2. The Copenhagen’s metro

2.1. Introduction

Copenhagen, as the main urban area of the Nordic countries with more than one million people and its great situation linking Denmark with Sweden, makes the capital a strategic point, especially for commercial activities. Hence, the city needs good infrastructures to connect other cities as fast as possible, but without forgetting its own development. Although the Danish capital has been always a city with a bicycle custom, where a lot of people move through the city by bike, the use of public transport has been increased during the last years. However, due to the extension of the city towards new areas developing business activities and dwelling spaces, Copenhagen needed a better public transport network to fulfill the demand. Aside from the improvement of the bus and railway services, the idea to construct a new urban railway through the city came up in the beginning of the 90’s.

The Danish State, together with the Municipality of Copenhagen, founded the Ørestad Development Corporation, which was in charge to study the viability for the implementation of this new urban transport mode. Moreover, the company had two different tasks: the construction of the new infrastructure and the development of a new district in the southeastern part of Copenhagen, known as Ørestad.

After the analysis of different alternatives, an automatic minihetto option was chosen as the best solution, both for traffic and social economic effects. This metro would use the most advanced technology in terms of safety, comfort and functionality for the passengers.

The new line would connect the city center with Kastrup airport and it would give a better link with Frederiksberg area, which was weakly connected by railway traffic. Moreover, metro would help to develop the Ørestad region, which will be the new business center of Copenhagen within the next 30 years. The driverless operation of the metro, as well as the underground condition in the center boring a double tunnel under the city, will be the main features for the metro line. Hence, this new metro was a challenge for Copenhagen, as it would be the first urban railway line of these characteristics in Denmark. Most of the population was agreed with this project and the metro was a reality in 2002 when the first phase was opened. At the moment, the metro is very successful and Copenhageners use it everyday as the best urban public transport mode. In 2007, the third phase will reach the airport culminating the idea that came up many years ago, but such a success, together with political reasons have been the point of departure to extend the metro network towards some forgotten districts, develop little by little the public transport and compare Copenhagen with the main European cities. Thus, The City Circle line can be a reality in 10 years and it will complement the demand that now is dissatisfied, neither by the actual metro line, suburban trains or bus network.

In the following chapters the planning process of Copenhagen’s metro will be explained, laying emphasis on some points above like the choice of the minihetto solution, the new Ørestad region, as well as the situation of the stations, the safety system adopted by the metro, social impacts and general characteristics of the actual and the future lines.
2.2. Background of the metro

After the disappearance of the last tramway in 1972, the idea to construct a new urban railway through Copenhagen came up in the beginning of the 90’s. Although there were good suburban railways infrastructures and a good enough public bus network inside the city, some of the demand remained weakly connected depending on the areas, specially Frederiksberg with Christianshavn and Amager region. This new urban transport needed the last and more advanced technology and safety system, as one of the aims of this project was that Copenhagen could be compared with the main European cities in urban transport development.

For that reason, the project was authorised through the Danish Parliament and in 1993 the Ørestad Development Corporation (ØDC) was formed in order to study the viability and keep going with the project. This company is owned between the Municipality of Copenhagen and the Danish State, with 55% and 45% of the total holding, respectively. One of the first tasks of this company was to study and analyze the different alternatives of transport modes between metro, tram or light rail. Traffic studies, together with social economic analysis, proved that a metro line was the best solution for Copenhagen and its development in a future.

The initial idea for the metro’s layout was the connection between the west and the east parts of Copenhagen, linking Frederiksberg with Ørestad region and Kastrup airport. Hence, two sub companies were founded in 1995: Frederiksbergbaneselskabet I/S, owned by ØDC in a 70% and Municipality of Frederiksberg in a 30%, and Østamagerbaneselskabet I/S, owned by ØDC in a 55% and the Copenhagen County in a 45% of the total holding. The first company was in charge for the Frederiksberg line, the west part of the metro line to Nørreport, and the second one was created to construct the rest of the line. (Ref: [1]).
Basically, the main tasks of these three companies are:

1. Construction and Operation of the New Metro
2. Development and Sale of Ørestad
3. Developed according to the New Town Principle

The first task, as explained before, is to construct and operate the metro line, separated in different areas and phases.

The second point represents the urban plan and development of Ørestad region. This area will be the new urban district of Copenhagen and it will be fully developed during the next 25 years according to The Master Plan (Ørestaden). The connection between the metro and Ørestad region will be explained in the next chapter, but basically, the operations and sale of land in Ørestad, as well as the contributions from Frederiksberg and Copenhagen cities will be the funds for the repayment of the loan given some years ago to construct the metro. This repayment will be done after the fulfilment of the urban development area, which means at least in 2030.

New Town Principle is based on the construction of the metro in the Ørestad region before building the urban district. This will increase the value of the surrounding areas and it will help to repay the loan that ØDC took to develop the metro.

After some bids and evaluations, ØDC gave out the consultancy tasks to different companies such as Carl Bro Gruppen, COWI, KHR architects, etc. They had to develop different parts of the project like rolling stock, project management, traffic planning, urban planning, environmental planning and so on.

Metro is being developed in three phases and at the present time the third phase, which connects Løgås parken with the airport, is still under construction.

Moreover, in 1996, Comet group and Ansaldo Transporti won the contracts for phases 1 and 2. The first company was contracted for the construction of the tunnels and stations under the name of civil works. Ansaldo Transporti received the award for all the transportation system, as well as the first five years of operation and maintenance. That means rolling stock, Automatic Train Control (ATC) system, power supply and other railway installations. The duties for the operation and maintenance of the metro are carried out by Metro Service A/S Company, which is a sub contractor to Ansaldo. (Ref: [1])

After the implementation of the first phases of the metro and its success for the good operation and the agreement by the population, Copenhagen is thinking to enlarge the metro network with other lines in order to fulfil the demand, as well as the improvement of the bus service along the city. ØDC has been authorized to study and analyze the possibility of this new metro line, called phase 4 of the Copenhagen metro. Later on, the future of the metro will be explained in further details.
2.2.1. Metro as the best new urban railway

The studies to choose the most accurate new transport system for Copenhagen were carried out for different consultants through ØDC. They analyzed three alternatives, each one with its pros and cons: (Ref: Søndergaard M.)

- An automated driverless minimetro
- A driver operated tram
- A driver operated light rail

The minimetro would run in an exclusive right-of-way, that means no interaction with other transport modes, and in consequence a high average speed all along the route. It combines a tunnel section in the city centre with elevated tracks in the other parts of the layout. Besides, it would be the first automatic transport system in Denmark, increasing the attraction for the population. This system could reach headway times of 90 seconds, which means shorter trains and shorter length of the platforms. Besides, the tunnel diameter can be smaller thanks to the third rail powered system that minimetros will have. All these characteristics will reduce the construction costs for the tunnels and stations, both for underground and elevated. Although the constructions costs when boring a tunnel under the city are higher, it is a very good solution in terms of safety and nuisance for the citizens during the construction, as well as later on, when the metro is operating.

The tramway would run at level's street, getting a good and fast accessibility from other transport modes. The high flexibility provides the tram with a very small radius and it permits a good adaptation through the streets’ configuration. However, the non right-of-way of the tram makes a scheduled minimum headway time of approximately two minutes and a half, which implies a lower frequency than the minimetro. This headway time is adopting the typical signalling system of the streets. One of the advantages of the tram is the construction and maintenance costs, which are much lower than the minimetro, but on the other hand, the troubles for the population are much higher and the powered system provided by overhead conductor system is not as smart as the third rail system.

Finally, the light rail is a combination of the other two alternatives. It is a driver operated system like the tram, adopting the street signalling system with the same headway time, but in the city centre goes underground like the metro. The higher is the the headway time, the lower is the frequency, and in consequence, the longer are the trains and the platforms, increasing the costs for the underground stations. Moreover, the powered system like the tram increases the diameter tunnel, which means again an increasing of the construction costs. It seems that this alternative takes the bad points of the other two, but actually it is not. In the city centre goes underground, making easy the safe, noises and vibrations’ problems for the neighbourhood. In the suburbs, west and east parts of Copenhagen including Ørestad region, the light rail adopts the tram solution, reducing the costs. In this area, both the tram and the light rail, they would run in an exclusive right-of-way with level crossings.
Next table shows some of the characteristics for each alternative:

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Minimetro</th>
<th>Tram</th>
<th>Light Rail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. speed (km/h)</td>
<td>80</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>Min. radius (m)</td>
<td>240</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Max. gradient (%)</td>
<td>6</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Min. Tunnel diameter (m)</td>
<td>4.9</td>
<td>-</td>
<td>5.1</td>
</tr>
<tr>
<td>Platform length (m)</td>
<td>53</td>
<td>32</td>
<td>70</td>
</tr>
<tr>
<td>Power supply</td>
<td>3rd rail</td>
<td>Overhead</td>
<td>Overhead</td>
</tr>
<tr>
<td>Signalling</td>
<td>Fully automated</td>
<td>Street signalling</td>
<td>Street signalling</td>
</tr>
<tr>
<td>Min. Headway time (sec)</td>
<td>90</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>Rolling stock length (m)</td>
<td>26.4</td>
<td>34.6</td>
<td>34.6</td>
</tr>
<tr>
<td>Number of passengers</td>
<td>192-205</td>
<td>238</td>
<td>238</td>
</tr>
<tr>
<td>Acceleration (m/s²)</td>
<td>1.3</td>
<td>1.3</td>
<td>1.3</td>
</tr>
<tr>
<td>Deceleration (m/s²)</td>
<td>1.2</td>
<td>1.3</td>
<td>1.3</td>
</tr>
</tbody>
</table>

Table 2. Characteristics of the three alternatives. (Ref: Søndergaard M.)

A traffic forecast model was developed to analyze the future traffic, taking some factors into account:

- The planned extension of the infrastructure in the region: it is important when developing a new infrastructure to analyze its hinterland. It means the region that will be affected not only for the construction and operation, but also for other developments due to the infrastructure, as well as studies about possible extensions of the new network in a future.

- The changes in the bus and train service after the opening of the urban railway: following the layout of the new infrastructure and its connections with other modes of transport as train and bus, some changes in the service can be observed, especially in the bus service, which is more flexible than the train. For example, there could be some buses doing the same route as the new urban railway and hence their demand after the opening of the new infrastructure would decrease. Then, the bus can change its route giving other opportunities through other roads or even disappear from the bus network.

- Statistical forecasts of the population and workplaces: to study how the new infrastructure will affect to the population, it is necessary to do surveys and statistical forecasts trying to analyze how many people will use the infrastructure and the type of trip that they will do, specially between work trips and non work trips. Besides, it is important to study the availability of the workplaces inside the city and all along the route, as this will influence the number of work trips.

- Plans for development of Ørestad with dwellings and business space: connected with the point above, Ørestad region will be a business area, with a lot of offices, as well as housing areas, generating a lot of job opportunities. This new town will rise with the new infrastructure as the main transport system and it needs a good developed plan, giving a good connection between both sides of the
railway line. Thus, it is not the same an elevated infrastructure independent of the road traffic or one with grade crossings.

- Development in car ownership and parking possibilities: one of the aims of this new urban railway is to connect the city centre with the suburbs within a short travel time. People living outside Copenhagen could use this infrastructure to reach the centre, leaving their cars in car parks specially created for this purpose, as parking possibilities in the centre are really few. Hence, it would help to reduce the congestion in the city centre.

- Travel expenses and travel time: this new urban railway will reduce the time going between east and west of Copenhagen, specially with the minimetro and light rail options, as they go underground in the city centre, where the traffic problems are bigger due to the narrow streets. This could be a handicap for the tramway. However, not only the travel time has to take in account, but also the travel costs, as for example, going by bike through Copenhagen is much cheaper than public transport.

- Frequency, transfer times, capacity, comfort and access times: these characteristics for the urban transport modes are different depending on the alternative and they have to be analyzed. Hence, minimetro has the best frequency, as it has the minimum headway time, but due to the underground stations, transfer times from other modes to metro are higher than the tramway, which is really fast connected being at level street. In terms of comfort, all the alternatives are fitted with the most advanced products with low noise, vibrations and high comfort. However, the fact that tramway is going through the streets in the city centre makes less comfortable than the others because of the more accelerations and decelerations. The access times analysis is similar to the transfer times. Underground and elevated platforms need more time to reach one point from the street.

- Network for other transport modes in Greater Copenhagen area: it is important to analyze the other networks like road traffic, both for private cars and buses, trains, both for suburban and regional lines, and even bicycle and walk paths. This will help to understand the layout of the new urban railway and the locations of the stations, optimizing the connections with other transport modes.

- Capacity restrictions in peak hour traffic: finally, a deeper analysis for the capacity is done in order to ensure the good operation, specially in peak hours. Mornings when people go to work and afternoons when they come back are the critical hours in terms of capacity. Besides, as the new infrastructure will connect the city with the airport, it means an extra amount of traffic. All this factors are important when developing the trains and platforms’ length, but also the frequency of the service.

The model was using stochastic assignments and it was run in a three different scenarios for each alternative: (Ref: Søndergaard M.)
Planning system of metro networks. Comparison between Copenhagen and Barcelona

1. Year 2000 with the initial of phase 1
2. Year 2010 with the operation of all 3 phases and half of new Ørestad has been developed
3. Year 20xx with all the new Ørestad developed

Next results were obtained after run the model:

<table>
<thead>
<tr>
<th>Alternative Minimetro</th>
<th>Tram</th>
<th>Light Rail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mill. Boarding/year</td>
<td>28</td>
<td>69</td>
</tr>
<tr>
<td>Mill. Pass.-km/year</td>
<td>329</td>
<td>149</td>
</tr>
<tr>
<td>Mean length of journey (km)</td>
<td>4.0</td>
<td>2.9</td>
</tr>
</tbody>
</table>

Table 3. Results obtained from the stochastic assignment model. (Ref: Søndergaard M.)

It can be observed that minimetro option attracts a greater number of passengers, for all the three scenarios. Light rail is quite similar than minimetro, but tram alternative is the less attractive option for passengers. Travel speed and high frequency are the most decisive factors when people choose the alternative.

Even though metro seemed the best idea for the new urban railway in terms of traffic analysis, other studies were taken into account to offset the other possibilities. Basically, it was a Cost-Benefit analysis with different factors:

- Accidents
- Inconvenience during construction
- Environment
- Economy

The idea that tramway is more dangerous to crash with road traffic, bicycles or persons due to the shared space in the streets seems clearly from the beginning, but other kind of accidents were analyzed like fire in tunnels, underground stations or vehicles. These accidents occur rarely, but the number of casualties can be much bigger than typical crashes in the street. Hence, accidents have been divided in different categories depending on the casualties: catastrophe means 100 fatal accidents, while serious is 10. Minor consequences have the categories of major, small and trivial, with 1 fatal accident, several injuries and bruises, respectively.

The results are shown in the next table:

<table>
<thead>
<tr>
<th>Alternative Type of accident</th>
<th>Minimetro</th>
<th>Tram</th>
<th>Light Rail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catastrophe</td>
<td>0.0004</td>
<td>-</td>
<td>0.0003</td>
</tr>
<tr>
<td>Serious</td>
<td>0.0013</td>
<td>0.0017</td>
<td>0.0044</td>
</tr>
<tr>
<td>Major</td>
<td>0.3</td>
<td>1.1</td>
<td>0.9</td>
</tr>
<tr>
<td>Small</td>
<td>0.51</td>
<td>3.6</td>
<td>2.7</td>
</tr>
<tr>
<td>Trivial</td>
<td>7</td>
<td>50</td>
<td>38</td>
</tr>
<tr>
<td>Fatalities per Billion. Pass.-km</td>
<td>100</td>
<td>787</td>
<td>339</td>
</tr>
</tbody>
</table>

Table 4. Results obtained from the accidents' analysis. (Ref: Søndergaard M.)
Planning system of metro networks. Comparison between Copenhagen and Barcelona

Tram has a bigger index of trivial accidents, and underground stations and tunnel sections in minimetro and light rail increase the risk of catastrophic accidents, though the probability to occur is really low. To sum up, minimetro is the safest alternative, followed by the light rail and the tramway.

The inconvenience during construction analyzes the nuisance for the daily routines that the new infrastructure will make to the population. Hence, tunnel boring machine when constructing the tunnel is less annoying than working at level street. Moreover, the implementation of cables for overhead power supply in the tram alternative inside the city centre is more contradictory with neighbourhood’s activities, both for the construction and operational phases.

Environment aspects’ analyses are made in purpose to find the less damaging alternative. Noises, vibrations, visual impact, etc, are different factors to be taken into account. As trains are fitted with most advanced technology, the noises and vibrations are minimum, even for the tram, running outside. More problematic is the visual impact, where the overhead conductor system of light rail and tram is worse than metro. However, in non underground stretches where minimetro goes in embankments or elevated tracks, the visual impact is even stronger.

Finally, the economic analysis for each alternative is compared, showing the results in the next table:

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Minimetro</th>
<th>Tram</th>
<th>Light Rail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital cost phase 1 (Mill. DKK)</td>
<td>3,600</td>
<td>2,000</td>
<td>3,700</td>
</tr>
<tr>
<td>Capital cost all phases (Mill. DKK)</td>
<td>5,200</td>
<td>3,900</td>
<td>4,900</td>
</tr>
<tr>
<td>Internal Rate of Return (%)</td>
<td>2.4</td>
<td>0.5</td>
<td>2.0</td>
</tr>
<tr>
<td>NPV/pass.-km/year</td>
<td>100</td>
<td>262</td>
<td>121</td>
</tr>
</tbody>
</table>

Table 5. Economic results for minimetro, tram and light rail. (Ref: Søndergaard M.)

Results show that minimetro is the most expensive alternative, similar with light rail, probably due to the construction of underground stations and tunnel sections, increasing the construction and maintenance costs. Summing up all the analysis, the conclusion is that minimetro is the best solution for: (Ref: Søndergaard M.)

- Provides the passengers with the best service with respect to travel time, frequency, reliability and safety, and hence attracts more passengers.
- Will create less inconvenience for the citizens of Copenhagen during the construction and operational period, especially as compared to the tram system.
- Is a safer and more reliable system with very fewer accidents compared to the alternatives
- Environmental impact during operation is negligible in the city centre and less than the tram system in the construction period.
- Initially is more expensive than the other systems, especially the substantially cheaper tram, but seen over a number of years, and from a socio-economic point of view, the minimetro is superior.
2.3. Connection between Ørestad region and metro

Many years ago, the idea to extend the city of Copenhagen to the south part came up. This area, known as Ørestad region, is a natural landscape with wetlands and fauna corridors. Hence, the urban development of this area had to follow a basic procedure trying to preserve this natural environment as much as possible. On the other hand, a new urban transport system should develop in order to provide the new town a good connection with the rest of Copenhagen. The basis to construct the new area integrated in the environment and the metro as the main transport mode is The Master Plan. This plan ensures that Ørestad will be a modern architectural district, built in a natural landscape around the new infrastructure. Water will be an important feature and different land uses will be integrated in the town like education, research institutes, enterprises, cultural institutions, dwelling space, commercial zones, etc. University is placed in the northern part of Ørestad. Besides, the proximity of the zone with the airport and Sweden will make Ørestad as the new business space in Copenhagen about 2030, when the new town will be fully developed. (Ref: The Master Plan)

The Master plan was prepared by ØDC, together with Ørestadsrådet, which is a statutory council, where Danish Society for the Conservation of Nature and the Open Air Council are members of it. They took the basis from an international architectural competition made in 1994 in order to determine the general framework to develop the planning of Ørestad. This competition was won by a Finnish group. After the approval of The Master Plan, it was incorporated in the Municipal Plan of Copenhagen in 1997.

Fig. 12. Situation of Ørestad city. (Ref: www.orestad.dk)

Aside from the metro line and the building of new Ørestad, ØDC was in charge to construct the Ørestad Boulevard, going from Amager Boulevard in the north to Øresund motorway in the south part. This Boulevard will be the main street, parallel with the metro line and where the main events will take place, but it has to be integrated in the new town sharing the same features, with a moderated speed and being able to absorb all the road traffic without congestions, but not with a high capacity.
According to The Master Plan, metro line must be the main transport system in the zone, increasing the demand of the public transport. The line must not be a barrier and in consequence, if the new infrastructure was at ground level, it would break the connection between different parts of the new town, giving a worsening for the future activities. Anyway, the metro line has to be central and visible to reinforce the use of the public transport for the population. An elevated urban railway would be the solution, but always taking into account the best integration in the urban architectural and functional development of the new city.

Metro line has 6 stations in Ørestad region, each one with a different urban planning vision, according to the land uses. From north to south: Islands Brygge, Universitetet, Sundby, Bella Center, Ørestad and Vestamager. (Ref: The Master Plan)

Following the suggestions of The Master Plan, the first two stations catch the university area along Amager Fælledvej Street. Here, Copenhagen University is at the moment developing its founding, together with institutes and some enterprises based on research and technology. A building of even 20 storeys can be the best feature to locate the district.

Sundby Station will be the central point of a housing area, as well as commercial, situated between wetland areas that have an interesting natural environment, and the buildings will not pass more than five floors.

The main feature for the Bella Center area will be some particular buildings with 50 meters high. The southern part will be a district with a high density of buildings. Ørestad station will be the central station of the new town, where its connection with the railway and the proximity of the Øresund motorway will make the place as the central part of Ørestad. Buildings with maximum fifteen storeys will be built parallel to the freeway, but in the rest of central Ørestad, the building height will vary from three to eight floors. The southern part of Ørestad, where Vestamager station is, will be a commercial and office area, together with the possibility to locate a dwelling area with an attractive surrounding, as the boundary with the protected areas in Vestamager is currently a large lake.

The development of these districts will take some years and it will be progressively divided in five phases.

First of all, and following the New Town Principle explained before, the metro line will be built before the development of the area. The reason is to increase the value of the surrounding areas and takes advantage of it to pay the investment done by ØDC. After the construction of the metro line and the Ørestad Boulevard, the first and second phases start with the development of the central Ørestad, around Ørestad station and the University area in the northern part, with the extension of the actual university in order to attract more students. At the moment, these two districts are totally in developing process.

The third phase will be the development of the districts along the boulevard and the canal, with the metro stations as the central point. The fourth phase will be the development of the southern and western part of Ørestad with a lot of housing construction. Finally, the Plan prepares the building of the urban area in Sundby station.

The Ørestad region will be fully developed in about 25 years, according to The Master Plan, and it is planning that 60,000 people will work in Ørestad, there will be 20,000 living there and approximately 20,000 students in the university area, with a total of 310 hectares for all the Ørestad new city. (Ref: www.orestad.dk)
Taking advantage of the area, ØDC built its headquarters between Ørestad and Vestamager stations. This space, known as the Control and Maintenance Center (CMC), is where metro trains are maintained and parked. Moreover, all the driverless operation system and safety procedures are controlled from here. The CMC is divided in two areas: (Ref: [1])

- A fully automatic servicing area where the trains are serviced, washed, tested and parked.
- A manual maintenance area where the trains are kept in working order.

Depending on the type of maintenance, there are separate tracks for internal and external maintenance. Wash areas, bogie replacements, wheel lathe to reduce noises and vibrations when metro is running, etc. CMC is also equipped with a test track, where the correct functionality of the trains after being repaired can be observed. This test track was also used to check all the monitoring system before the metro was opened in 2002.
2.4. The existing line

The metro line is connecting the west part of Copenhagen between the east part, passing through the city centre with Nørreport as the main station, both for its central location and its important connection with other transport modes. The main points through Copenhagen are: Frederiksberg district, Kongens Nytorv as the heart of city centre, new Ørestad town and Kastrup airport.

The metro’s layout is going from Vanløse to Christianshavn stations. From here on, the line splits in two different ways, one going to Vestamager through new Ørestad town and the other one connecting to the Copenhagen airport via Lergravsparken station.

Metro have been divided in three phases for its easier implementation. The first one was opened in October of 2002, when the stretches between Nørreport-Lergravsparken and Nørreport-Vestamager were inaugurated. The second phase opened during 2003, where Nørreport-Frederiksberg was firstly linked, continuing few months later to Vanløse, where the line ends in the west part of the city. Finally, the third phase is still under construction and it will be opened probably in 2007, linking Kastrup airport with Lergravsparken station, which will permit a fast connection between Copenhagen city centre and the airport.

![Layout of the metro line with the different phases](Ref: [1])

The route has a total of 21 kilometres double track, where the central part is going underground, doing a total of 11 kilometres in tunnels. The rest of the line is going on elevated tracks or on embankments.

The construction of the tunnels was done almost all the stretch by a Tunnel Boring Machine (TBM) of 5.5 meters of diameter. Due to the composition of the soil, basically limestones, and the presence of water, an Earth Pressure Balance (EPB) was used. This kind of TBM is boring the soil in a sealed off chamber, avoiding the fall of the earth walls with the pressure, while is covering the perimeter with a concrete ring panels. Other construction methods used for the tunnels were the Cut and Cover process and the...
New Austrian Tunnelling Method (NATM), where the two parallel tunnels, one for each direction, are connected in certain points allowing the switch from one track to the other one.

One of the characteristics of the tunnels is that there are dips between stations which are closer to the surface. It allows reducing the energy consumption by the train, taking advantage of the descents for the acceleration and the slope up for the break operation. On the other hand, the elevated tracks were constructed through viaducts and embankments. Although embankments are really annoying for the neighbours, acting as a barrier, the costs are much cheaper than bridges. These elevated tracks will be the most known feature of the metro for the new Ørestad city. (Ref: [1])

![Fig. 16. Tunnel section with concrete panels (left). Elevated tracks in Ørestad (right).](image)

Metro can run at a maximum speed of 80 km/h, with an average in all along the route of 40 km/h. This urban railway permits the fast connection between stations and for example, it will be possible to reach Nørreport station from airport in 16 minutes, and crossing all the line within 25 minutes. Such good travel times provide the metro with a good service as the best urban transport mode in Copenhagen.

Due to the high frequency of the metro service, passengers do not need a timetable, and after the implementation of all the three phases, trains will run from Vanløse to Christianshavn with headway of 90 seconds. At the moment, trains are running with 2 minutes of headway for the rush hours. During the weekend’s nights, metro runs every 15 minutes. (Ref: www.m.dk)

A total of 34 trains will fit in the line after its completion. These trains consist of three units with access between them and allow a capacity of 300 passengers. Due to the driverless operation, one of the main features is that there are big front and back windows permitting the sight of the tracks and tunnels or the city in case of elevated tracks, giving to the passengers an extra safety.

Moreover, trains do not depart if the automatic doors are not completely close. These doors are provided with a pressure sensor, which opens the doors if any object is caught between them.

Basically, tracks are different depending on their location. If the line goes underground, concrete is used between the sleepers. On the other hand, on elevated tracks, the use of ballast is the most common feature. Both systems are implemented with the most advanced technology to minimize the vibrations and noises.
Next table shows some of the train and tunnel characteristics:

<table>
<thead>
<tr>
<th>Tunnel data</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum depth (m)</td>
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</tr>
<tr>
<td>Outer diameter (m)</td>
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</tr>
<tr>
<td>Inner diameter (m)</td>
<td>4.9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Train data</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Length (m)</td>
<td>39</td>
</tr>
<tr>
<td>Maximum speed (km/h)</td>
<td>80</td>
</tr>
<tr>
<td>Acceleration (m/s²)</td>
<td>1.3</td>
</tr>
<tr>
<td>Brake deceleration (m/s²)</td>
<td>1.3</td>
</tr>
<tr>
<td>Seating capacity</td>
<td>96</td>
</tr>
<tr>
<td>Standing capacity (4 pass./m²)</td>
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</tr>
<tr>
<td>Total passenger capacity</td>
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<tr>
<td>Bogies</td>
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<tr>
<td>Motors</td>
<td>6 x 105 kW</td>
</tr>
<tr>
<td>Power</td>
<td>750 V DC 3rd rail</td>
</tr>
<tr>
<td>Track gauge (mm)</td>
<td>1435</td>
</tr>
</tbody>
</table>

Table 6. Technical characteristics. (Ref: [1])

### 2.4.1. Stations

The location of the stations is one of the main features for the metro, as it is what determines the final layout. Besides, they need good connections with other transport modes, a good accessibility and an optimal capacity space. The length of the platforms is determined by the capacity, and in underground stations it is really important to reduce construction costs.

There are 22 stations all along the line, including the stretch between Lergravsparken and airport, which is still in process. 9 of them are underground stations: Solbjerg, Frederiksberg, Forum, Nørreport, Kongens Nytorv, Christianshavn, Islands Brygge, Amagerbro and Lergravsparken (see fig. 15). The other stations are elevated stations and on embankment, except airport station that will be integrated in the terminal station.

Some requirements have to be taken into account when constructing the deep tunnel stations: due to its difficult construction process and the necessity of free spaces, these stations were built in streets or big squares. Hence, the nuisance for the neighbours is minimum, and nobody needs to move out from their houses. Taking advantage of these streets, new urban spaces have been created, providing areas with new square furnishings, green areas or even shopping possibilities or cultural events.

However, the construction of these underground stations was not easy due to the groundwater level, which is near the surface. Engineers were afraid that a lowering of the water level when constructing the deep stations could affect some building foundations, specially in old buildings of the city centre, as they are made of wood. An exposing of these foundations with the air would cause their disintegration in few years, with a dangerous risk of instability. For that reason, the water level is checked continuously with an accurate care. (Ref: [1])

Stations are constructed with modern features like glass lifts, skylights, but also with a functionality use. Thus, these skylights provide the underground stations with daylight.
Approximately, the platforms are located at 18 metres below the surface using island platforms, which are more functional giving a better access through escalators and lifts. Moreover, there is a glass wall between platforms and tracks with doors that lines up with train’s doors when metro stops. These platform doors have some characteristics: (Ref: [1])

- Protection against passengers falling or jumping onto the track. This means fewer accidents, fewer suicides and fewer service interruptions.
- Easier, better and less costly control of the ventilation at stations and in tunnels.
- Improved indoor climate.
- Greater safety for visually impaired passengers.

On the other hand, the elevated stations are located in viaducts or embankments, but both have a same design, similar to the underground stations using the same materials and modern features, escalators, lifts, platforms and so on. One of the aims of these stations is provide the passengers with a good access from the streets and other transport modes. Although these stations do not have platform doors, an electronic system detects the presence of an object on the tracks, stopping immediately the train, as a safety system procedure.

In the Ørestad town, where the metro will be the central transport mode in a future, the stations are made of lightweight materials to minimize the visual impact that these elevated stations will cause to the population.

Stations have an important role with the connections with other transport modes and this is an important task in the planning process. Almost each station is well connected with the public bus network and the good bicycle paths along the city, but not all of them can be connected with railway network. Hence, the metro line had to complement the demand that was not fulfilled with the Suburban railway network (S-trains) and it had to connect with S-trains in some points, as well as regional trains. Also Park&Ride has been implemented in some stations allowing a good connection with cars.

The first discussion was placed in the main station. Should be Nørreport or København H? Both are important, central stations, and connected with regional trains, but looking at the S-trains network it is observed that south-west part of Central Station is well
connected with suburban lines going to Ballerup and Frederikssund through Enghave, Valby and Langgade stations. Hence, Nørreport was the best option, providing the Frederiksberg central area with a better connection with the city center, through some metro stations like Forum, Frederiksberg and Solbjerg. Moreover, Flintholm metro station gives access to S-train to Nørrebro area up to Hellerup (F line), and also to C and H lines, as well as Vanløse station (see the S-trains map on www.m.dk).

The second point is that metro had to fulfil the demand in city centre and Christianshavn, as there was any railway transport mode. The station in Kongens Nytorv is a strategic point for citizens and tourists, which are able to reach the center in few minutes. On the other hand, Christianshavn island district was weakly connected with only two bridges to get in. Metro will help to liven up the mobility of the zone and probably to uncongest the road traffic in these bridges.

The third analysis of the connections is at Ørestad station, which is connected with regional trains going from Copenhagen to Sweden via airport and Øresund Bridge. This station will be the central station of the new business city with different possibilities. Hence, people could go to airport or København H with regional trains, or take the metro to the city center and Nørreport station. Besides, bus lines are also a good alternative, and the presence of the motorway gives a good connection with road traffic, both going to Copenhagen and Malmö.

Finally, the airport station is the special feature of the line. It will allow approaching the citizens to the Copenhagen airport and it will connect the metro with the air traffic, as well as regional and intercity trains.
2.5. Safety system

One of the most important points when developing a new railway transport mode is to implement a safety system, expounding all the regulations and rules that must take into account.

However, when the metro project came up, there were no regulations in terms of urban mass transit systems in Denmark, as the last tramway was removed in 1972 and it had not any specific traffic regulations. For that reason, and after some discussions and investigations, ØDC decided to adopt the German BOStrab regulations, as well as the technical guidelines from the association of the German mass transit companies, known as “Verband Deutscher Verkehrsunternehmen” (VDV). Moreover, some of the European CENELEC standards were took for the use of the hardware and software, as well as the American fire standard NFPA, together with some Danish national standards. (Ref: Frederiksen, G S., July 2000)

CENELEC, which means European Committee for Electrotechnical Standardization, was created many years ago to prepare electrotechnical standards in order to help the development of the European Economic area for electrical and electronic goods and services removing barriers to trade, creating new markets and cutting compliance costs (Ref: www.cenelec.org). The fact is that almost all the European countries have their own rail systems and equipments and sometimes is difficult to put them all together by common consent. Hence, one of the aims of CENELEC railway standards is to create compatible railway systems based on common standards.

Aside from all the regulations and standards, ØDC created a Safety Organization on the supplier side in order to control their fields. Although the Danish national railway (DSB) made its own safety assessment without any external organization, this is not the case of the metro, as ØDC has an independent Assessor (TÜV Intertraffic) to carry out the safety assessment.

Within the Safety Organization, there are 3 sub-organizations coming from Comet Groups and Ansaldo Transporti, working together as they have to cooperate in the safety procedures. They are TS-SUP (Transportation System Supplier), TS-O&M (Transportation System Operation & Maintenance) and CW (Civil Works). This last organization is from Comet group and the other two are from Ansaldo Transporti. Their responsibilities are: (Ref: Frederiksen, G S., 2001)

- Perform the safety planning.
- Manage and control the production of the safety plans and safety cases.
- Manage safety permits and licenses internally in the contractor organisations.
- Forward all safety relevant documents to the Independent Assessor.
- Prepare and forward the safety applications to the Railway Inspectorate via ØDC.

A good point is that BOStrab and VDV regulations are used to work with independent assessors like TÜV for many years and they have a lot of experience, not only in German, but in all European countries.
BOStrab regulations come from Germany and have a big success for many years all over the continent. These regulations are based on the construction and operation of light rail transit systems. BOStrab is used as the main rule for Copenhagen’s metro and some applications of these rules are: (Ref: Frederiksen, G S., Haspel, U.)

- Platform edge protection: due to the driverless operation, BOStrab requires additional protection for the platforms, in order to protect the passengers. As it was explained before, platform screen doors are set in the underground stations, and an electronic detection system in case of platforms without doors, on elevated tracks.
- Vehicle automatic sensing functions: metros have obstacle and derailment detection to stop the train if necessary.
- Emergency concept: this is based on reaching the next station to evacuate the passengers if any problem is originated on board.
- Tunnel ventilation: fan units and emergency shafts are arranged all along the tunnels to fulfil the BOStrab requirements in case of fire, smoke or any other inconvenience.

Related with the points above and the BOStrab regulations, tunnels must have emergency exits at least every 300 meters to ensure a good evacuation in case of any problem. Hence, there are shafts between stations also to ensure good ventilation. On the other hand, an emergency walkway has to be placed along the track to permit a good access to the nearest shaft or station. This walkway has a width of 70 centimetres.

Moreover, to ensure a good operation some of the important systems are duplicated. Hence, even if something fails, the metro can follow the normal routine. Two computer systems on the trains, redundant power supply, redundant fans to ensure the ventilation, redundant optic cables to prevent the communication at any time, etc. If half of the motors are broken, the metro can keep going on with the other half, or for example, even if half of the train is damaged, the call system to communicate with the control room is working. (Ref: [1])

Fig. 18. The Operational Safety Organization. (Ref: Frederiksen, G S., 2001)
Due to the driverless system of the metro, the emergency concept is an important point, both for passengers and rescue missions. Hence, four principles were developed to proceed correctly in case of any emergency: (Ref: Frederiksen, G S., July 2000)

1. Stopping along the line should be avoided. In case of an emergency the preference is to try to run the train to the nearest station (also on viaducts and embankments).
2. If in any case a train is stopped on the line it shall be attempted under controlled conditions to move the train to the next station before evacuating the passengers.
3. Safe evacuation is based upon self rescue of passengers.
4. Assistance in a rescue operation by third parties is deemed essential.

If the train reaches the nearest station, then it is much easier the evacuation of the passengers. Moreover, it prevents that passengers get trapped in tunnels in case of fire, smoke or any other problem, and minimizes the affection of the service for the other trains.

Although sometimes passengers will have to evacuate themselves before the arrival of rescue personnel, it is preferred to wait for them, as it is easier to proceed, help and guide the passengers, minimizing the panic and evacuating in a calm way.

For example, if a metro stops between underground stations with fire on board, a procedure is taken in order to evacuate the passengers safely. First of all, the emergency ventilation is initiated in the train’s original direction, and secondly, the passengers are evacuated in the other direction to ensure the fresh air as soon as possible.

In order to control all these emergencies and the technical systems like traction power, ventilation system, cameras, tunnel alarms, stations, electrical equipment and so on, metro uses a SCADA system (Supervisory Control and Data Acquisition). On the other hand, as metro is driverless, it is equipped with Automatic Train Control (ATC) system, which controls all the railway operational system. ATC will be explained in further details within the next chapter.

Although SCADA and ATC are two independent systems, they exchange data for the good operation of the metro.

Both systems, as well as all the metro line are controlled from the control room, which is situated in CMC building in Ørestad. Different supervisors are controlling the different parts like SCADA system, automatic operations, call points, trains and...
stations’ cameras, etc, and they are permanently in contact with the metro stewards, situated in the stations and inside the metros controlling the operations, helping the passengers and checking the travel tickets.

Different cameras are situated in stations and trains controlled from the control room and staff can communicate between each other through radio system, as well as police and fire departments. Moreover, passengers can communicate as well with the control room through call points, both in the platforms and on board, in case of emergency, assistance or people with disabilities. The correct functionality of the trains and the interaction of all the factors with the control room for a good operation were proved three years before that metro was opened in 2002, and almost everyday the operational system was tested. (Ref: [1])

![Image](https://www.railway-technology.com)

**Fig. 20. Control room in CMC building, controlling all the monitoring system. (Ref: www.railway-technology.com)**

### 2.5.1. Automatic Train Control System

The driverless operations of the metro and its fully automatic system are based in the Automatic Train Control (ATC) system, which is divided in three sub-systems: (Ref: [1])

- The Automatic Train Protection (ATP) system: this is the basic system protecting passengers, avoiding collisions, controlling the speed, the position of the trains, etc. ATP divides the track in block sections, where only one train can be fitted in one block section and prevents the entrance of another train in the same block. These sections are fixed and they are what determine the headway times.
- The Automatic Train Operation (ATO) system: this is the autopilot system, which basically controls the operation in the stations, controlling the doors, the dwelling times, as well as the breaking and starting operations.
- The Automatic Train Supervisory (ATS) system: this system controls all the traffic movements, as well as all the monitoring system, updating data on each train to stations and updating all the safety system.

Although all the sub-systems are important for a good operation, only the ATP system is the one that ensures a level of security. If ATO or ATS fail, ATP will act to avoid any accident.
The three sub-systems are constantly related between them. When the ATP control data indicates that a metro is in the block section, this data is sent to the ATS system, which controls if the train is running with the right schedule. If not, ATS can send information to the ATO system, which gives the stop command at the stations. ATO controls the dwell time, the departure time, as well as how fast has to be the metro to reach the next station without any conflict with the ATP system. Next figure shows how the three sub-systems are connected:

Summing up, there are lots of variations of ATC around the world but all contain the basic principle that ATP provides safety and is the basis upon which the train is allowed to run. ATO provides controls to replace the driver, while ATS checks the running times and adjusts train running accordingly. This system was implemented many years ago and for example, in London and Paris’ metros, ATO and ATS have been operational since the beginnings of the 60’s.
The main difference for the driverless operation of the Copenhagen’s metro is the necessity of an accuracy break operation, as the metro’s doors have to line up with the platform’s doors in underground stations. Here, the ATC system updates the position of the train when approaching the stopping point and checks the precise position before the doors are opened.

One of the good points of the automatic control system is the generation of accurate data of the service. At the stations, passengers know constantly the minutes left for the arrival of the next train, the possible delays, etc.

Moreover, the driverless operation provides some advantages: (Ref: [1])

- Instead of long trains with infrequent service, the Metro has many short trains with very frequent service. The interval between trains on the central section will be as short as 1.5 minutes. This means brief waits.
- The automatic operation enables the trains to run at closer intervals than under manual operation. Apart from the shorter waiting times, this also makes it easier to make up for delays.
- The trains are more punctual. At least 98% of the departures will be on time.
- Instead of driving the train, the Metro staff will serve the passengers and create a feeling of security.
- Using the Metro will be very safe since human error is avoided.

Although the driverless operation ensures a minimum headway of 90 seconds, it was not possible to get this time when the metro was opened in 2002. The safety management set an additional measure to run the trains with 6 minutes of headway to ensure the success in case of rescue operations, as they did not have yet enough experience. If metros had run with 90 seconds from the beginning and some train had failed between underground stations, the rescue activities would have to evacuate two or three trains with 300 passengers each one. Hence, the headway of 6 minutes ensured that only the failed train should be evacuated.

However, due to this high headway time, the passenger capacity was not reach and there were some problems of queues at stations, as all Copenhagener wanted to try the metro in the first days of operation. In order to solve these problems and reduce the headway time, Metro Service Company made daily reports with information about all the systems that take part in the operation, such as false alarms of ATC system, failures in the platform screen doors at tunnel stations, etc.

With this information, periodical meetings were made with all the safety organization, ØDC, suppliers, Safety Assessor, Safety manager, operator, etc, and little by little the headway time was reduced reaching 2 minutes in March of 2003. (Ref: Frederiksen, G S., Haspel, U)

Next paragraphs show some examples of rescue activities, safety procedures and railway manoeuvres like turn around operations and applications of the switches:

For instance, in order to disconnect the power system via 3rd rail, there are Emergency Power Cut off Handle (EPCH), one on the control room, two on the platforms and one in the shafts. If there is any emergency and the EPCH is activated, then the ATC system will brake all the trains around. Then, trains are moved to the next stations under ATP control, as the emergency concept indicates.
Another example of rescue and safety procedure is if a train fails between two stations, and sends radio alarms, the train dispatcher sends emergency stop and immediately the ATC system extends the dwell time at previous stations for the other trains and avoids the entrance of another train in the same block section. Immediately, a rescue train and two stewards are selected from the control room, one going to the rescue train and the other one to the next station, while passengers on board of the failed train are informed on how they have to behave. Dispatcher is checking the possible track way and destination for both, the rescue and the failed train, in order to remove them from the actual schedule. They can go to CMC, terminal station or some halt track.

As ATC system was blocking the track around the failed train, it has to remove this blockade and clear all signals in order to couple the two trains. Once both trains are coupled, they go to the next station to evacuate the passengers and finally they reach the final destination, for example CMC. (Ref: Frederiksen, G. S., January 2000)

The fact that metro runs with a low headway time, requires a good, fast and safe turn around operation, specially at Vanløse station. Looking to the next track diagram, it can be observed the location of the switches along the line, as well as the situation of the shafts, stations, pocket tracks and provisions for future extensions.

Although the headway time is really low and trains are running close between each other, the position of the switches in km 0,15 (see diagram, page 44) allows a good turn around operation, as one train is following the same track to stop at Vanløse station and the next one changes the track to stop in the other side of the platform, while the first train is waiting for the passengers going to the city center direction. Hence, one side of the platform is for trains going to Lergravsparken and the other side is for trains going to Vestamager, so trains have more than 2 minutes to proceed with the operation, which is enough time.

The turn around operations both in Vestamager and Lergravsparken are much easier, as the headway between trains is higher. Anyway, these operations are carried out in different ways. As Lergravsparken is a tunnel station, it uses the crossover in km 10,07. First of all, metro arrives at the station, passengers go out and then the train makes the operation. Usually one steward is controlling that all passengers go down to the station before metro departs. In Vestamager, the operation is similar to Vanløse station, using the switches in km 13,56. Depending on the headway time, trains can use both sides of the platforms. A similar procedure will be used at Lufthavnen station.

Approximately there are switches every three stations to ensure the possibility for a train to change the track and the direction if any problem is appeared.

For example, a train has failed between Vanløse and Frederiksberg stations and the rescue operation will be longer than usual. Hence, supervisors in the control room decide to disrupt the service in this stretch and immediately Frederiksberg acts as a terminal station. Switches in km 2,68 allow the continuity of the normal service in such a way that trains can make the turn around operation like at Vanløse station.

Similar operations can be carried out in the other switches, avoiding the disruption of the service as long as possible. Here, the role of stewards and controllers are fundamental, as they have to find a solution as fast as possible, with the best solution for the service.
Fig. 23. Schematic track diagram of the metro line. (Ref: www.orestadsselskabet.dk)
2.6. The future metro

The third phase of the metro will arrive at the airport in 2007. At the moment the stretch between Lergravsparken and airport is under construction, with five stations: Øresund, Amager Strand, Femøren, Kastrup and Lufthavnen as the airport station. As in the Ørestad region, metro will run on elevated tracks and in the airport it will be integrated in the terminal. Last traffic prognosis estimates that in 2010, nearly 257,000 people will use the metro line everyday. Moreover, Øresund station will give service to 5,700 passengers. Amager Strand, Femøren and Kastrup stations will be used for 1,400, 6,300 and 5,300 passengers, respectively, and finally 6,500 people or more will use the airport station. Metro’s budget for the three phases is 11.5 billion DKK and after the implementation of the third phase in 2007 it is expected that approximately 80 million of passengers per year will take the metro. (Ref: www.m.dk)

The operation’s success of the metro since 2002, when the first phase was opened, and the better expectations that traffic prognosis gives for the future, together with the satisfaction of the population with this new urban transport system, have contributed to start the planning of the metro network’s extension. A new line, called City Circle Line (Cityringen) will be developed in few years. The Ministry of Transport, together with the municipalities of Copenhagen and Frederiksberg, as well as ØDC, is studying the viability of the new line and its possible layout. This fourth phase would cover the Frederiksberg part that it is not fulfilled by the actual metro and S-lines. Moreover, the new line would pass through Østerbro, Nørrebro and Vesterbro districts, as well as the city center. Initially, different alternatives were studied in order to find out the best layout, especially in Frederiksberg area, where different possibilities were factible:

![Fig. 24. Different alternatives of the City Circle line’s layout. (Ref: www.m.dk)](image-url)
After some analysis and prognosis about the passengers, the connections and the viability, two final alternatives were studied in detail:

![Fig. 25. Forum and Frederiksberg alternatives. (Ref: www.m.dk)](image)

The passengers’ estimations, together with political reasons to connect the metro to Frederiksberg station instead Forum have been the factors to choose the Frederiksberg alternative. The final chapter will deal these estimations and other studies about it. Hence, a first stage of the planning layout has been done with 17 possible stations along the route.

![Fig. 26. Final layout, in orange, of the City Circle Line with the stations. (Ref: www.m.dk)](image)
This route will be approximately 15 kilometres long, all of them constructed underground. The procedures to bore will be similar than the first phases, using a TBM, and a round trip is expected to take about 25 minutes.

The main features of this line is that after its implementation, 85% of the population of Copenhagen will have one station of metro or S-train at less than 600 meters. It means less than 10 minutes walking from home, work, city center, etc, to the nearest station. (Ref: www.m.dk)

The metro network will contribute to the citizens a high quality of life, as some points in Copenhagen that now are weakly connected to the public transport will be joined to the railway network.

The City Circle line will have one of its main stations in København H (Central Station). The fact that Central Station is the main station in Copenhagen, where regional trains departs to all points of Denmark and almost all the Suburban lines pass over there, will give a perfect connection with the metro. Hence, metro network will cover the main train stations in Copenhagen, which are København H, Nørreport (with the actual metro line) and Østerport, as this last station will have also connection with City Circle line.

On the other hand, the stretch between Central Station and Østerport will pass through the City centre, complementing the demand that now covers the actual line.

Four stations will be in the old town, with Rådhuspladsen as the most important point, as it is the nerve centre of Copenhagen. From here on, Christiansborg, Kongens Nytørv and Frederikskirken will be the other central stations, where Kongens Nytørv will connect with the first line of the metro.

Following the route, Østerbro will be one of the most favoured districts for the new line. At the moment, the area between Østerport and Nørrebro stations are not connected by any railway system and people living there have the bus as the only resort in public transport. It means high travel times due to the road traffic. For that reason, the new line has built up the population’s hopes.

Metro will connect with S-train in Nørrebro station and it would make up for the demand that now is not fulfilled by the F line, which is going through the west part of Nørrebro district. Thus, metro would pass to the east part of the district to Nørrebros Runddel and going down to Frederiksberg station, where would connect with the actual line.

Finally, Platanvej and Tove Ditlevsens Plads points would be the stations in Vesterbro area, going again to København H. Although Vesterbro district is pretty well connected now with the S-trains in Dybbølsbro and Enghave stations, the metro would complement the service that suburban railway line is giving to the citizens.

Further on, metro could extend the network in København H and Nørrebro stations, doing a new line going to the south west of Copenhagen and Brønshøj districts, respectively.

It is expecting that the City Circle line will be opened around 2017 and its project could start in 2009. Planners will have the experience of the three previous phases to improve some shortcomings for the planning procedure of the new line. Taking advantage of this knowledge and using the new technologies that year by year companies are putting on the market with the most advanced products, the new City Circle line will be a success, with an estimation of 275.000 passengers per day. (Ref: www.m.dk)
2.7. Social Impacts

There are a lot of social impacts when a new infrastructure is developed. These impacts mean transformations, not only physical changes, but also in the economy, lifestyles and so on. These transformations are the consequences of the new infrastructure, which is constructed due to the different aims, such as town-planning, economic, political and social objectives.

The development of new urban districts such as Ørestad region and the improvement of existing areas in order to extend the Danish capital and increase the quality of life are the most clear aims of the town-planning. These are closely connected with economic aims, as the construction generates a lot of workplaces and even more in Ørestad region, which will be the new business center in Copenhagen. A lot of companies and enterprises will move out, fixing their headquarters in new Ørestad. The presence of the metro in this area will help to develop the mobility and will link the new town with the city center.

When talking about political questions, probably is more accurate to talk about interests. The idea to develop a new urban railway transport with the most advanced technology and provide Copenhagen with a good public transport network is due to the interests to make the capital as a reference point in Nordic countries and even in all European Union and compare it with the main cities. Hence, the economy of the city is strongly connected with these interests and the fact that Copenhagen is a strategic point between Denmark and Sweden, makes the political interests more ambitious, not only in a local scale, but also affecting all Denmark.

Finally, the metro is also constructed to fulfil the demand, which in some districts are weakly serviced by public transport, reduce the travel times from the center to other areas of the city, as well as reduce the congestion problems in the city centre due to the road traffic. These arguments will help to improve the quality of life, which is one of the social aims for this project.

During the construction of the infrastructure and later on, during its operation, metro develops some transformations, both positives and negatives:

- Territory impacts: Metro changes the territory. Although it goes underground in the city centre, the fact that is going on elevated tracks or embankments in the inner suburbs creates a visual impact, breaking in some points the continuity of the territory. On the other hand, the good point is that stations are constructed in the streets or existing squares, without the necessity of expropriations and pulling down any building. Moreover, the construction of car parks at the end of the line will take up big spaces, which could be useful for other activities or services.

  In Ørestad region, impacts are higher, as there are wetlands and natural corridors. The development of the new town, together with the new infrastructure will change completely the territory.

- Town-planning impacts: the highest impacts of urban development are in Ørestad region, where the arrival of the metro will connect this area with the rest of the city. As it was explained before, new Ørestad will be a space with different land uses, basically business, education and dwelling areas. Hence, the city will suffer a big transformation, as many enterprises will move out to
Ørestad. The development of the new town, following the basis of The Master Plan, will create a modern town, architectural and caring for the environment.

- Environmental impacts: this is one of the most important points when developing an infrastructure. For the metro planning, construction and operation, ØDC implemented an environmental management system where contractors must carry out the following points: (Ref:[1])
  
  o Environmental considerations should be included in all decisions.
  o Preventive measures must be taken to reduce energy consumption, the use of resources and the environmental impact.
  o Landscape and archaeological values must be protected to the greatest possible extent.
  o Efforts must be made to ensure good, healthy workplaces.
  o There must be openness about environmental matters, and the public should be kept continuously informed on the company’s environmental activities.
  o The manpower and financial resources required to comply with our environmental policy must be made available.

When planning the infrastructure, different alternatives have to be compared in terms of impacts on the environment. Hence, a lot of factors must take into account such as noise, geology and geomorphology, soils, hydrology, vegetation, fauna, landscape, population, territorial organization, cultural heritage, etc.

There are different ways to compare alternatives. One of the most known is the Batelle method. It lies in the sum of four factors with a total of 1000 points: Ecology, environmental pollution, aesthetic aspects and human interest aspects. There are a lot of sub-factors within each factor, and the more points get an alternative, the less environmental impact has.

For example, noise is a sub-factor within the environmental pollution and can be represented graphically:

![Noise impact graph](image-url)
Hence, if there is no noise, which means 0 dB, the quality will be optimum with the value of 1. Otherwise, the quality is zero if is dangerous for the human hearing, which is around 90 dB.

ØDC took a range of environmental standards to ensure the environmental policy:

<table>
<thead>
<tr>
<th>Subject</th>
<th>Example of standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noise during construction</td>
<td>Noise Impact (Lr) must comply with the following limits measured at the house façade in residential areas:</td>
</tr>
<tr>
<td></td>
<td>Weekdays 07:00-18:00: Lr 70 dB</td>
</tr>
<tr>
<td></td>
<td>Other days 07:00-18:00: Lr 40 dB</td>
</tr>
<tr>
<td></td>
<td>Daily 18:00-07:00: Lr 40 dB</td>
</tr>
<tr>
<td>Noise during normal operations</td>
<td>Outdoor noise impact from trains, stated in day-equivalent, A-weighted noise levels must comply with the following threshold values:</td>
</tr>
<tr>
<td></td>
<td>Residential and public areas: L(eq, 24h) 60 dB</td>
</tr>
<tr>
<td></td>
<td>Offices, hotels, etc.: L(eq, 24h) 65 dB</td>
</tr>
<tr>
<td>Air pollution</td>
<td>Dusty materials shall be kept covered or wetted down during transport.</td>
</tr>
<tr>
<td>Soil and groundwater</td>
<td>Tunnelling must not cause the pollution of soil and/or groundwater</td>
</tr>
<tr>
<td>Waste</td>
<td>Contractors must sort waste so that as much as possible can be recycled. Sorted waste is to be stored so as not to reduce the possibility of disposing of the individual components.</td>
</tr>
</tbody>
</table>

Fig. 28. Environmental standards for the Copenhagen’s metro. (Ref: [1])

A special care has to take into account in Ørestad region, where there are wetlands, fauna corridors and natural environment. Hence, it is important the planning of new urban town, integrating the buildings with the surrounding environmental areas and preserving the actual landscape as much as possible. Within the environmental impacts, it has to pay special attention to the cultural heritage, such as old buildings, monuments, archaeological zones, etc. For example, during the construction of the metro, some archaeological traces of medieval fortification were found in some excavations, and for that reason, Copenhagen City Museum followed the construction work of the metro in case to find something else.

On the other hand, some old buildings from Old town in Copenhagen near the underground stations were treated with special care, as a lowering of the ground water level could damage their foundations. Moreover, vibration studies were carried out in order to ensure the safely pass of the TBM under some sensitive buildings.

- Economic impacts: these impacts are connected basically with the development of the new Ørestad district. Enterprises will put their headquarters in this region, doing the new business center of Copenhagen. Although the construction costs for the metro have been really high, they will be compensated with the sales of Ørestad lands, and later on, this region will generate more economy with the implementation of these companies and commercial areas.

On the other hand, the metro line has been a revulsive to relaunch the local economy in some districts. Local shops near the stations along the line have been increase their sales, specially in Frederiksberg area, Christianshavn island, and at the end of the line, such as Vanløse and Lergravsparken stations.
• Impacts on the activities: dividing the activities between different sectors as primary, secondary and third, it can be observed that the most important is the last one, where commercial activities and offices will be increased, basically thanks to the development of new business space in Ørestad region. It is closely connected with the economic impacts explained before.

• Impacts on the lifestyles: finally, the metro will change some habits of the population. For example, if car parks situated at the ends of the line are implemented, people could leave their car there and take the metro to reach the city center. This will help to increase the use of public transport and reduce the traffic congestion in some particular points in the center, which is one of the aims of the metro line.

On the other hand, metro has been constructed in Ørestad region in order to be the main transport system in this zone, and it is expected that people will move by metro, bike or walk, minimizing the use of the car.

All these transformations are important to be analyzed and even though each project is different, causing different social impacts, planners will take advantage of the experience of the actual line for the planning, construction and operational process of the City Circle line, minimizing the bad points and standing out the main features in terms of social benefits for Copenhagen.
2.8. The pros and cons of the metro

The idea to construct a driverless metro in Copenhagen was supported from the beginning, both for the authorities and most of the population. After its inauguration in 2002, and more than three years of operation, metro has been a success and thanks to this, new lines will be a reality in few years, like the City Circle line.

However, not all the analyses are positive, as there were some troubles, both for the implementation and operational phases of the metro.

First of all, minimetro was chosen as the best new urban railway over the other two alternatives. Anyway, the idea of a light rail option could be better in some aspects. When planners studied the three different alternatives they took the street signalling system for tram and light rail, which was about 150 seconds (see table 2). However, changing the signal configuration and giving priority to the railway system, a light rail can run with a really short headway time, approximately 30 seconds. That means a high frequency. Taking advantage that light rail has the good points of a metro system and the good points of a tramway, this kind of railway system could be more useful.

For example, in the central part of Copenhagen where metro goes underground, light rail could also run in a tunnel with headway times of half a minute. When light rail reaches the surface and adopts the tram system, the line could be split up in different lines, giving a better access to the public transport for some weakly connected districts. Hence, each branch would have a headway time of 90 seconds, which is still a high frequency.

In short, if the new urban railway was a light rail with these characteristics, more passengers could use this public transport, even spending less money than the metro’s option. The final budget of the metro has been increased a lot compared with the initial planning. It has cost around 15 billion DKK and not 11.5 as some people say, but political reasons and pressures made the metro a reality, independently of the money. A similar process is happening with the City Circle Line.

Fig. 29. Sketch of the light rail option. A could be Frederiksberg and B Christianshavn.
Another point to criticize is the configuration of the stations such as their entrances and exits to the streets. The illustration of an underground station in the figure 17, with two escalators, one to up and the other one to down, and where there is only one point to reach the street, makes that people coming from everywhere have just one possibility to get the station. Although the constructions costs are reduced, as the excavation is smaller, the catchment area of the stations is also reduced, against the interests of the users.

Moreover, the way out of some stations is in traffic islands, where then people have to wait for the green light to cross the street, spending more travel time. This is the example of Nørreport station. Another clear example is the Lindevang station, where people have to cross a big traffic road through one bridge to get or leave the station.

Thus, it would have been a good idea to construct more way outs in different streets, giving a better access to the stations, even if it means to spend a little bit more of money.

The connection with the airport will be one of the main features of the line in 2007. Hence, people will have different alternatives to reach the airport, by train, metro, bus or private transport. If people need to go to Central Station, they could catch the regional train. Otherwise, if they have to go to the city center, Nørreport or Frederiksberg, they could take the metro.

At the moment, Nørreport is the metro station with more passengers, with a lot of traffic in peak hours, and sometimes is difficult to catch the metro or leave it due to the amount of people around the doors. This situation, taken in conjunction the new passengers generated for the airport connection, can give some capacity problems at the station. However, the high frequency of the metro will ensure a fast flow of passengers.

Usually, metro is running with a really low percentage of delays, but sometimes operational problems come up and the service is disrupted in some stretches of the route for a long time, causing troubles to the passengers. Although supervisors in the control room are doing their best, the inexperience of this automatic train system in Denmark makes these rescue operations longer than usual.

For example, automatic doors do not work as well as they seem. Normally people go up and down to the train from the doors situated at the ends of it, as the way out is nearer. Thus, these doors are broken more often and then the agglomeration of people at the other doors is a problem for the good operation. But this is not the only problem found in the metro. Although most of the systems are duplicated, the computer chip on the trains is not. It means that if the chip fails, all the safety system of the train fails until the spare part is fitted.

At the beginning of the operation, there were some problems in the switches at Christianshavn, where the line splits up into two lines. Anyway, month by month, the experience helped to reduce these conflicts.

As it was said before, metro runs with fixed block sections, which is the normal operational procedure of railways, but not for the new metros. New infrastructures use also fixed block sections. However, on approaches to the stations, a floating block system is used, which allows the headways between trains to be reduced to help meet peak-hour demands, and it is constantly exchanging data with the control room. Why the Copenhagen’s metro does not use this floating block system is unknown, but it is a bad point for the future improvements of the line.
Anyway, the main aims of the metro have been fulfilled. Frederiksberg has a good and fast connection with the center, the travel times are much better comparing with other transport modes and the passengers’ estimations from the forecasts are being the expected ones, always taking into account a required level of safe. All these factors can be taken to improve the planning process of the future lines, such as the City Circle line. Hence, the configuration of the stations can be updated to be more efficient. Special attention has to be paid at big stations such as Central station and Østerport, requiring a good and fast connection between metro, train and bus. Chips, doors, switches, catchment areas, way outs, safety system or whatever, it is not allowed to make the same mistakes in a future if Copenhagen wants to be a good urban traffic city in terms of planning and development public transport.

Finally, as it can be proved, metro has had a general positive social impact. The economic and town-planning impacts are really good for the city, especially due to the development of the new urban area in Ørestad. The concept of the new city under the basis of The Master Plan, taking into account modern buildings, metro as the main transport and a good integration to the natural landscapes, will make the new town as a reference point to the other cities in terms of urban planning. On the other hand, the implementation of new companies in Ørestad region with the possibility to increase the competition inserting new products in the market will be a good point for the economic development of the city. Besides, Ørestad will generate a lot of workplaces, which will help the reduction of unemployed people and will bolster up the local economy. Moreover, both metro and new Ørestad are pretty acceptable with the environment, causing the minimum impact. The underground condition in the city center causes the minimum nuisance for the neighbourhood. However, the discussion of the elevated tracks and embankments in Ørestad is not as easy as it seems. Aside from economic reasons, the decision to stand out the metro on elevated tracks in order to make the metro as the best feature in the region can be damaging in a future. Not only the visual impact is high, but the embankments and viaducts can be a barrier for the future activities in Ørestad. Although this problem was taken into account during the planning process, nobody knows what will happen in 30 years, when Ørestad is fully developed. Would to construct the metro underground have been better? Will the metro be an architectonic hindrance through the district? Future has the answers.