road	-61	552
Time savings, public transportation	-205	4.165
Time savings, freight transportation	0	2
Distance savings, road	-34	-12
Ticket expenditures, public transportation	5	39
Total net present value (NPV)	**-295**	**4.746**

Table 21: User benefits (NPV in mDKK)

The negative result of Alternative 1 indicates that consumers of transportation spend more time in traffic and drives a longer distance compared to the base scenario. For Alternative 2 the consumers experience a time saving but at the same time experience a small increase in the distance travelled. In total, alternative 2 implies large positive benefits for the consumers.

10.2.4 External effects

Externalities include the effects to the society that the individual traveller does not take into consideration when choosing which mode of transportation to use. Individuals are not expected to consider the noise or air pollution generated when considering their favourite travel plans. The external effects can either appear as benefits or costs depending on how the consumption pattern changes. All externalities are determined by the amount of kilometres driven in each alternative. This means that if more kilometres are driven more externalities occur. When more kilometres are travelled externalities are occurring causing negative influence to society and when less is travelled externalities influence society positively.

The socio-economic analysis includes changes in externalities such as climate, air pollution, noise and accidents that arise due to the changes in travel consumption patterns. When more kilometers are driven more accidents, pollution and noise is expected to occur. 'Air pollution' includes emission of NOx, HC, SO_2, CO and PM2.5 whereas 'climate' only includes emissions of CO_2. The inconvenience due to noise is also estimated using unit costs. Lastly, the number of accidents depends upon the kilometres driven and the costs to society increase as number of accidents increase. An extended description of externalities and how they are determined can be found in appendix section 13.

The benefits or costs of externalities are valued using unit prices as a function of train and car kilometers driven in each alternative compared to the basis scenario. E.g. for each additional kilometer driven by individuals due to implementation of the project society is expected to lose value as more accidents, noise and pollution is expected to occur. Table 22 shows the net present value of the externalities in the two alternatives. As both alternatives result in net more kilometers driven both alternatives have negative externalities.

Entry	Alternative 1 – Base UTO	Alternative 2 – Flex36
Accidents	-5	-128
Noise	-1	-13
Air pollution	-1	-48
Climate (CO2)	-1	9
Total net present value (NPV)	**-8**	**-180**

Table 22: Externalities (NPV in mDKK)

10.2.5 Other effects

The category 'other effects' include tax consequences for the public, work supply distortion and work supply gains. Each has been calculated using the TERESA-model and adhere to the assumptions in the manual for socio-economic analysis within transportation. Table 23 specifies each of the three categories. An elaboration of each of the separate subcategories can be found in the appendix section 13 or in the manual for socio-economic analysis with transportation projects.

Entry	Alternative 1 – Base UTO	Alternative 2 – HA36
Tax consequences	25	-353
Work supply distortion	271	-415
Work supply gains	-38	582
Total net present value (NPV)	**257**	**-185**

Table 23: Externalities (NPV in mDKK)

10.3 Sensitivity

Socio-economic analysis always involves some uncertainties due to uncertainty surrounding the used input and assumptions. To determine the robustness of the analysis, these uncertain parameters have been varied to investigate how important these are to the socio-economic result.

We have identified the following parameters which we consider crucial for the analysis and which might involve uncertainty.

- Investment in capital
- Socio-economic interest rate (the rate of return which can be expected from similar projects)
- Value generated through time savings (time saving unit prices)
- Expected passenger growth rate

Entry	Alternative 1 – Base UTO	Alternative 2 – Flex36
Main result	**594**	**3.114**
Investment in capital: +25 pct.	106	2.551
Investment in capital: -25 pct.	1.081	3.676
Socio-economic interest rate: 3 pct.	1.052	4.415
Socio-economic interest rate: 5 pct.	261	2.148
Unit prices for time savings: -25 pct.	669	1.791
Unit prices for time savings: +25 pct.	518	4.436
Passenger growth: 0 pct.	572	2.393
Passenger growth: 2 pct.	531	3.038

Table 24: Sensitivity (NPV in mDKK)

Table 24 indicates that the socio-economic results are rather robust as neither of the sensitivity scenarios resolve in negative net present values. This is the case when changing the amount of investment in capital, the interest rate, unit price for time savings and passenger growth.

11. CONCLUSION

The conclusion is derived from the overall analysis where there is focus on the strongest key findings and can be summarized as follows:

- **UTO attraction**
  When purchasing the next generation of rolling stock for the S-Bane in Copenhagen, it is possible to define UTO scenarios as much more attractive and viable option, than a comparable STO mode. From a financial perspective the attraction can be clearly demonstrated in the possibility to provide the same service at reduced cost (frequency of 30 trains per hour in central section with an operational pattern as it is today), or to increase the service level at the same cost (frequency of 36 trains per hour in central section with a combination of classic and metro style operation). If also taking the Social Economic analysis into account, the scenario with best service provision also exhibits the best economic performance.

- **Operational flexibility**
  The UTO attraction and the investigated scenarios should be understood as a confirmed proof-of-concept, rather than suggestions for specific future operational plans. For that reason, it's not required that a decision about introducing UTO is necessarily followed by decisions about exact operational plan, or a specific traffic pattern. This could be addressed as a part of the potential future tender process.

- **Technical feasibility**
  From a technical point of view, feasibility can be provided by different solutions that are all functioning in commercial operation today. The major technical elements comprehend CBTC based rolling stock with a max. speed of 120 km/h, coupling into units from 1 to 3 sets, stepless boarding, objective detection systems (ODS) on platforms and fences in between stations. No of the suggested technical solutions are characterized as green field. However, due to innovation, even more efficient and robust solutions are expected to be developed and introduced within the next 10 years.

- **Rollout based on early deployment and stepwise implementation**
  The recommended rollout scenario is based on the test and early deployment on Ringbanen, leaving the vast majority of the network undisturbed until a more robust solution is implemented and sufficient lessons learned are collected, reviewed and assessed. Once the Ringbane is converted into a UTO mode, a three step successive rollout plan encompassing the outer lines, shall be planed taking the complexity of each line into account, including the accessibility to depots and workshops.

- **Organisational impact**
  The most obvious organizational impact will be that +500 of the existing train drivers that will be made redundant on the S-bane. The existing on-train and platforms service personnel may probably be enlarged to a team of an estimated 200 service stewards, as known from the Metro today. The changes give a major positive contribution to the final financial results. However, a combination of natural reduction in staff (retention, job changes) and potential transfer of train drivers into regional- and long distance trains (fjernbanen), makes the redundancy among train drivers and the need for layoffs manageable. It's recommended to keep a strong focus on the general transition process, which should be supported by change management strategies and strong leadership.

- **Risk Assessment**
  The overall risk assessment points in the direction that the most considerable incidents may well be related to dependencies on other external development projects, which are outside the control of potential UTO project. And, the combination of newer proven solutions mixed with an exsisting system, i.e. UTO mode in a large railway network not originally designed for driverless solution almost entirely above ground, may also be a challenge. Due to these uncertainties and the early stage in the investigation, a risk premium of 50 pct. is added to all infrastructural investments, while 30 pct. is added to the rolling stock. In addition, when it comes to external dependencies, a strong mitigating response will be, that much more evidence about the actual performance will be available long before the necessary decisions will need to be made in regards to UTO.

- **Financial and socioeconomic results**
  From a financial perspective, the UTO attraction is derived from four main sources: Extra cost related to new infrastructure, extra cost to UTO compliant Rolling Stock, increased income due to more passengers, and reduced staff costs due to UTO mode. All this is estimated as a delta result, compared to a STO mode. From a Socio economic perspective, the major contributor comes from user benefits, in particular, time savings in public transportation, in the scenario with 36 hourly trains.

To summarize, the analysis emphasises that UTO is the best option with the best obvious potential for future benefits. It’s therefore, the recommendation to take the next step in the decision process in the direction of UTO. And as it stands, further investigation will be required. However, this can be incorporated in a long term procurement strategy based on a controlled decision gates, and thereby allowing the process to continue as soon as the required decisions are made.