Assessing Traffic and Air Quality in Central Copenhagen

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Interactive Qualifying Project (IQP) Final Report
Denmark '15

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Abstract

Sponsored by Miljøpunkt Indre By, we assessed the traffic congestion and air quality in the city center of Copenhagen, Denmark. We conducted surveys with locals, interviewed experts, and conducted direct observations of the area. After analysis of the data, we evaluated the feasibility of a tunnel, explored possible alternative solutions, and offered recommendations for alleviating congestion and reducing air pollution. We found that while a tunnel would reduce air and noise pollution, it may not be effective in reducing traffic volume. Instead, we recommend discouraging car use and promoting public transportation by incorporating a light rail system, reducing lanes, implementing a park and ride system, and improving bicycle infrastructure.

Acknowledgements

We would like to thank Professors Hou, Belz and Taylor for guiding us through this process. We would also like to thank our sponsors Marietta Bonnet, Dorte Heiss and Kjeld Larsen from Miljøpunkt Indre By for warmly welcoming us to Copenhagen and being our mentors. Lastly, we would like to thank our experts, Professor Per Homann Jespersen, Mr. Ivan Lund Pedersen, Mayor Morten Kabell, Professor Kåre Press-Kristensen and Mr. Morten Engelbrecht, for their enthusiasm and helpfulness.

Executive Summary

The Problem

Copenhagen is the capital city of Denmark, a small Scandinavian country in Northern Europe. With an increasing population, the city has been plagued by problems of traffic congestion and air pollution. These problems are particularly present on H.C. Andersens Boulevard, a main arterial road that goes through the central neighborhood of Indre By and connects mainland Copenhagen with the island of Amager. According to the public, the congestion on H.C. Andersens is heaviest in the morning at 9:00 and in the evening at 16:00. Furthermore, based on direct observations of the area, it is evident that the majority of cars are travelling through Indre By and there is little cross traffic. This indicates that the road is mainly being used to commute between the outer neighborhoods of Copenhagen and Amager. With the increasing traffic congestion in the area, comes increasing air pollution. H.C. Andersens is the most polluted road in Copenhagen with almost 70% of its pollution originating from the road traffic (Press-Kristensen, 2014). The average NO_2 emission on H.C. Andersens Boulevard is 44.5 $\mu g/m^3$ which exceeds the European Union's limit of 40 $\mu g/m^3$ as seen in Figure A. Similar to the traffic, there are several patterns for NO_2 with emissions on the road peaking in the morning and the evening rush hours.

The traffic congestion and air pollution on H.C. Andersens impact the quality of life experience for those working, living, and commuting on the road. The traffic causes

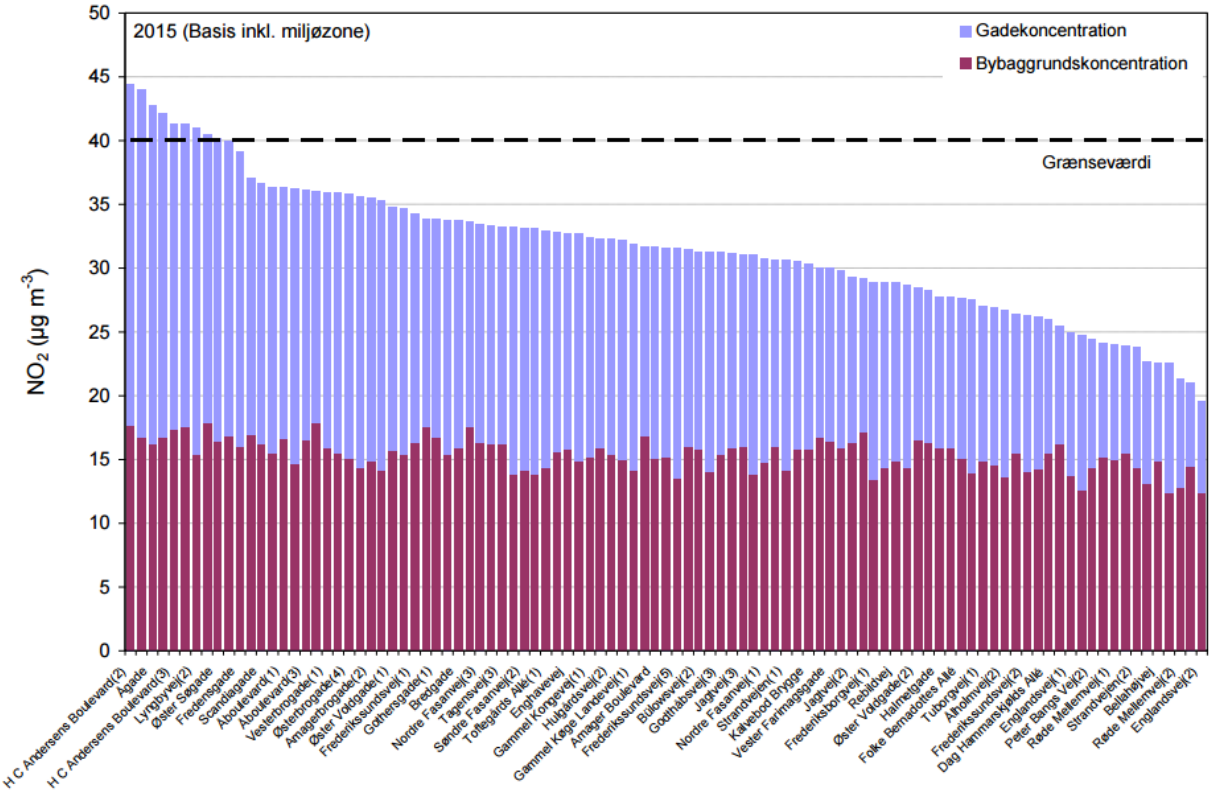

Figure A. Average NO_2 Concentrations on main roads in Copenhagen compared to the EU's limit, with H.C. Andersens on the far left. The blue represents traffic emissions and the purple represents background emissions.

Source: Luftkvalitetsvurdering Af RenLuftzone I København

delays for bus and personal vehicle users due to the long waiting times at several intersections. Also, the high density nature of the area creates barriers for pedestrians and bicyclists. The pollution in the air is a health hazard for people in the area. For example, ultrafine particles such as soot are carcinogenic and cause a variety of illnesses such as cardiovascular disease and chronic lung disease (Personal Comm., Engelbrecht 2015). Furthermore, there could be several negative impacts on the tourism in the area. Copenhagen plays an important role for the Danish tourism industry which contributes approximately DKK 82 billion in revenue and 120,000 full-time-equivalent jobs (The Danish Government, 2014). Recently, Denmark has been experiencing decreased numbers of tourists and the congestion in Copenhagen may be one of the reasons.

The Copenhagen municipality has taken several steps to alleviate congestion and improve air quality in central Copenhagen. For example, the Five Finger plan was created in 1947 when citizens realized the city was developing at an uncontrollable rate (Rahunen, 2015). The goal of the plan was to concentrate the development of Greater Copenhagen in the urban "fingers" created around the railway network with natural green spaces in between. Furthermore, the city of Copenhagen has been developing a Metro system which will be completed in 2019. The Metro will hopefully increase travel efficiency and reduce congestion on the roads. In order to improve air quality, several solutions were proposed, including a law mandating the use of close particulate filters on trucks.

Despite these measures, more steps must be taken in order to reach Copenhagen's goal of reaching carbon neutrality by 2025. Our sponsoring organization, Miljøpunkt Indre By is working towards bringing people together in order to create optimal solutions for the environment and climate. They aim to help Copenhagen reach its carbon neutrality goal and are focused on improving conditions on H. C. Andersens Boulevard.

Goals, Objectives, and Methodology

In order to address the problem, the goal of our project was to analyze traffic in central Copenhagen and its effect on air quality, and determine the appropriateness of a tunnel for congestion alleviation and air quality improvement. To achieve this goal, we constructed the following objectives:

1. Understand current traffic patterns and identify main causes of congestion in the Indre By and Christianshavn areas.
2. Determine stakeholder opinion on traffic conditions and air quality.
3. Explore the appropriateness of tunnels to alleviate traffic and air quality issues and explore possible alternative solutions.
4. Compile recommendations and suggest the most appropriate course of action.

To accomplish this goal and the subsequent objectives, we conducted research using a variety of sources and methods, including reports, interviews, a questionnaire, and direct observation.

To gain an understanding of the current air quality patterns on H. C. Andersens, we obtained pollution data from reports regarding air pollution in Copenhagen provided by the Danish Ecological Council. Furthermore, we obtained data from Aarhus University's air quality measuring station on H. C. Andersens Boulevard.

To understand the current traffic patterns, we directly observed seven intersections on H. C. Andersens Boulevard, and compared congestion levels of each intersection to one chosen baseline. The intersections were observed over two days at 9:00 and 16:00. We created maps with our data shown in Figure B.

Semi-structured interviews were conducted with several experts on traffic and air quality, including members of The Danish Council for Sustainable Traffic, and professors from Roskilde University and the Danish Technical University.

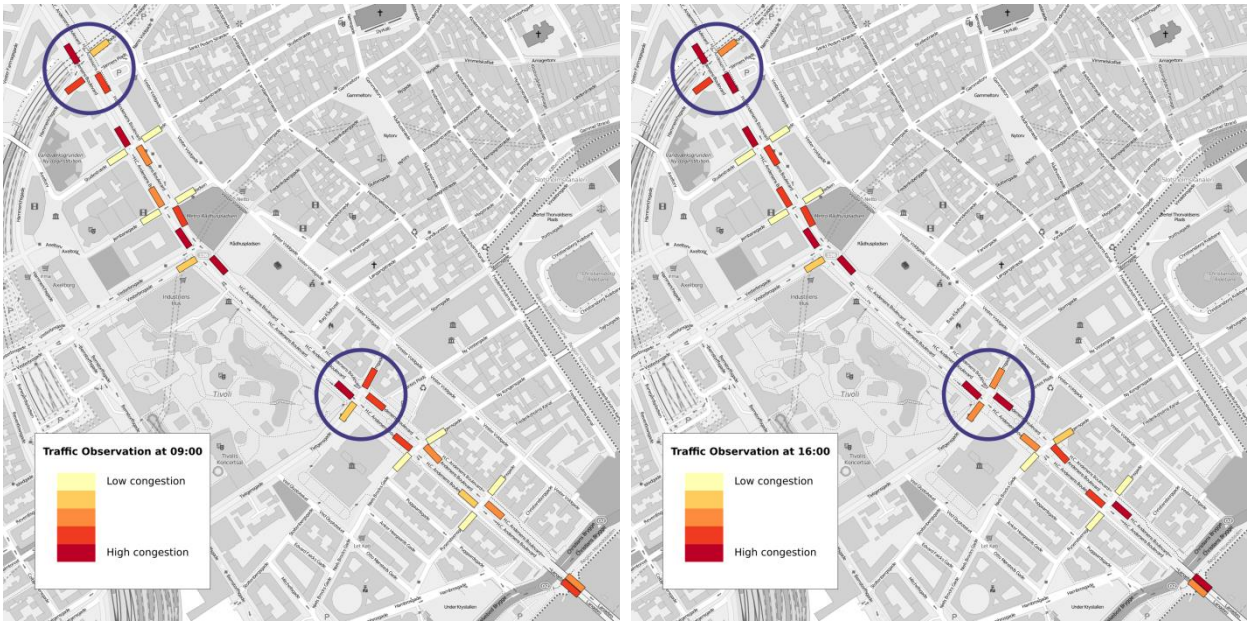

Figure B. Maps showing traffic congestion on H.C. Andersen Boulevard in Copenhagen at 9:00 and 16:00 with colored blocks representing congestion levels. The circled intersections have high cross traffic.

We also conducted email interviews with a member of Letbaner.DK and the Mayor of Technical and Environmental Affairs of Copenhagen.

A short structured questionnaire was created, in both English and Danish and pedestrians were surveyed near H. C. Andersens Boulevard. A link to the online version of the questionnaire was distributed via Miljøpunkt Indre By's social networking site, their contacts, and by passing out flyers. In total, we received 47 responses. We also explored literature regarding alternative solutions.

Key Findings

A proposal has been made by local organization to implement a tunnel under H.C. Andersens Boulevard and replace the road on the surface with a green space. We found that while a tunnel and a green space has the potential to reduce air and noise pollution, it would not be the most suitable solution for reducing traffic volume. According to our public surveys, 93% of the respondents said that a tunnel would reduce air and noise pollution. Furthermore, implementing a tunnel would eliminate noise pollution and air pollution would collect around the openings of the tunnel instead of along the road, posing less health hazards to people in the area (Personal Comm., Press-Kristensen 2015). The addition of a green space on the surface would also improve the quality of life by providing a recreational area and improving the aesthetics of H.C. Andersens Boulevard.

Implementing a tunnel would allow continuous flow of traffic and thus alleviate the congestion in the Inner City. However, this solution conflicts with the goal of the city to be carbon neutral by 2025 because it would encourage more car drivers to enter the city and use the tunnel to commute. Currently, almost 70% of the air pollution on H.C. Andersens Boulevard originates from traffic and this number needs to be reduced if the city is to fulfill their climate goals (Press-Kristensen, 2014). The tunnel and green space solution only aims to move the traffic quicker and does not discourage private car use. According to Mr. Ivan Lund Pedersen from the Danish Council for Sustainable Traffic, with the addition of cars, there is a possibility that more traffic congestion would build somewhere else in the Indre By area (Personal Comm., Pedersen 2015). Furthermore, the construction of a tunnel is expensive and the city currently cannot support it (Personal

Comm., Kabell 2015). During construction, the tunnel would also create barriers for pedestrians and bicyclists. Although this solution has the potential to alleviate traffic congestion, it will not reduce the number of private cars in central Copenhagen.

Aside from a tunnel, other alternative solutions were also explored. These solutions aim to encourage public transportation and disincentivize private car use. It is vital that prices for public transportation are reduced because low cost incentives influence ridership more than convenience. The primary solution for improving public transportation is a light rail system. The current proposal connects the outer neighborhoods of Copenhagen. This tram-like system uses electric wiring and can run on different infrastructure like rails, roads, and tunnels. Light rail is a good solution because it will connect the outer neighborhoods to the Inner City and will improve connections among the existing public transportation. The stations are built on the surface making the system cheaper to build and easier to access (Kjaer Jensen, 2014).

There are several possibilities for discouraging car use. Congestion pricing, a fee paid to use a particular road, was a potential solution proposed in 2012 but was rejected by politicians. These politicians were wary of not being reelected as many of their voters are car drivers who feel that taxation on cars is high and no more fees should be paid (Personal Comm., Jespersen 2015). Technically speaking however, congestion pricing is an effective solution that will reduce the traffic volume and encourage public transportation use (Personal Comm., Larsen 2015). It may also be effective to combine the road pricing system with a tunnel, if it was to go through, so that car users are only required to pay a fee for using the tunnel. This was done in Seoul, South Korea and proved to be a success, reducing traffic volume by 25% in the first month (Son & Hwang, 2002). Further solutions for disincentivizing car usage include the reduction of parking spaces or the increase in parking prices. This may discourage people from bringing cars into the city center however, it may be met with the same opposition that congestion pricing experienced. Yet, if a park and ride styled parking lot was built outside the Inner City, people may have the incentive to park outside and take public transportation into Indre By.

The last alternative proposal is eliminating lanes on major roads (Personal Comm., Jespersen 2015). Although it may initially cause increased congestion, the inability to quickly move through an area will divert car users to other roads or may encourage people to switch to public transport or bicycles. An example of the success of lane removal is the Cheonggyecheon River in Seoul, South Korea shown in Figure C. The government restored a river and the large arterial road was reverted to a natural green belt in 2005 to combat air pollution and traffic congestion. As a result, traffic volume in the city decreased by 170,000 cars and air pollution decreased by 35% (Rutherford, n.d.). If this principle was applied to H.C. Andersens Boulevard in Copenhagen, similar effects may be observed. Instead of a river restoration, the road would be converted to a green space with plenty of room for pedestrians and bicyclists, and with a lack of lanes for traffic.

Recommendations and Conclusions

There are significant problems with air pollution and congestion on H. C. Andersens Boulevard, and these problems are likely to get worse over time if no actions are taken.

In our opinion, implementing a tunnel would not be the most appropriate solution for H. C. Andersens Boulevard because the disadvantages outweigh the benefits. Though a tunnel will improve the continuous flow of traffic, it will attract more car users to the Inner City which will interfere with the city's goal to reach carbon neutrality. However, there is currently a tunnel proposal that stretches from Nørrebro to Amager. We recognize that this proposal would make the

Figure C. The before and after of the restoration of the Cheonggyecheon River in Seoul, South Korea
Source: http://www.nclurbandesign.org/wp-content/uploads/2015/01/Cheonggyecheon-Stream-Before-After1.jpg

tunnel a preferred solution in order to promote continuity through the three areas. If a tunnel was to be constructed, Miljøpunkt Indre By should advocate congestion pricing as an addition to the tunnel. Congestion pricing will hopefully discourage car usage. Overall, this would decrease the traffic volume on H. C. Andersens Boulevard.

We think that constructing a light rail is a very effective solution, especially if the current proposal in the outer neighborhoods is extended to Indre By. Implementing a light rail system would reduce car lanes and replace bus lines on H. C. Andersens since the system runs on exclusive lanes 90% of the time. Reducing car lanes would discourage car usage. This solution would be especially effective if public transportation prices were lowered and parking spots were reduced. We found that many commuters believed that public transportation was expensive and therefore, lowering prices might encourage more people to utilize the systems. Reducing parking spots on the road and near businesses disincentivizes car usage. Furthermore, bike lanes on roads leading to H.C. Andersens could be extended further, discouraging car usage.

Although we have provided several solutions to Miljøpunkt Indre By, there are steps that need to be taken before these solutions can be considered.

We recommend that Miljøpunkt Indre By propose their plan with our report as a supplement to the Copenhagen Municipality. The Copenhagen Municipality's budget should be taken into consideration when moving forward with these proposed solutions. Meanwhile, Miljøpunkt Indre By can take other approaches such as informing the public of the traffic situation on H. C. Andersens Boulevard. With the support of the public, the Copenhagen Municipality might be inclined to take further action.

It is clear to us that the actions that are being taken by the Copenhagen Municipality to combat air pollution at this time are not sufficient. We conclude that action must be taken to improve the air quality and traffic congestion on H. C. Andersens Boulevard by incentivizing less private car usage and more public transportation. Hopefully, the solutions we proposed will push the city of Copenhagen one step closer to their goal of carbon neutrality in 2025.

Authorship

The following table outlines the primary contributors to each section and the individuals responsible for revising each section.

Chapter	**First draft by:**	**Edited by:**
Executive Summary	Khurana, Mendez, Ong, Stepanian	Khurana, Ong
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Chapter 1: Introduction

Copenhagen is a role model for urban planners across the globe and a world leader in sustainability. It is the largest city in Scandinavia and the capital of Denmark. Founded in the late 1100s, the city began as a fishing village in the time of the Vikings. Eventually, the village grew to gain city status and became the home of the royal families of Denmark (Brief History, 2015). In the nineteenth century, following the Industrial Revolution, many cities around the world, including Copenhagen, were building factories and residences in close vicinity of each other in an effort to bring laborers closer to the industries. These changes, often called urbanization, caused the shift of populations from rural areas to expanding urban settings. In the modern age, urbanization has caused cities to become overcrowded and with the increase of personal vehicles, air quality is declining. Despite Copenhagen's careful urban planning, the impacts of urbanization cannot be completely avoided.

Copenhagen is highly focused on sustainable development, an effort to improve the city for the current generation without endangering resources for future generations (International Institute for Sustainable Development, 2013). The city aims to be carbon neutral, to achieve net zero carbon emissions, by the year 2025. While they are on the way to achieving this goal, congestion in the city, particularly in the central areas of Indre By and Christianshavn, is hindering their progress. Traffic congestion is a major problem in urban settings, as is the loss of aesthetic green spaces. Traffic creates barriers for pedestrians and bicyclists and can be detrimental in terms of air pollution.

Population growth leads to the increasing need for transportation, and along with high tourism in central Copenhagen, traffic congestion is becoming a problem. Population growth in Copenhagen accounted for approximately half of Denmark's total growth in the past few years (Københavns Kommune, 2014). This problem can be clearly observed on H.C. Andersens Boulevard, one of the main roads in Indre By. In accordance with the city's goal of being environmentally friendly, this road would ideally be free of congestion in order to preserve the air quality. However, there is a high traffic volume and the current infrastructure is inappropriate for this load. The busy traffic leads to poor air quality as a result of the emission of carcinogenic pollutants. This poses a threat to pedestrians and bicyclists because these pollutants lead to illness such as leukemia and hypertension (Rank, Folke & Jespersen, 2001). If the current condition is not addressed, Copenhagen's tourism industry could also be impacted. The decreasing quality of life experience from the congested roads and the poor air quality could discourage tourists from visiting

the popular destinations located in central Copenhagen (Wiersma, Robertson, & Robertson, 2003). The tourism industry alone generates more than DKK 80 billion every year (The Danish Government, 2014). Therefore, decreased tourism could have negative impacts on the country's economy.

Carbon neutrality and quality of life experience is obviously important to the people of Denmark, and several systems have been put in place. For example, the implementation of the Five Finger plan was Copenhagen's first attempt at urban planning. The Five Finger plan was created in 1947 when citizens realized the city was developing at an uncontrollable rate (Rahunen, 2015). The goal of the plan was to concentrate the development of Greater Copenhagen in the urban "fingers" created around the railway network with natural green spaces in between. Furthermore, the city of Copenhagen has been developing a Metro system which will be completed in 2019. The Metro will hopefully have a positive impact on Copenhagen's traffic by increasing travel efficiency and reducing congestion on the roads.

While previous solutions have been successful in reducing traffic in Copenhagen, there is still more to be done to address the growing health concerns of the diminishing air quality. An environmental non-governmental organization, Miljøpunkt Indre By, has been working towards bringing the community together to better the climate and environment. As a part of their mission, the organization aims to reduce congestion and improve air quality in the neighborhoods of Indre By and Christianshavn and the purpose of this project is to aid them in their mission. The goal of the project was to collect and analyze data on the traffic condition in central Copenhagen and its effect on air quality; with that information, we were able to evaluate the feasibility of a tunnel and explore possible alternative solutions such as congestion pricing and propose the best fit for the problem. In order to achieve this goal, we conducted research on the current traffic patterns in the area. By doing so, we have a better understanding of the problem at hand. Other data was collected by surveying the public and local inhabitants, and interviewing experts on traffic and air pollution.

Our analysis assisted the sponsor, Miljøpunkt Indre By, in suggesting an appropriate solution that will aid Copenhagen in tackling traffic congestion and air pollution in the central neighborhoods. The following chapter will discuss relevant background concepts such as the impacts and causes of the traffic and air quality problems, current and possible solutions, and the sustainable initiative that Copenhagen has adopted. The methodology chapter will outline the major goal and objectives and explain the process we underwent in order to achieve them. The findings chapter outlines the main conclusions drawn from the research we conducted and will detail supporting evidence for the

claims. Finally, the recommendations and conclusion chapter will present our suggestions for Miljøpunkt Indre By.

Chapter 2: Background

Copenhagen welcomes approximately 1,000 new inhabitants every month (Københavns Kommune, 2014). This puts a tremendous strain on the traffic infrastructure causing congestion, pollution, and creating barriers for pedestrians. The city has been a role model for urban planners around the world. Politicians and town planners have visited Copenhagen to gain an understanding of sustainable urban planning including waste management, transportation, and heating systems. Copenhagen aims to be carbon neutral by 2025 and its first main objective lies just up ahead: to diminish carbon emission by 20% in 2015. The city was named the world's most livable city in 2014 and Danish people are among the happiest of the world (Copenhagen, 2015). However, despite their urban planning and adaptability to sustainable initiatives, the high density nature of the central areas in the city, such as the neighborhoods of Indre By and Christianshavn, and the growing population are causing problems with air quality and diminishing tourist appeal. Even with existing solutions, such as the Five Finger Plan, and the developing Metro system, personal vehicle use is increasing and people are exposed to the health hazards of pollution. This chapter outlines the impacts of traffic congestion and explores the concept of tunnels and other possible options to deal with the problem in Copenhagen, such as roundabouts and congestion pricing.

2.1 Causes and Impacts of Traffic Congestion

2.1.1 Population Growth and Density

Copenhagen's growth in population contributes to about half of the total population growth in Denmark. For example, between 2013 and 2014, the population grew in Copenhagen by 10,731 people compared to a total growth of 24,607 people in the country (Københavns Kommune, 2014). Thus the population growth in Copenhagen accounted for 43.6% of the total population growth in Denmark. Clearly, the increase in inhabitants in the area is a significant figure and is preventing the country from efficiently reaching its goals to become carbon neutral. A growth in residential population in a particular area increases the demand for food, clothing, household goods, more homes, stores, and businesses. This requires more infrastructure along with more waste disposal and transportation. Essentially, there will be an increase in the movement of goods to and from urban areas, increasing traffic and the pollution that it causes (Conley, 2002).

Another factor that must be examined when looking at congestion is population density. Indre By has a high population density. In 2014, the area had 51,424 inhabitants (Københavns Kommune, 2014). With an area of 8.98 km_2, this gives central Copenhagen a density of 5,762 per km_2, similar to Boston which has a density of 5,167 per km_2 (US Census Bureau, 2015). High population density leads to traffic and pedestrian congestion and decreases the efficiency of travel and the general quality of life in the area.

2.1.2 Personal Vehicle Use

With increased population, there is a growing need for efficient transportation and subsequently an increasing number of personal vehicles. The city has checkpoints along major traffic carriers and the data is reported by the Danish Road Directorate. The data shows that traffic counts in central Copenhagen have grown considerably since 1998 (Vuk, 2005). In particular, Langebro is the highly dense bridge that connects H.C. Andersens Boulevard and Amager Boulevard. This bridge connects the two islands that make up the city of Copenhagen, Sjælland and Amager, as shown in Figure 1. Langebro has an annual average daily traffic count of 57,567 (The Danish Road Directorate, 2014). This volume of vehicle traffic, albeit fluctuating and even diminishing over the past few years, is still high compared to other bridges that connect the islands. For example, Sjællandsbroen, another bridge connecting the two islands sees an annual average daily traffic count of only 43,204 (The Danish Road Directorate, 2014). Furthermore, the total number of cars increased from 97,229 in 2013 to 99,242 in 2014 (Københavns Kommune, 2014). The high traffic volume in addition to the increasing number of personal vehicles leads to congestion, particularly on

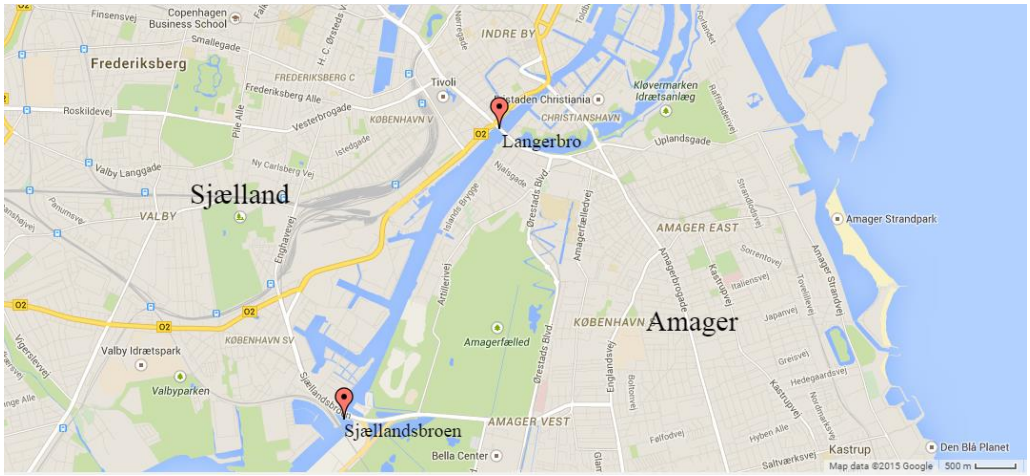

Figure 1. Map of connections between Sjælland (mainland Copenhagen) and Amager including Langebro and Sjællandsbroen

Source: maps.google.com

H.C. Andersens Boulevard. The road is shown by the blue lines in Figure 2 with important landmarks outlined in red. Congestion in this area has a multitude of negative impacts and it is important to understand how it occurs.

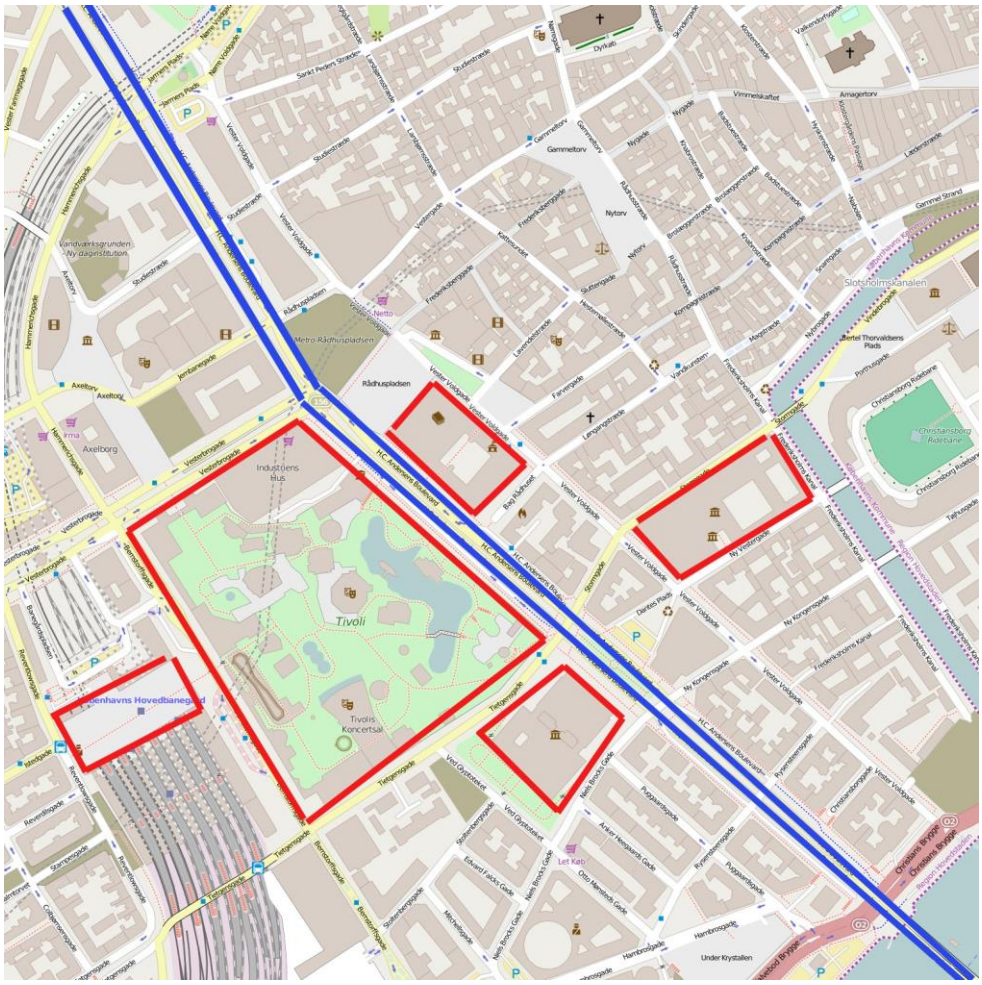

Figure 2. Map of H.C. Andersens Boulevard and surrounding landmarks
Source: openstreetmap.org

2.1.3 Source of Congestion

According to the Federal Highway Administration (FHWA), congestion is defined as an excessive number of vehicles that leads to the lowering of the normal speed on the road (Federal Highway Administration, 2013b). Often, it is when vehicles on the road are stopped or are in the form of stop-and-go traffic.

The sources of congestion can be categorized into six roots. The first cause is physical bottlenecks or capacity of the road. Capacity is when the maximum number of vehicles on a road is achieved (FHWA, 2013b). The high volume of traffic, along with factors such as the number of

lanes, their width, and merge areas contribute to how congested the road can be. The second root is traffic incidents that occur on the road which impede the moving vehicles and cause them to stop or move at slower speeds. The third cause is construction occurring on a road with ongoing traffic. This can constrict the vehicles to a smaller area of movement due to reduced lanes or closure of the road. The next possible cause is the when weather affects drivers' behavior on the road. For example, in order to be safe, drivers will slow down when there is heavy rain or snow. Traffic devices are also a reason because if traffic lights are improperly timed, there would be traffic delays. The last possible cause for congestion is when the flow of traffic in the area is heightened by an event such as a concert, which leads to congestion of vehicles on the road (FHWA, 2013b). With all of these different sources of congestion, traffic congestion is a problem that is widely faced today by cities all around the world.

2.1.4 Impacts of Traffic Congestion in Central Copenhagen

The traffic congestion on H.C. Andersens Boulevard is particularly concerning due to the high population density in the area. Indre By and Christianshavn, the two areas directly connected by the bridge are considered the center of the city with many historical and tourist sites. Copenhagen is a popular tourist destination because of its unique atmosphere, almost 50% of its population commutes by bicycle (Denmark, 2011). Despite the high percentage of bicycle users, there is still increasing traffic which creates barriers for pedestrians and bicyclists and diminishes the appeal of the tourist area.

Tourism

Because of their historical significance, Indre By and Christianshavn have many popular tourist destinations and attractions especially around H.C. Andersens Boulevard. Tivoli Gardens in Indre By is Scandinavia's most popular attraction and fifth most visited theme park in Europe. Between 2013 and 2014, Tivoli Gardens experienced an increase of 167,000 visitors (Tivoli A/S, 2015). Other popular attractions include The National Museum of Denmark, the Rosenberg Castle, the National Library, and The Ny Carlsberg Glyptotek. All these attractions create significant income for the country. Annually, tourism generates approximately DKK 82 billion in revenue and 120,000 full-time-equivalent jobs in Denmark (The Danish Government, 2014). Compared to other Scandinavian countries, Denmark has a large tourism industry and the country seems to depend significantly on income from the industry. However, growth in Danish tourism has decreased in recent years. From

2007 to 2012, Denmark experienced a reduction in international tourism (The Danish Government, 2014). On the other hand, Europe in general enjoyed growth, which means that Denmark lost tourists to competitors in Europe. A potential reason for this loss is the traffic congestion in the vicinity of tourist attractions. Increased traffic can negatively impact tourists' experience and tourists' desire to return or give recommendations to friends. For example, a study on New Hampshire's scenic coastal Route 1A/1B corridor showed that fewer people visited the road as a result of growing congestion (Wiersma, Robertson, & Robertson, 2003).

It is also important to note, that traffic and tourism exist in a cycle of consequences. Thus far, population growth and increasing personal car use have been attributed as the major cause of traffic congestion in the central Copenhagen area. However, the adverse effects of tourism must also be examined. According to a case study from Mallorca, Spain, tourism plays a role in traffic externalities such as accidents and air pollution (Saenz-de-Miera Rosselló, 2012).

Air and Noise Pollution

Not only does the traffic congestion create barriers for pedestrians and tourists, it causes air and noise pollution. Traffic is the main source of benzene exposure to people in Copenhagen because it is emitted from petrol-fuelled cars. Gasoline compositions are shown in Figure 3. Benzene is a carcinogenic compound which causes leukemia. Campaigns in Copenhagen conducted by the Monitoring of Atmospheric Concentrations of Benzene in European Towns and Homes (MACBETH) project found a strong correlation between the general level of exposure to benzene, home concentrations of benzene, and the outdoor level of benzene. This indicates that traffic is a possible source for indoor concentrations of benzene and for the general exposure to benzene (Skov, Hansen, Lorenzen, Andersen, Løfstrøm & Christensen, 2001). Benzene exposure is an issue for people outdoors as well. Though people generally spend 90% of their time indoors, outdoor air accounts for 40% of exposure to contaminants and indoor air accounts for 31% while the rest is attributed to personal transportation by car (19%) and smoking (10%). Although pedestrians, bicyclists, and drivers are all exposed to pollutants like benzene, toluene, ethylbenzene and xylene (BTEX), car drivers are exposed the most (Rank Folke, Homann Jespersen, 2001). It has been found that concentrations of these volatile organic compounds are higher inside vehicles compared to outside. Furthermore, a study in a Swedish municipality revealed that there is an association between road traffic noise and cardiovascular disease (Barregard, Bonde, Öhrström, 2008). Noise pollution is the disturbing or excessive noise that may harm activity or balance of life (Conserve Energy Future,

2013). Long-term residential exposure to road traffic noise increases the risk of hypertension in men. As the population increases, it brings increased road noise as well as traffic congestion.

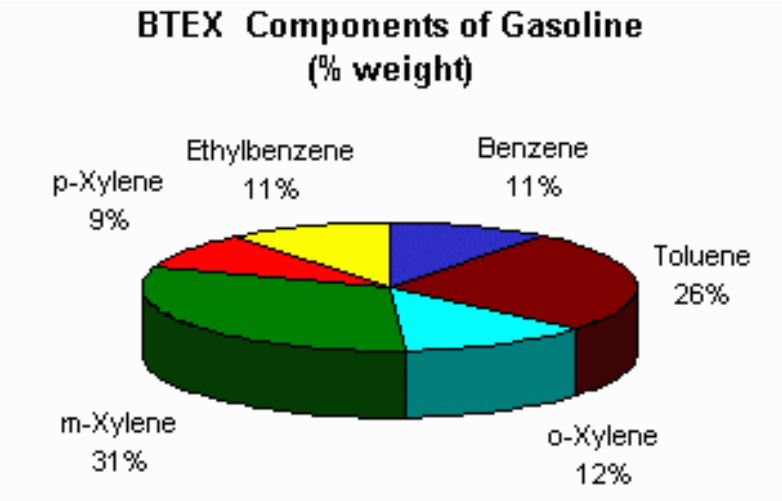

Figure 3. Benzene, toluene, ethylbenzene and xylene (BTEX) composition of gasoline by percent weight
Source: http://www.webapps.cee.vt.edu/ewr/environmental/teach/gwprimer/btex/btex.html

2.2 Current and Possible Solutions

With the increasing number of personal cars and the health hazards associated with the ensuing air pollution, the city center needs a solution to alleviate congestion. The city needs to find ways to convert large traffic areas to more environmentally conscious spaces with lighter traffic. Copenhagen is well known for its sustainable city planning and traffic infrastructure, such as the Five Finger Plan and developments in the Metro. However, with growing concerns for air quality, further resolutions must be studied. The following sections will give an overview of the current traffic infrastructure in Copenhagen.

2.2.1 The Five Finger Plan

The Five Finger plan was introduced to Greater Copenhagen in 1947 when a group of planners realized that the city was beginning to spread uncontrollably (Rahunen, 2015). Furthermore, urban planners strongly believed that the public should have access to infrastructural facilities such as green spaces, bike paths, commuter trains, and motorways. Since then, the Five Finger Plan has been the main guiding principle for urban planning in Copenhagen (Cahasan & Clark, 2003). The goal of the plan was to concentrate the urban development of Greater Copenhagen in the urban "fingers" created around the railway network. In between the fingers, undeveloped space was proposed for

green wedges as shown by the orange outline in Figure 4. The red outline shows the development of the fingers in 2003. In 1987, the urban planners of Greater Copenhagen implemented a "Close to Station" policy that complemented the Five Finger Plan. This policy stated that the areas for additional structural developments would be limited to within one kilometer from a railway station which would promote the use of public transportation. More recently, Finger Plan 2007 put the concept into national law and has judicial binding over Greater Copenhagen and its further planning initiatives. Additionally, the impacts of this "Close to Station" principle were calculated in the updated Finger Plan. It was estimated that it could reduce up to 100,000 tons of CO_2 emissions per year in the coming 30 years (Rahunen, 2015).

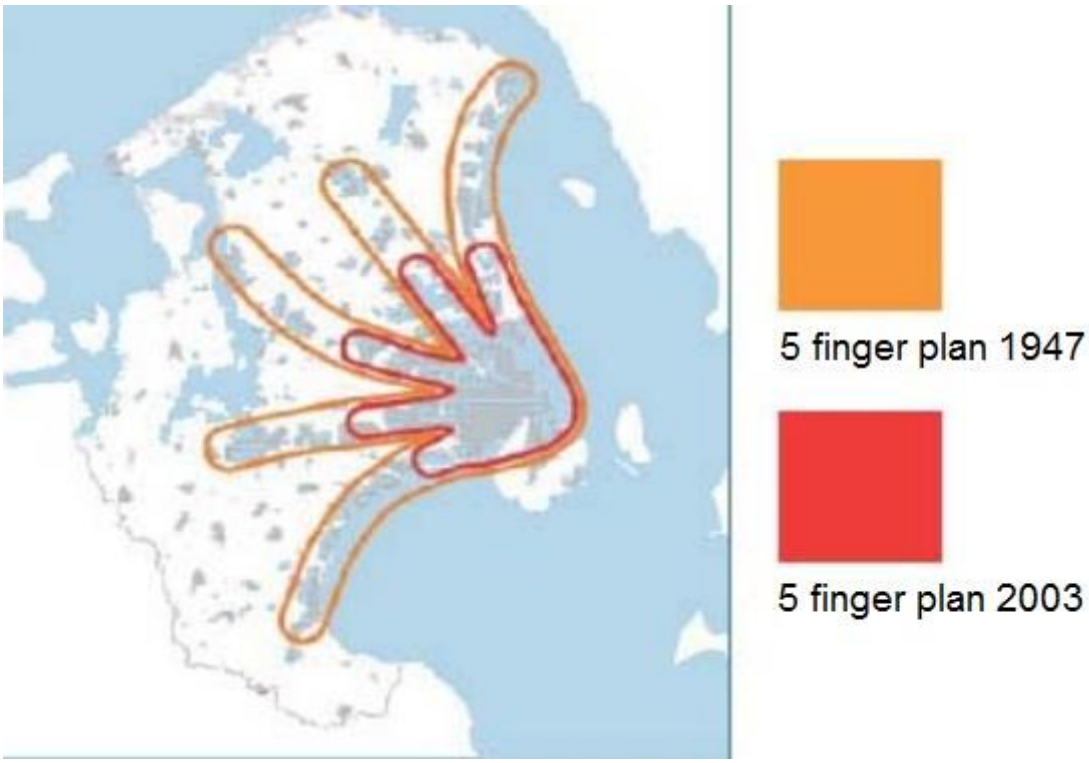

Figure 4. Development of the Five Finger Plan from 1947 to 2003
Source: http://depts.washington.edu/open2100/Resources/1_OpenSpaceSystems/Open_Space_Systems/copenhagen.pdf

2.2.2 The Copenhagen Metro

In more recent times, a Metro system was created in Copenhagen, with the same objectives of carbon neutrality and encouraging public transportation. Two lines (M1 and M2) are already functional; the first stage opened in 2002 and the two lines finished in 2007 (Københavns Metro, 2015b). Two more lines are under construction, the M3 line, called Cityringen and the M4 line, called Nordhavnen. The four lines are diagrammed in Figure 5. There will be 17 Cityringen stations,

all underground, which will service the core of the city and form a connected circle. The Cityringen line construction is planned to be completed in 2019 (Københavns Metro, 2015b). One of the new stations will be Rådhuspladsen, providing a stop below a popular square in Indre By (Københavns Metro, 2015a). Rådhuspladsen is notable because it is on H.C. Andersens Boulevard, the road most frequently used by commuters in Indre By. The Metro system has been found to reduce automobile, bus, walking, and bicycle traffic, and increase railroad traffic count and average length of trips. Usage of the trains is increasing because they are now connected to the Metro and thus more convenient for travelers (Vuk, 2005). Furthermore, Metro construction projects in other cities like Manchester, UK (Knowles, 1996) and Athens, Greece (Golias, 2002) have successfully alleviated traffic congestion. In Manchester, the Metrolink showed increased patronage, mostly from former car users. Similarly, in Athens, the new Metro system attracted 53% of bus riders and 24% private car users. Attracting passengers is important in reducing personal vehicle use and, as a result, reducing traffic on the roads.

Figure 5. Current (M1 and M2) and proposed (M3 and M4) Metro lines in Copenhagen
Source: http://intl.m.dk/#!/about+the+metro/cityringen/about

2.2.3 Tunnels

With a plan for city expansion and the development of the Metro system, Copenhagen is in the process of addressing the problem at hand. However, based on models used in other cities, there are several other solutions that the city could consider. A potential solution is implementing a road tunnel. According to the American Association of State Highway and Transportation Officials (AASHTO), road tunnels are defined as enclosed roadways accessible to vehicles through selected openings. Road tunnels serve as a means to cross physical barriers such as a body of water, mountains, and railroads, or to fulfill environmental regulations. They contribute to improving the environment around the area by minimizing traffic congestion and noise pollution while improving air quality (FHWA, 2013a). However, road tunnels must have certain characteristics in order to alleviate traffic congestion. For example, the traffic capacity of the tunnel must be at least the same as the road it is replacing on the surface. Studies have shown that if tunnel traffic is properly controlled, it will flow better compared to a surface road (FHWA, 2013a). Using road tunnels provides some control in the number of vehicles that pass through during a period of time due to the dimensions of the tunnel that were determined based on current traffic flow. Factors such as tunnel height and the number of lanes restrict the type and number of vehicles that are permitted to use the tunnel. Although implementing a road tunnel does not guarantee a lighter traffic flow, it certainly provides an option with a high likelihood of alleviating traffic congestion and presents additional benefits such as promoting environmentally conscious development.

Tunnels' Impact on Air Quality

One of the advantages of implementing a tunnel is the reduction of air pollution. A study was done in Oslo, Norway in 1999 to determine whether implementing a road tunnel affects the air quality of the surrounding area. Two tunnels were built in the busiest part of the city to alleviate traffic congestion. The study, conducted by the Norwegian Institute for Air Research, focused on two pollutants, nitrogen dioxide (NO_2) and particulate matter (PM). The results show that the tunnels improved the surface air quality by reducing the level of NO_2 and PM compared to when the traffic was on the surface road. The major difference was seen in the residential areas around the tunnels whereas the most concentrated pollution was measured around the opening of the tunnel during peak traffic hours (Bartonova et al., 1999). The outcome of this study suggests that implementing a tunnel to divert traffic leads to the containment of the polluted air and allows the quality of the air around the surface to improve. Thus, a safe method of disposing the polluted air

from the tunnel is needed when discarding it into the atmosphere. Specifics such as proper ventilation of the tunnel are important aspects in maintaining human health while people are passing through the tunnel (Bari & Naser, 2010). Nevertheless, this study supports the possibility of improving surface air quality when a tunnel is implemented to alleviate traffic congestion.

Urban Green Spaces

Another benefit of road tunnels includes the addition of green spaces to the landscape of the area. If a tunnel is implemented, the surface area above it could be converted to an urban green space in place of the road. A green space is a piece of land open to the public that is partially or completely covered in vegetation such as trees and grass (Environmental Protection Agency, 2014). Green spaces are usually built in the form of playgrounds and public parks that will improve the quality of life for pedestrians and surrounding population. A study in the Greater Manchester Area, United Kingdom, has shown that aside from the benefit of aesthetics, green spaces have been proven to promote health aspects by filtering air pollution and reducing stormwater runoff (Gill et al., 2007). Aside from reducing air pollution, green spaces also combat the heat island effect. The heat island effect refers to urban centers that are higher in temperature compared to surrounding regions because of the lack of vegetation and permeable surfaces which hold water. The mean temperature of a city with 1 million inhabitants is usually 1 to 3 °C higher compared to the surrounding region, and the difference increases to 12 °C at night (EPA, 2013). These changes in temperature negatively impact the community's quality of life by increasing the energy consumption for air conditioning, the production of greenhouse gases by power plants, and decreasing physical health. The cycle of the heat island effect then continues to rapidly degrade the environment by contributing to climate change. Thus, the addition of a green space in the city would promote sustainable development of the area and work against the threats posed by climate change.

Tunnels in Other Cities

As a result of the numerous benefits of tunnels, other cities in the world have implemented them. Poor infrastructure and high flooding in Kuala Lumpur, Malaysia led to the implementation of the SMART (Stormwater Management and Road Tunnel) project. The project calls for a dual-purpose tunnel that can also be used to divert stormwater into a river near the city (Abdullah, 2004). The success of this project inspired a past team of students from WPI stationed in Nørrebro, Denmark to design a tunnel with similar properties. They were faced with the problem of traffic congestion

and the challenge of daylighting a canal. The team proposed a dual-purpose tunnel. If needed, one of the tunnels could be repurposed as stormwater drainage to prevent the surface from flooding (Ruddy, Hassan, Anglin, & Higgins, 2012). The project was deemed a success because further research is currently being conducted by city officials to determine the feasibility of this solution.

Another example of a successful road tunnel is Boston's Central Artery/Tunnel (CA/T) Project. The project, nicknamed Boston's Big Dig, diverted Interstate 93 (I-93), the main highway of the city, into the Thomas P. O'Neill Jr. Tunnel. The project included connecting Interstate 90 (I-90) to Logan International Airport by adding the Ted Williams Tunnel, diverting airport traffic from passing through the busy area of downtown Boston. Aside from alleviating traffic flow, the project provided open space on the surface which was developed as the Rose Kennedy Greenway (Tajima, 2003). The Greenway allows a large area to be converted to public parks, creating scenic views, and green spaces in the heart of Boston. Pedestrians are also positively impacted since the parks constructed along the Greenway provide access to the east and west side of the city, previously complicated by the highway overpass.

Disadvantages of Tunnels

On the other hand, constructing a tunnel is a very large-scale project that can have negative effects on the surrounding area. There are several aspects that must be taken into account in deciding whether a tunnel is the most effective solution for alleviating traffic congestion in Copenhagen. Construction and maintenance costs can be expensive and strenuous on the economy (Flyvbjerg, 2010). There are health hazards of concentrated fumes in the tunnel. Simulations reveal that emissions released from stationary cars when engines are running pose serious health threats inside tunnels (Bari, 2010). During construction, several short-term disadvantages include increased traffic and pollution, and decreased tourism impacting local businesses and the economy in general. Although it is temporary, the additional traffic would worsen the current traffic flow (Planning and Community Development Department of Santa Monica, 2013). Particulates and odors released from construction sites can have unfavorable off-site effects if they are not properly maintained or controlled (New South Wales Office of Environment and Heritage, 2013). However, the benefits of a tunnel outweigh these disadvantages, especially considering the hindrances can be mitigated.

2.2.4 Roundabouts

While tunnels are an important possibility to consider, other ideas such as roundabouts have been explored as well. Roundabouts have been implemented extensively throughout Europe and other places around the world to reduce accidents, congestion, air pollution, and construction costs. Roundabouts have cut hydrocarbon emissions at intersections by as much as 42% because cars are moving continuously, decreasing stop-and-go traffic and lessening the idle time that contributes to air and noise pollution. Numerous studies have shown significant safety improvements at intersections converted to roundabouts due to the elimination of crossing conflicts and higher speed limits present in conventional intersections (FHWA, 2010). Roundabouts have been shown to reduce accidents as much as 76% in the US and 86% in the UK (Baranowski, 2015). Roundabouts typically have lower operating and maintenance costs due to the elimination of traffic signals which amount to $3,500 per year per intersection for maintenance and $1,500 for electricity (Baranowski, 2015).

Despite the several benefits roundabouts provide, roundabouts would not be a suitable solution for Copenhagen. In a busy city like Copenhagen, roundabouts do not work well because heavy traffic flow from one direction impedes traffic from other directions. Furthermore, queue development can cause long lines at the entry points. Roundabouts are also not suitable for emergency vehicles like ambulances that cannot navigate through them easily. They are not friendly for handicapped people, especially the visually impaired due to the lack of pedestrian and traffic signals (Goel, 2011). Another reason roundabouts would not be a fitting solution for Copenhagen is the high volume of bicyclists that travel through the city every day. Roundabouts are a constant source of stress for cyclists since collision rates are higher compared to intersections (Bicycle Network, 2015).

2.2.5 Congestion Pricing

Yet another idea that has been successful in reducing traffic and air pollution in other cities is congestion pricing. Road pricing is a direct charge for the use of a road. It holds great potential as a strategy to reduce levels of congestion and pollution. Road pricing projects have been implemented on four continents (Asia, Australia, Europe and North America) and include notable projects in Germany, Singapore, and the United Kingdom (Smith et al., 2010).

In 2003, London launched a bold initiative by applying a congestion charging zone in central London, as illustrated in Figure 6. The image shows the charged roads in grey and uncharged roads

in white. The aim of this initiative was to reduce traffic, improve travel times for buses, generate new revenues for public transit and enhance the quality of life in London. The congestion charge caused the number of vehicles entering the charging zone to decrease by 70,000 vehicles per day. The amount of circulating traffic fell by 15%, travel speeds increased by 30%, trip times decreased by 14%, and traffic delays plummeted by 25% (Smith et al., 2010).

Figure 6. Map of Central London's congestion charging zone
Source: http://international.fhwa.dot.gov/pubs/roadpricing/roadpricing.pdf

Despite the success of congestion pricing in certain cities, there are certain drawbacks to this practice as well. Congestion charging requires technology and a high operation cost. Since the congestion charge has been introduced, there has been growth in the use of false number plates and schemes to avoid paying the tax. Additionally, the shops within the charging zone see the congestion charge as lost business due to the traffic reduction (Pettinger, 2011). Although congestion zones reduce traffic within the area, drivers trying to avoid the charging zone may take longer alternate routes. Thus, the vehicle uses up more gas, creating more pollution.

In the past, the Copenhagen Municipality attempted to implement congestion pricing, however the plan was rejected by the government. Car owners and neighboring municipalities were opposed to the extra cost associated with it and as a result of the opposition, the government decided not to implement congestion pricing in the city (Buley, 2012). Neighboring municipalities are against the plan because most of the cars in the Inner City originate from their areas outside of

Copenhagen. Statistics gathered from 1970 to 2010 show that the number of cars in the Inner City originating from outside of Copenhagen has been steadily increasing while those within the Inner City have remained approximately constant (København Kommune, 2012). Instead, the government decided to repurpose funds to further incentivize bicycles and public transportation.

2.2.6 Light Rail System

Another possible solution is a light rail system. Light rail is a modern, urban form of public transportation that is similar to a tram. The light rail system uses sleek bus-like structures which employ a track approximately 90% independent of car traffic. This allows for high speeds and less delays than other forms of transportation. Light rail is a hybrid system which means it can run on several different types of infrastructure including the road, rails or a tunnel. They run using electric wiring which allows them to be environmentally friendly. In most European cities, light rail stations are on the surface which allows easy access and allow the system to be more flexible in terms of implementation into a city's public transportation. Furthermore, it requires less construction and easier integration with existing infrastructure compared to a Metro system, despite the similar passenger capacity. However, with the implementation of a light rail there will be several negative impacts on car users such as reduced lanes and reduced street parking (Letbaner.DK, 2008).

2.3 Miljøpunkt Indre By and Their Role in Alleviating Traffic and Pollution Problems

The benefits and disadvantages should be considered in proposals aimed at alleviating traffic in Copenhagen. One of the organizations working towards this is Miljøpunkt Indre By-Christianshavn. The organization is passionate about issues such as air quality because they strive to help Copenhagen reach its goal of carbon neutrality.

2.3.1 Agenda 21

In order to reach its goal of carbon neutrality, Copenhagen has taken on the Agenda 21 initiative. Agenda 21 is a sustainability plan conceived in 1992 at the United Nations Conference on Environment and Development (UNCED) held in Brazil. The main goal of this plan is to serve as a sustainable development action plan for not only the UN but for other individual governments and organizations around the world. Agenda 21 is coined with the number "21" referring to the overall goal of sustainable development in the 21st century. The UN specifically defines sustainability as

"meeting the needs of the present without compromising the future generations to meet their own needs" (Beatty, Jenna, Coletta, Tom, Rogan & Ryan, 2009).

2.3.2 Agenda 21 in Copenhagen

Over 178 governments at the UNCED conference adopted Agenda 21. Since implementation was voluntary and varied by country, The Commission on Sustainable Development (CSD) was created in 1992 to ensure proper adoption. Agenda 21 involves action at the international, national, regional and local levels. Most member governments have advised authorities to implement the plan locally. There are 216 local Agenda 21 organizations in Denmark alone. The local Agenda 21 organizations in Copenhagen itself have four main goals. First, staying consistent with Agenda 21's theme, they are focusing on continued sustainable development in Copenhagen. Secondly, they aim to keep open communication between government officials and the community to achieve their goals. Next, they want to encourage citizens to make more environmentally friendly decisions and lastly, reduce the use of local and global resources (EPA, 2006). Our sponsor, Miljøpunkt Indre By-Christianshavn directly cooperates with other local organizations to raise Agenda 21 awareness in Copenhagen (Miljøpunkt Indre By-Christianshavn, 2012).

2.3.3 Our Project

The growing population of Copenhagen puts a heavy strain on the traffic infrastructure, causing congestion, pollution, and barriers for pedestrians. Miljøpunkt Indre By wants to analyze the infrastructure of H.C. Andersens Boulevard. By analyzing where the traffic comes from and where it needs to go, we identified suitable solutions such as traffic limitation measures, tunnels, and additional public transport options. We needed to find ways to convert large traffic areas into pollution-free urban spaces with light traffic, such as bicycles, pedestrians, and improved public transportation. One of the major focuses was evaluating the feasibility of implementing a tunnel solution by understanding traffic flow patterns, the impact on air pollution and traffic in Indre By, and technical obstacles presented by the solution. We also explored alternatives such as light rail, reducing parking and improving bicycle infrastructure. In the next chapter, we explain the details of how we accomplished this.

Chapter 3: Methodology

3.1 Introduction

The goal of the project was to analyze traffic in central Copenhagen and its effect on air quality, and determine the appropriateness of a tunnel for congestion alleviation and air quality improvement. In order to achieve this goal, we constructed the following objectives:

1. Understand current traffic patterns and identify main causes of congestion in the Indre By and Christianshavn areas.
2. Determine stakeholder opinion on traffic conditions and air quality.
3. Explore the appropriateness of tunnels to alleviate traffic and air quality issues and explore possible alternative solutions.
4. Compile recommendations and suggest the most appropriate course of action.

This chapter outlines how we achieved the proposed goal of providing recommendations for diverting traffic and decreasing air pollution in central Copenhagen, specifically the neighborhoods of Indre By and Christianshavn. In order to accomplish this goal and the subsequent objectives, we employed different methodologies. The main methods we used include interviews, a structured questionnaire, and direct observation of the traffic in the area. The chapter will focus on a detailed description of the methods implemented and how the objectives were accomplished.

3.2 Objective 1: Understand current traffic patterns and identify main causes of congestion in the Indre By and Christianshavn areas

In order to orient the project, it was important to gain an awareness of the area and the community. To begin, we utilized a mix of methods such as observation of the area, discussing the problem with the sponsor, obtaining air pollution data in the area, and reading literature about traffic patterns in central Copenhagen. It was important to employ this combination of methods in order to fully understand the current traffic situation and the existing air pollution.

First, we directly observe traffic patterns in the area to identify which areas are the most congested and at which time they are experiencing this congestion. We observed several different intersections along H.C. Andersens Boulevard to understand the flow of traffic from other neighborhoods and within Indre By. In groups of two, we observed the congestion on seven intersections starting at the intersection of Hammerichsgade and H.C. Andersens Boulevard and going down towards Langebro bridge. Congestion can be defined, in the context of transportation,

as an excess of vehicles on a section of the road which leads to speed that is slower than the normal speed (FHWA, 2013b). Each group conducted two readings at the intersections at each of the two timings which the public considered most congested: 9.00 and 16:00. During each reading, an intersection was selected as the baseline and was given the score 100. Each intersection following was given a score relative to the baseline. After the readings were completed, the ranges of scores were given colors and four sets of data were compiled into two maps: one for 9:00 and another for 16:00. The observation allowed us to understand how constructing tunnel exits would impact the area.

It was also important to understand the current situation of the air pollution on H.C. Andersens. In order to do so, we obtained data on NO_2, CO and PM levels on the road from an air quality station owned by Aarhus University. The data is available on the webpage of the university's Department of Environmental Science. The air quality data, which corresponded to the days when we conducted the direct observation of the traffic, was collected and used to examine the fluctuations of NO_2 concentration at the hours of 9:00 and 16:00. Furthermore, the data was used to compare Copenhagen's NO_2 emissions to the EU's limit.

For further understanding of air quality and congestion, we explored relevant reports such as any literature regarding pollution, traffic and case studies provided by our sponsor and by experts. These documents were valuable at this stage to provide a background because the information helped shape our future interview topics to be more suitable.

Second, we had an initial discussion with the contacts from the sponsoring organization, Miljøpunkt Indre By-Christianshavn. In particular, this involved conducting a face-to-face semi-structured interview with the sponsor's traffic engineering specialist, Kjeld Larsen and his colleague from The Council for Sustainable Traffic, Ivan Lund Pedersen. Mr. Larsen and Mr. Pedersen gave us an accurate picture of the current problem that the neighborhoods of Indre By and Christianshavn are facing. A semi-structured interview was useful because the order and wording of the questions was variable and flexible (Berg & Lune, 2007). While certain topics were necessary to touch upon, the flow of the conversation varied in response to Mr. Larsen and Mr. Pedersen's answers. This was important because we gained new information and the less rigid structure helped bring up unanticipated topics. Interviewing experts in a semi-structured method provided valuable insights for understanding the problem from a valid perspective. The topics that we explored in the interview with Mr. Larsen and Mr. Pedersen, included how traffic has changed over the past few years, the traffic patterns in Indre By and Christianshavn, their perception on the most congested

times and areas, and how well or how poorly Indre By's traffic infrastructure is handling the current traffic. The questions are detailed in Appendix A. Mr. Larsen and Mr. Pedersen's responses and other ideas that they felt were relevant were noted and audio-recorded with their permission.

3.3 Objective 2: Determine stakeholder opinion on traffic conditions and air quality

In addition to the research on the current traffic patterns and air pollution conditions in Indre By and Christianshavn, we gathered public opinion from people who live and work in the area and information from experts. For objective 2, we conducted interviews and street surveys, distributed an online survey, and analyzed literature provided by experts.

We gathered information and opinions from experts on several aspects of the project. The experts were interviewed in face-to-face semi-structured fashion and topics such as traffic mitigation, air quality issues, and potential issues were explored. Experts were a good source because they had in-depth knowledge in their field and as a result, were credible resources. The complete list of proposed questions for the traffic and air quality experts is available in Appendix B of this report. The interviews were recorded as per the permission of the interviewees and audio transcripts are available upon request.

The first expert we interviewed was Kåre Press-Kristensen. He is a professor at the Danish Technical University in the Department of Environmental Engineering and a senior advisor at the Danish Ecological Council. Professor Press-Kristensen provided us with an understanding on the history of air quality in Indre By as well as information regarding the different types of pollutants that exist in the area. Additionally, we received literature from Professor Press-Kristensen on air pollution data in Copenhagen.

The second expert we interviewed was Mayor Morten Kabell, the Mayor of Technical and Environmental Affairs of the Municipality of Copenhagen. We requested a face-to-face interview with the Mayor, however due to his busy schedule, we conducted an email interview instead. A set of questions regarding the current traffic condition and air quality as well as possible solutions were sent to the Mayor's office. His responses provided us with a political perspective on the situation, including the financial and political complications associated with different solutions.

The third expert we interviewed was Professor Per Homann Jespersen. He is an Associate Professor in the Department of Environment, Technology, and Social Studies at Roskilde University. Professor Jespersen is familiar with the traffic situation due to his involvement in projects that

explored the various transport systems which politicians were considering implementing in Copenhagen.

The last expert we interviewed was Morten Engelbrecht, a member of the traffic group Letbaner.DK. The group focuses on informing the public about implementing a light rail system in Copenhagen. While he was unavailable to meet in person, he sent us a letter with his comments regarding our project. His insights were helpful in informing us on the impacts of light rail systems on the air and noise quality and its appropriateness for the traffic problem on H.C. Andersens Boulevard.

We obtained public opinion on aspects such as traffic, the upcoming Metro station, potential solutions and air quality. In order to receive this information, we used two methods: street surveys and online surveys distributed through social media, contacts of our experts, and flyers. In total, we collected 47 responses through both methods. We provided these structured surveys in both English and Danish, with the help of our sponsor in translating the questions. The participants of the street surveys included commuters and employees that work on H. C. Andersens Boulevard as well as frequent visitors of the area. Our questionnaire asked about their view on pollution in the area and how they would feel if a green space was put in place. A green space is land that is partly or completely covered with grass, trees, or other vegetation (EPA, 2014). The concluding questions gauge the public's attitude towards certain proposed solutions, such as a tunnel and the upcoming Metro station. We approached each respondent in groups of two and began with a brief introduction of who we are and what our project is about. Their responses were then recorded on paper or in an electronic survey on a smartphone. Overall, the street surveys conducted over the course of 4 days, assisted us in understanding the local stance on the current air quality and traffic congestion. The data was analyzed using Qualtrics, software used for survey gathering and analysis.

Another useful method we utilized to determine public opinion was distribution of the online survey. The main benefit of the online survey was the ability to reach the participants that we could not otherwise find. The online survey was posted on social media sites and sent via email to the contacts of Miljøpunkt Indre By and the experts we interviewed. Since the contacts were familiar with Miljøpunkt Indre By and aware of the issue, they were more likely to respond in a timely and helpful manner. We also provided the online survey links on a flyer and distributed those around parking lots and local businesses. Our goal with the online survey was to obtain more views on the overall traffic condition. The complete list of proposed questions for both the online survey and the paper questionnaire are available in Appendix C of this report.

3.4 Objective 3: Explore the appropriateness of tunnels to alleviate traffic and air quality issues and explore possible alternative solutions

Miljøpunkt Indre By seeks to assess the appropriateness of a tunnel in alleviating air pollution and traffic congestion in comparison to other possible solutions. By thoroughly evaluating the possibilities, we worked towards a suggestion for the most feasible solution for the current condition. Evaluating the possible solutions was done by analyzing responses of the public and other experts, and comparing the infrastructure in central Copenhagen with other cities.

First we compiled the responses from the public regarding traffic and air quality. The data was compiled and presented using graphical representation such as bar graphs and pie charts which allowed for the visualization of the answers given to the questionnaires addressed in Objective 2. We analyzed this data which provided a consensus on whether traffic and air pollution are issues that need to be addressed and how the public feels about tunnels and other proposed solutions.

We also conducted a study of the implementation of different solutions in cities around the world, such as Kuala Lumpur, Malaysia and Boston, USA. The research was conducted using online resources such as the Federal Highway Administration and the Journal of Transportation Geography. Furthermore, case studies from Seoul, South Korea, which discussed alternative solutions for traffic, were provided by Kjeld Larsen and Ivan Lund Pedersen. The literature was examined to better understand how these ideas have worked in other cities and regions and to determine the necessary conditions or important factors for success.

With sufficient information gathered from the interviews and research, we worked towards recommending several possible solutions to address the traffic and air pollution issues in central Copenhagen and offered suggestions on implementation methods.

3.5 Objective 4: Compile recommendations and suggest the most appropriate course of action

The information gathered in Objective 3 was useful in determining whether a specific solution is appropriate for the traffic problem faced in central Copenhagen because the advantages and disadvantages related to each solution were evaluated. The data was gathered in a table and presented in a manner that presents the benefits, drawbacks and impacts on Indre By and Christianshavn. The timeline of how we completed our project, displayed as a Gantt chart, is shown in Figure 7, which illustrates the schedule we followed.

Timeline										
Objective	Description	Details	Week							
			1	2	3	4	5	6	7	8
Objective 1	Understand Current Situation	1. Discussed plans with sponsor 2. Conducted interview with Kjeld and Ivan 3. Contacted other experts like professors, air quality experts and politicians 4. Researched traffic patterns (observe the area) 5. Obtained literature and reports (Seoul, Clean Air Copenhagen, Indre By Revitalisering, Michael Schroder, WHO Air Quality) 6. Obtained air pollution data from Aarhus University								
Objective 2	Gather Expert Information (Traffic, the Metro Station, Tunnels and Air Quality)	1. Conducted interview with experts (Prof Jespersen, Mayor Kabell and Kaare) 2. Studied literature on air pollution and traffic patterns								
	Gather Public Opinion (Traffic, the Metro Station, Tunnels and Air Quality)	1. Conducted street interviews 2. Sent out online surveys to other contacts of our sponsor 3. Distributed flyers								
Objective 3	Analyze the appropriateness of tunnels and explore other solutions	1. Analyzed expert and public opinions (from Objective 2) 2. Compared with other tunnel proposals and other traffic solutions (other cities)								
Objective 4	Deliverables	1. Compiled recommendations 2. Final presentation								

Figure 7. Project timeline illustrated as a Gantt chart

3.6 Limitations

These methodologies presented several challenges and obstacles for us. For example, it was hard to accurately assess the overall impact of the Metro station because it has not been completed yet. As a result, the opinions and data that we gathered regarding the Metro were purely based on projected information. Furthermore, questioning people on the street was difficult due to several factors, including time, weather, and the unwillingness of subjects to talk to strangers. In particular, Indre By is a heavily tourist populated area and a large percentage of the pedestrians we stopped were tourist, who were unaware of the problems on H.C. Andersens or did not want to stop to talk. Another challenge we faced was the timeline of the project. The time frame was too short to complete this incredibly complex and vast project and as a result, many possibilities or ideas went unexplored. Lastly, interviewing experts brought several unexpected outcomes. Many experts that we contacted were unavailable for interviewing. While some experts such as Mayor Kabell, and Morten Engelbrecht were able to answer questions via email, many experts were simply inaccessible. Last, many of our online survey responses were biased as they were mostly contacts of Miljøpunkt Indre By and the experts and thus, simply a slice of the demographics. Overall, despite the challenges, we did our best to work through them and create a successful project. The following chapter will discuss our findings and recommendations.

Chapter 4: Findings

In the following chapter, we discuss the main findings of our project. We begin by thoroughly explaining the extent of the problem on H.C. Andersens Boulevard in terms of air pollution and traffic congestion. We will then discuss the possible solutions that are appropriate for H.C. Andersens Boulevard, mainly the tunnel and green space solution as well as other alternatives.

Finding 1: Vehicles on H.C. Andersens Boulevard generate the most air and noise pollution in Copenhagen and it has detrimental health effects

Approximately 51,000 vehicles commute on H.C. Andersens Boulevard on an average weekday and as a result, it is the most polluted road in Copenhagen compared to other arterial roads in the city (Press-Kristensen, 2014). The map in Figure 8 shows the NO_2 concentration at different roads in the Greater Copenhagen area. The red dots which represent the highest concentrations are clustered around H.C. Andersens proving that it is the most polluted artery in the city.

This can also be seen in data from Aarhus University's air measuring station, located right beside H.C. Andersens, which measures different ranges of emissions continuously throughout the day, seen in Table 1. Their Department of Environmental Science is responsible for the monitoring and management of air quality in Denmark and Greenland, and the data is available on their website. Table 1 shows the NO_2 level on H.C. Andersens Boulevard and H.C. Ørsted Institute on April 22, 2015. This data shows that the average NO_2 concentration throughout the day is 3.5 times higher on H.C. Andersens Boulevard compared to H.C. Ørsted Institute, which measure at 61.3 $\mu g/m^3$ and 17.3 $\mu g/m^3$ respectively. The staggering data retrieved from this air measuring station and further investigation has pushed the Copenhagen Municipality towards finding ways to combat air pollution on H.C. Andersens.

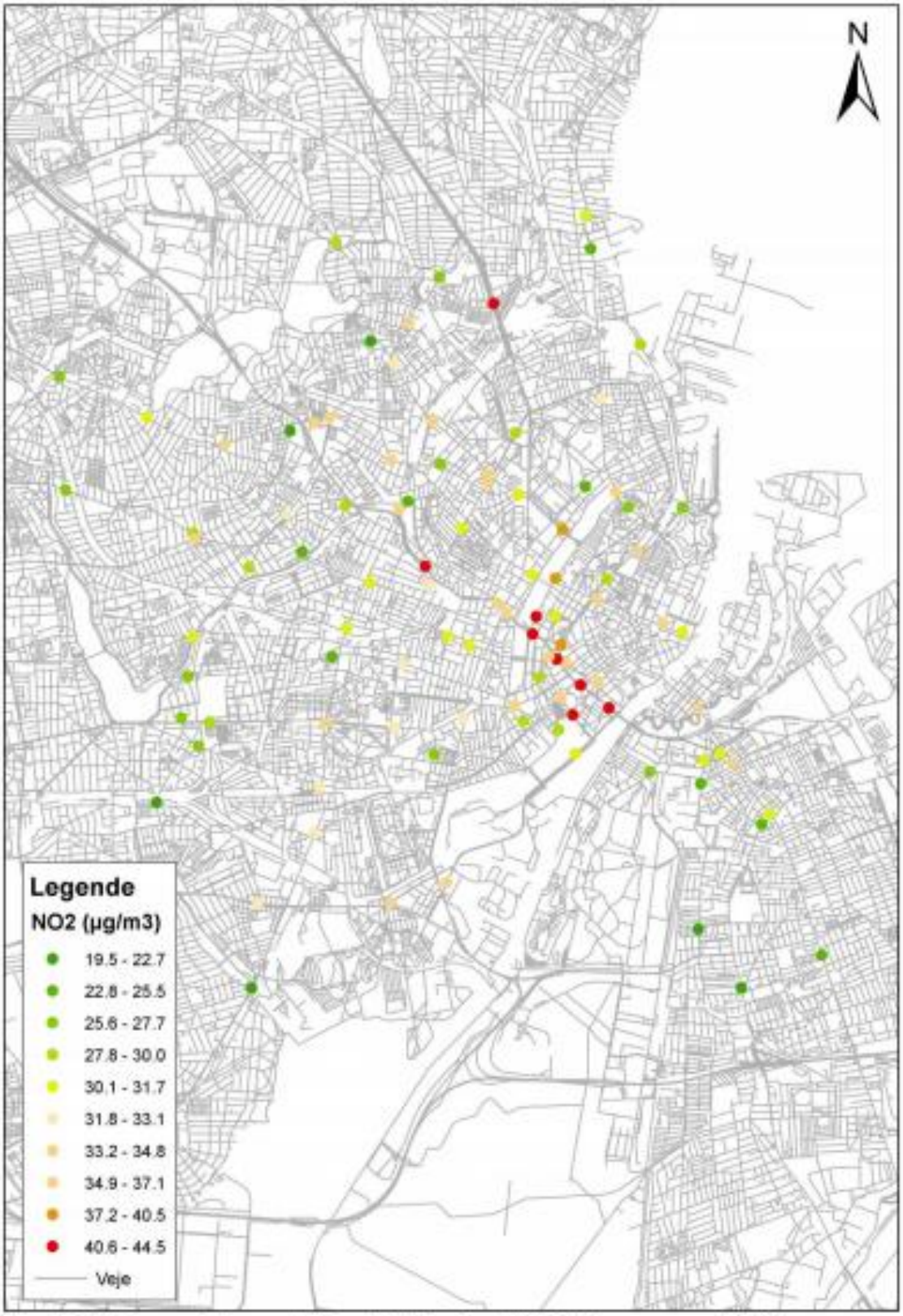

Figure 8. Map of NO_2 concentrations on main arterial roads in Copenhagen with the red dots representing high emissions along H.C. Andersens Boulevard

Source: Luftkvalitetsvurdering Af RenLuftzone I København

DATO - 2015	Tid	NO_2
22/4	23-24	12.38
22/4	22-23	13.98
22/4	21-22	15.21
22/4	20-21	18.76
22/4	19-20	16.64
22/4	18-19	12.23
22/4	17-18	13.86
22/4	16-17	11.71
22/4	15-16	8.88
22/4	14-15	13.71
22/4	13-14	20.98
22/4	12-13	31.89
22/4	11-12	25.99
22/4	10-11	17.37
22/4	9-10	14.52
22/4	8- 9	23.49
22/4	7- 8	47.12
22/4	6- 7	44.64
22/4	5- 6	24.35
22/4	4- 5	9.58
22/4	3- 4	5.59
22/4	2- 3	4.05
22/4	1- 2	3.89
22/4	0- 1	5.56

DATO - 2015	Tid	NO_2
22/4	23-24	31.56
22/4	22-23	42.75
22/4	21-22	44.02
22/4	20-21	50.21
22/4	19-20	47.98
22/4	18-19	49.36
22/4	17-18	64.89
22/4	16-17	45.83
22/4	15-16	57.82
22/4	14-15	44.60
22/4	13-14	53.78
22/4	12-13	70.06
22/4	11-12	97.46
22/4	10-11	110.52
22/4	9-10	90.99
22/4	8- 9	110.12
22/4	7- 8	123.36
22/4	6- 7	140.37
22/4	5- 6	100.73
22/4	4- 5	40.98
22/4	3- 4	16.75
22/4	2- 3	14.19
22/4	1- 2	8.91
22/4	0- 1	13.14

Table 1. Aarhus University air quality station emission data with H.C. Ørsted Institute (left) and H.C. Andersens Boulevard (right)
Sources: http://www2.dmu.dk/atmosphericenvironment/byer/forside.htm

We spoke to an air pollution expert, Professor Kåre Press-Kristensen about air pollution on H.C. Andersens Boulevard. According to a report he published in 2014, there are three main factors that contribute to air pollution near a road. The first factor is the background pollution in the air that enters the road. Background pollution consists of pollution from sources within and outside of the city. Second, is the pollution caused by local traffic on the road. Third, is the formation of pollution in the air from sources such as construction along the road (Press-Kristensen, 2014).

The majority of the pollution on H.C. Andersens comes from the high volume of traffic. Traffic on the boulevard consists of personal vehicles, buses, and bicycles with the first two modes contributing significantly to the pollution. The vehicle composition on H.C. Andersens is shown in

Table 2. Passenger cars alone take up over 76% of the road with vans following at 11%. Also, the number of diesel vehicles on H.C. Andersens has increased (Press- Kristensen, 2014). Diesel vehicles are known to produce more particulate matter and NO_x compared to a petrol vehicles (The Guardian, 2013). Table 3 shows that 69% of NO_2 concentrations on the road come from vehicular traffic while only 31% comes from background sources. In addition to air pollution, noise pollution is also a problem on H.C. Andersens Boulevard. Motor vehicles are the second highest contributor to the noise pollution in Copenhagen (Press-Kristensen, 2014).

	Division (%)	Fuel
Passenger cars	76.4	70 % Gasoline / 30 % Diesel
Taxis	7.5	Diesel
Vans	11.4	9 % Gasoline / 91 % Diesel
Trucks (< 32 tons)	2.6	Diesel
Trucks (> 32 tons)	0.35	Diesel
Buses	1.7	Diesel
Total	**100**	**---**
Heavy traffic (> 3.5 tons)	4.7	Diesel

Table 2. Vehicle composition on H.C. Andersens' Boulevard in Copenhagen
Source: http://www.cleanaireurope.org/fileadmin/user_upload/redaktion/downloads/The_Danish_Ecocouncil/Clean_air_CPH_2014_UK.pdf

		PM_{10}		$PM_{2.5}$		$PM_{0.1}$		NO_2	
		µg/m³	%	µg/m³	%	number/cm³	%	µg/m³	%
Background pollution from outside the city		16	52	10	66.5	2500	18.5	9	16.5
Background pollution from the city		1	3	1	6.5	2500	18.5	8	14.5
Background pollution from all sources		17	55	11	73.5	5000	37	17	31
Passenger cars:	Exhaust	1	3	0.7	4.7	3650	27	14.5	26
	Non-exhaust	7	22.5	1.5	10	0	0	0	0
Taxis:	Exhaust	0	0	0	0	0	0	2.3	4
	Non-exhaust	0.9	3	0.2	1.3	0	0	0	0
Vans:	Exhaust	0.8	2.5	0.6	4	3250	24	6.5	12
	Non-exhaust	1.6	5	0.3	2	0	0	0	0
Trucks:	Exhaust	0.3	1	0.2	1.3	950	7	10	18
	Non-exhaust	1.5	5	0.3	2	0	0	0	0
Busses:	Exhaust	0.2	0.5	0.1	0.6	650	5	5	9
	Non-exhaust	0.8	2.5	0.1	0.6	0	0	0	0
Total pollution from traffic on H.C. Andersen' Boulevard		14	45	4	26.5	8500	63	38	69
Concentration on road level		31	100	15	100	13,500	100	55	100

Table 3. Estimated sources contributing to the average concentration of particles and nitrogen dioxide on H.C. Andersens Boulevard in Copenhagen
Source: http://www.cleanaireurope.org/fileadmin/user_upload/redaktion/downloads/The_Danish_Ecocouncil/Clean_air_CPH_2014_UK.pdf

The pollution on the road is particularly problematic, according to Professor Kåre Press-Kristensen, a member of the Danish Ecological Council. In an interview, he stated that H.C. Andersens exceeds the European Union's annual limit for NO_2 concentration, which is 40 µg/m^3 for NO_2 (Ellerman, Nordstrøm, Christensen, Ketzel, & Solvang, 2010). The far left column in Figure 9 shows the average NO_2 concentrations on H.C. Andersens surpassing the EU's limit and sitting at 44.5 µg/m3.

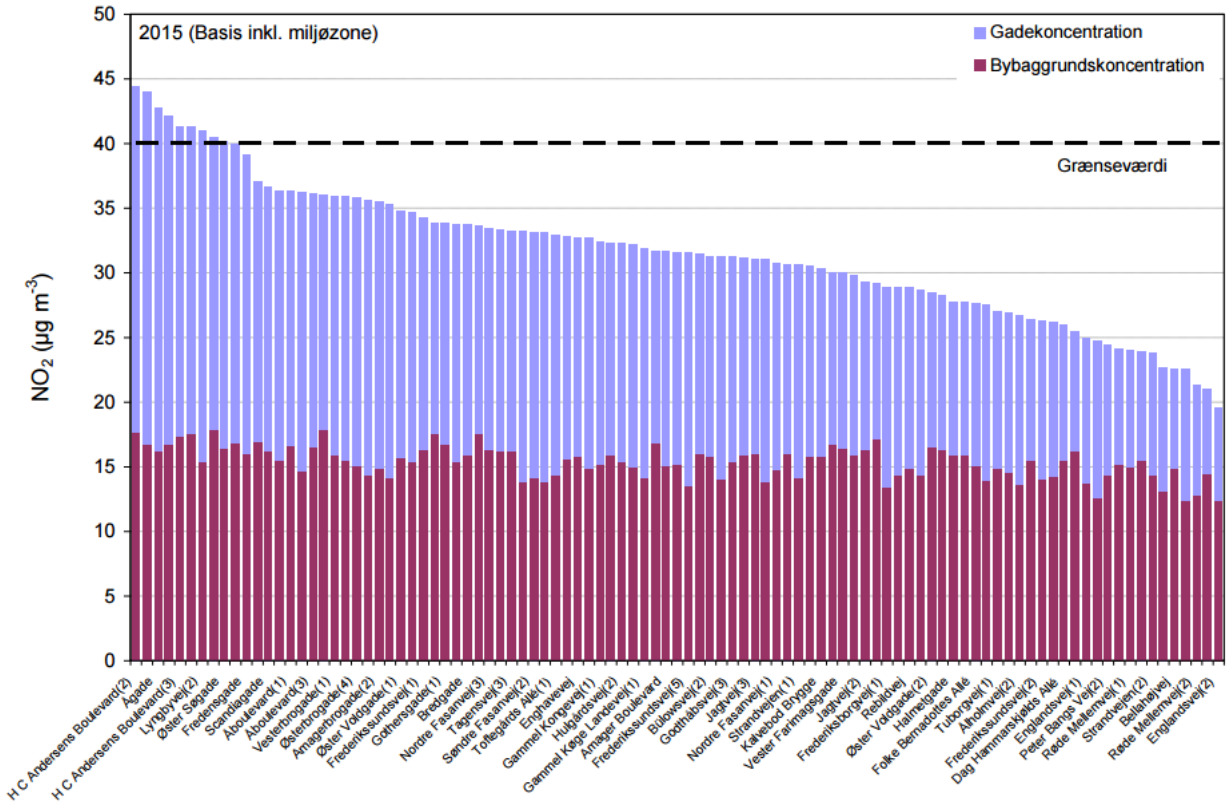

Figure 9. Average NO2 Concentrations on main roads in Copenhagen compared to the EU's limit, with H.C. Andersens on the far left. The blue represents traffic emissions and the purple represents background emissions
Source: Luftkvalitetsvurdering Af RenLuftzone I København

The Copenhagen Municipality has tried to counter this air pollution problem by moving the air quality station away from the boulevard to manipulate the data (Personal Comm., Press-Kristensen 2014). A more useful solution came in the form of a law the Copenhagen Municipality has passed, to mandate the installation of a closed particulate filter in the exhaust system of every truck. Closed particulate filters remove more than 99% percent of the particle emissions for all particle sizes. Figure 10 shows the flow of a closed particulate filter. It consists of closed channels where particles are retained and incinerated. In Denmark, a closed particulate filter costs about €2,000 including installation. Despite the municipality's effort, it has yet to make a long lasting effect

due to the leniency of the law. Currently, the requirement of this effective filter is only for trucks and should be expanded to all cars. Additionally, these filters are never required to be inspected so there is a possibility that many trucks are driving around with ineffective filters. Without frequent and mandated car inspections, the increasing pollution cannot be limited (Press-Kristensen, 2014).

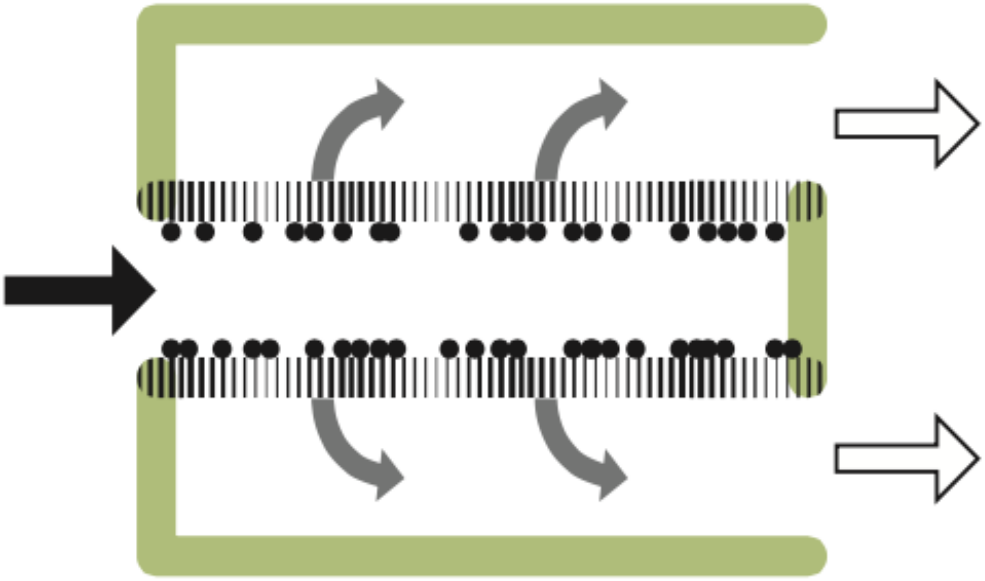

Figure 10. A closed particulate filter flow diagram with exhaust entering from the left and travelling through the filter, producing cleaner air.
Source: http://www.cleanaireurope.org/fileadmin/user_upload/redaktion/downloads/The_Danish_Ecocouncil/Clean_air_CPH_2014_UK.pdf

The pollution not only affects the environment but also the health of people traveling, working, and living near the boulevard. According to Morten Engelbrecht, a member of Letbaner.dk, a traffic group working towards promoting the idea of a light rail to the Copenhagen municipalities, there are several studies specific to Denmark that show negative health effects correlated with living close to vehicular traffic. These health effects include the increased risk of developing cardiovascular diseases, diabetes, chronic lung disease, blood clots, and premature death (Personal Comm., Engelbreacht 2015). According to our surveys conducted with the public, 29% believed that air pollution impacted them sometimes and 13% of the respondents said air pollution impacted them all the time.

Air pollution ranges from exhaust gases to dust created from the friction between asphalt and rubber tires (Personal Comm., Engelbrecht 2015). Ultrafine particles, such as soot, are the main suspect for many premature deaths and cardiovascular diseases in Copenhagen (Personal Comm., Press-Kristensen 2015). The World Health Organization (WHO) has classified diesel exhaust, which

is ultrafine soot particles, as a high-level carcinogen (Personal Comm., Press-Kristensen, 2014). Approximately 3,000 Danes die prematurely every year and tens of thousands become severely ill because of air pollution with ultrafine particles. Table 4 shows that Copenhagen alone accounts for 500 premature deaths annually due to ultrafine particles from the city's traffic compared to only 15 deaths caused by road accidents. People living or working near H.C. Andersens are not the only ones affected by traffic pollution. Surprisingly, drivers are more at risk of inhaling pollution for long periods of time compared to bicyclists since exhaust particles travel into vehicles where there is a lack of ventilation (Press-Kristensen, 2014). Furthermore, according to our public surveys, 25% of respondents believe that the noise pollution generated from automobiles on H.C. Andersens impact them all the time and 21% said it impacts them sometimes. Noise pollution causes adverse health effects such as hearing problems, sleep disorders, and cardiovascular diseases (Conserve Energy Future, 2013).

	Annual premature deaths in Copenhagen
Fine particles from all pollution sources *(Fine particles from sources in the city)*	500-600 *(65-70)*
Ultrafine soot particles from city's traffic	300-500
All particles (fine and ultrafine soot particles)	800-1100
Road deaths in Copenhagen	10-15

Table 4. Annual premature deaths caused by pollution verses road deaths in Copenhagen
Source: http://www.cleanair-europe.org/fileadmin/user_upload/redaktion/downloads/The_Danish_Ecocouncil/Clean_air_CPH_2014_UK.pdf

Finding 2: Traffic congestion on H.C. Andersens Boulevard follows distinct patterns in terms of timing and location, causing delays and barriers for pedestrians and bicyclists in the area

H. C. Andersens Boulevard is the main way for automobile commuters to get between mainland Copenhagen and the island of Amager, where there are many businesses and development is increasing rapidly (Personal Comm., Larsen 2015). Traffic congestion on H. C. Andersens Boulevard causes frustration for automobile users, pedestrians, and bicyclists. Of the respondents surveyed, 28% said that the cars on the road are always congested and 52% said that they consider the boulevard to be "sometimes congested." Furthermore, experts including Professor Per Homann Jespersen from Roskilde University and Mr. Kjeld Larsen, from the Council of Sustainable Traffic

claim that congestion on the boulevard is the worst in the city. This is because it takes longer to commute and travel compared to low density areas, and there can be unpredictable traffic delays. Traffic congestion lowers quality of life for drivers by affecting travel time. It also impacts pedestrians and bicyclists by creating barriers to movement (Personal Comm., Jespersen 2015).

Motor and car usage over the past 40 years is shown in Figure 10. Each red dot on the map is a location where automobile traffic was measured over time. The car usage inzone the outskirts of Copenhagen shown as "Kommunegrænsen" on the map is increasing which relates to increasing population and urban sprawl. In comparison, car usage in the Inner City of Copenhagen, shown as "Søsnittet" on the map, is decreasing. According to Ivan Lund Pedersen, another member of the Danish Council for Sustainable Traffic, this indicates that the majority of cars commuting through the Inner City come from neighborhoods in the outskirts of Copenhagen. This may mean that commuters to and from these neighborhoods contribute to the majority of traffic on the road when compared to those living and working within the Inner City (Personal Comm., Pedersen 2015).

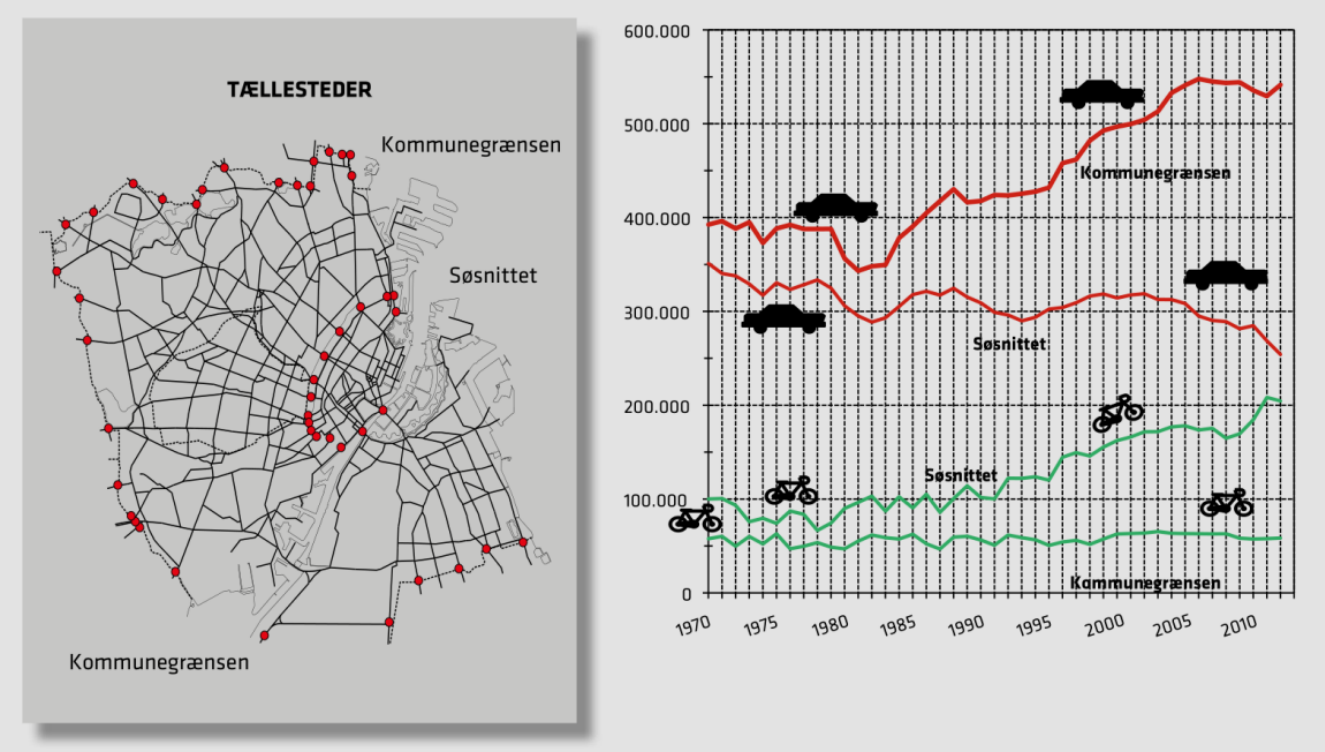

Figure 11. Number of cars from 1975 to 2010 in Copenhagen, with the red dots representing measurement locations, and Kommunegrænsen and Søsnittet indicating neighboring municipalities and the Inner City respectively
Source: Københavns Kommune, 2013

The peak congestion times, according to the survey, are 6:00 - 9:00 and 15:00 - 18:00, during which times vehicles are slowed and traffic delays are noticeable. Of the survey respondents, 49% felt that during the morning hours of 6:00 to 9:00, H.C. Andersens was the most congested, while 46% felt that the evening hours of 15:00 to 18:00 were the most congested.

We created two maps, shown in Figure 12, to visualize where there is congestion on H. C. Andersens Boulevard, based on the results of our direct observation. One shows morning rush hour, and the other shows evening rush hour. The colors represent how congested the entrances to each intersection are, based on our subjective assessments. We measured congestion based on how many cars were waiting, and how many got through each cycle of lights.

From our direct observation of H. C. Andersens Boulevard, we can draw some conclusions. During the peak hours, most of the traffic on H.C. Andersens goes all the way through Indre By, not turning off at intersections. However, there is a large amount of automobile traffic crossing H.C. Andersens Boulevard on the intersections with Nørre Voldgale and Hammerichsgade, and with Stormgade and Tietgensgade, which worsens the congestion. These two intersections are indicated by the blue circles on the map. On these intersections, there are long wait times for cars in turn-only lanes, because only a small number of cars can turn during each cycle of the traffic lights compared to those going straight. There is also pedestrian and bicycle traffic crossing the boulevard at every intersection, causing higher density and longer travel delays.

Aside from affecting travel time, congestion and construction creates obstacles for pedestrians and bicyclists. It is less convenient to cross H.C. Andersens Boulevard than other streets in Indre By, and as a result, people are more likely to alter their behavior based on traffic conditions. For example, the choice to visit certain restaurants and other business would be affected by the ability to access them. There are several intersections where pedestrians sometimes need to stop on islands between car lanes and wait for the cars to move before being able to continue across the boulevard. This means that buildings across the boulevard will be socially isolated and will suffer lower customer numbers (Personal Comm., Jespersen 2015).

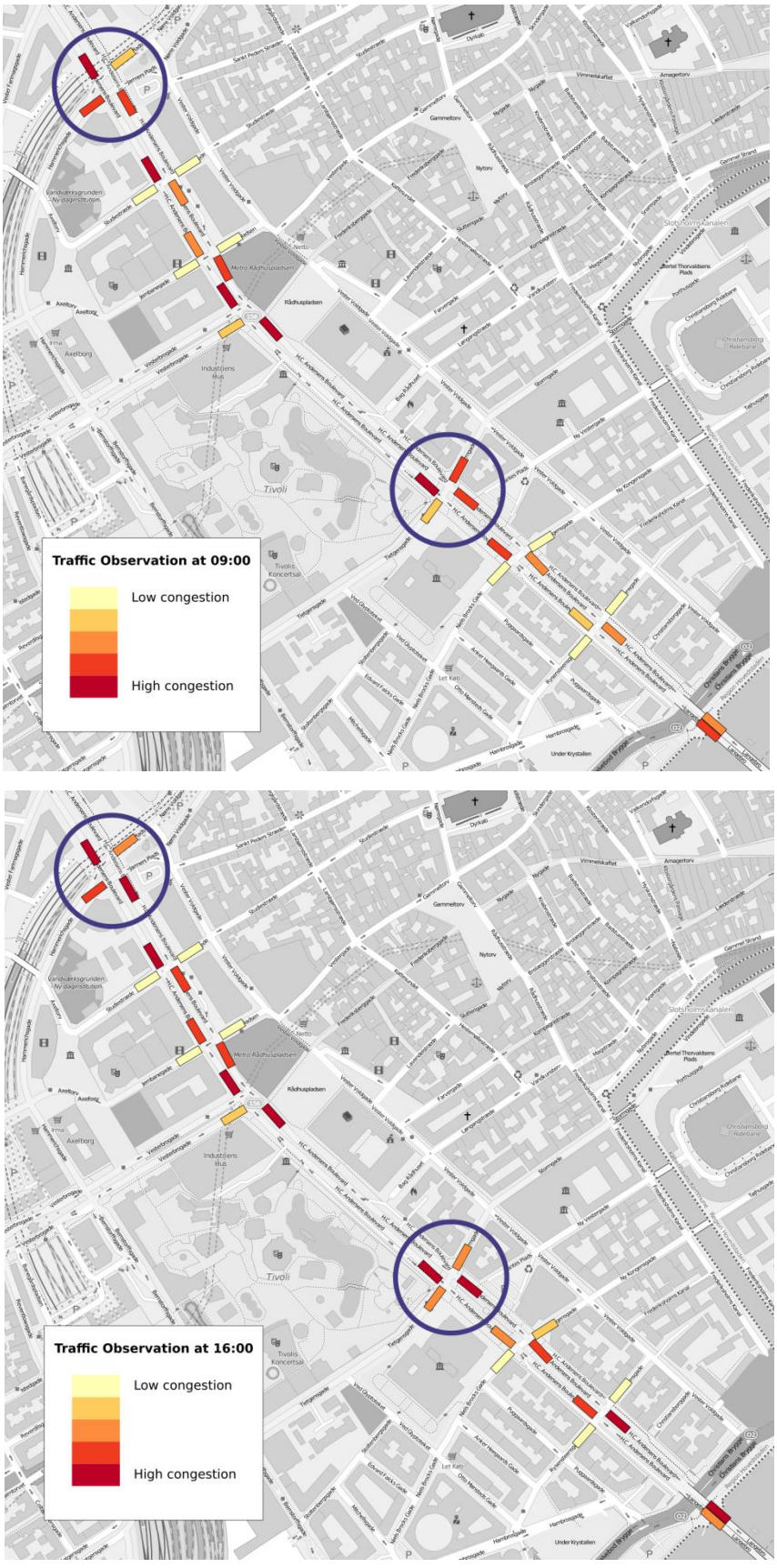

Figure 12. Maps showing traffic congestion on H.C. Andersen Boulevard in Copenhagen at 9:00 and 16:00 with colored blocks representing congestion levels. The circled intersections have high cross traffic

Finding 3: Implementing a tunnel would be a viable solution for air and noise pollution but it would be less effective in reducing the number of cars on the road

The results discussed in Finding 2 indicated that H.C. Andersens Boulevard is one of the main arteries in the inner city of Copenhagen and it suffers from congestion on certain times of the day. In order to address this problem, one of the solutions that has been proposed is implementing a road tunnel under H.C. Andersens Boulevard. Based on interviews with experts, public opinion surveys, and literature provided by experts, this finding discusses the advantages and disadvantages of constructing a tunnel and how it would impact traffic congestion as well as air and noise pollution. In order to determine if a tunnel was an appropriate solution, data was gathered to discover the traffic pattern in the area. The observations from finding 2 suggest that most car users use H.C. Andersens Boulevard to pass through the Inner City. Therefore, to alleviate congestion, the tunnel must address this popular route. If constructed, the tunnel would stretch from the intersection of Nørre Voldgade and H.C. Andersens Boulevard to Langebro bridge, as seen in Figure 13.

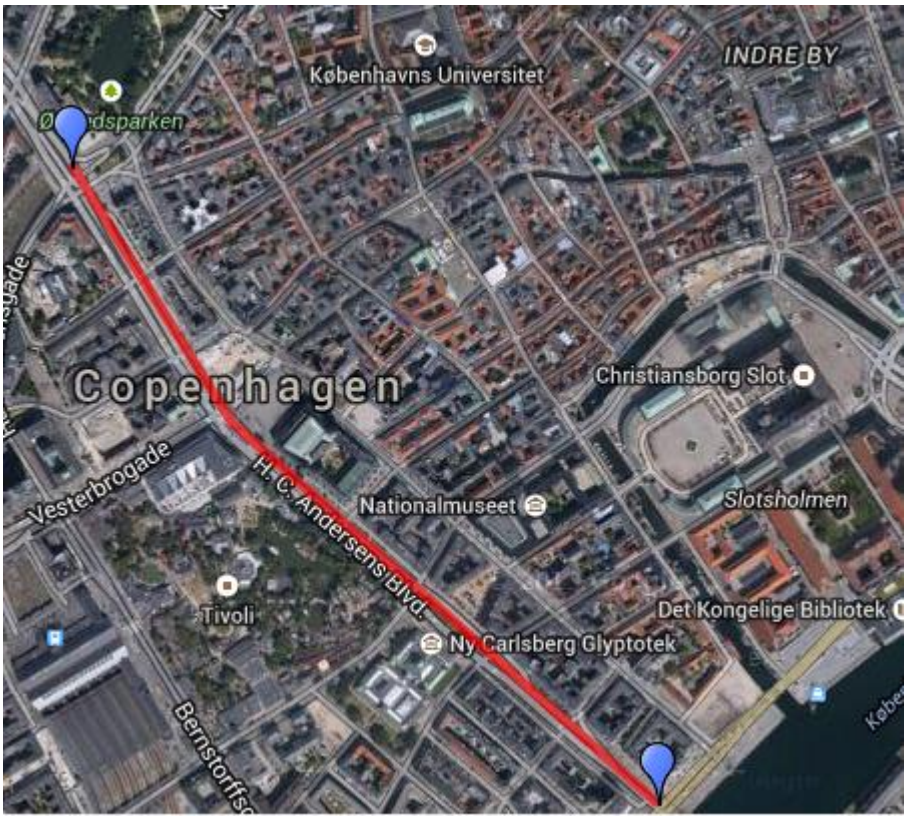

Figure 13. Map depicting extent of proposed tunnel which would replace H.C. Andersens Boulevard
Source: Scribblemaps.com

The first advantage of this tunnel is the improved traffic flow due to the lack of traffic signals. In fact, 68% of the 47 survey respondents believed a tunnel would help alleviate traffic congestion and 21% of the public surveyed stated that they are private car users and would use the tunnel. With all the traffic diverted underground, air quality on the surface would improve because the polluted air would be restricted to the openings of the tunnel. These concentrated areas would then be easier to treat (Personal Comm., Jespersen 2015). From the public survey, 93% of the respondents felt that tunnel would reduce air and noise pollution. Furthermore, when a method to filter the polluted air is implemented, the air from inside the tunnel would be released into the atmosphere as cleaner air, which would contribute to environmental betterment.

The tunnel we propose would replace the road, making room for a green space to be built on the surface. This will improve the air quality and the quality of life in the area by providing a recreational area and improve the aesthetics of H.C. Andersens Boulevard. Of the public surveyed, 86% thought that a green area would also improve the air quality. Vegetation and green areas absorb carbon dioxide and produce oxygen which helps convert polluted air into clean air.

With the elimination of the road on the surface area, motor vehicles will have to use the tunnel in order to pass through Indre By. Without a road on the surface to travel on, all the noise pollution generated from these vehicles would be eliminated from the surface (Personal Comm., Larsen 2015). Less noise pollution will lead to a better quality of life experience for the people who work and live in the area. The tunnel combined with a green space is a desirable solution for Copenhagen because it will help the city fulfill its climate plans (Personal Comm., Kabell 2015).
Taking into account these advantages, a tunnel may be a possible solution for the traffic condition in Indre By.

Currently, there is a report by Anders Jørn Jensen that proposes the construction of a different tunnel from Bispeengbuen to Ørestad Boulevard on Amager, with the tunnel passing under H.C. Andersens Boulevard as seen in Figure 13 below, represented by the colorful line. This tunnel corresponds with the possible tunnel for Indre By as mentioned before and validates the choice of intersections for the beginning and ending of our tunnel. Anders Jørn Jensen from Miljøpunkt Norrebro, the author of this proposal, argues that the construction of this 5,000 meter tunnel along with the construction of a green space on the surface in a large part of the city will allow for better access to the Inner City for the surrounding neighborhoods of Copenhagen.

The reduction or elimination of lanes on the surface will also allow for more residential and commercial properties to be constructed, which he argues to be important since 1,000 new inhabitants enter Copenhagen every month (Jensen, 2014).

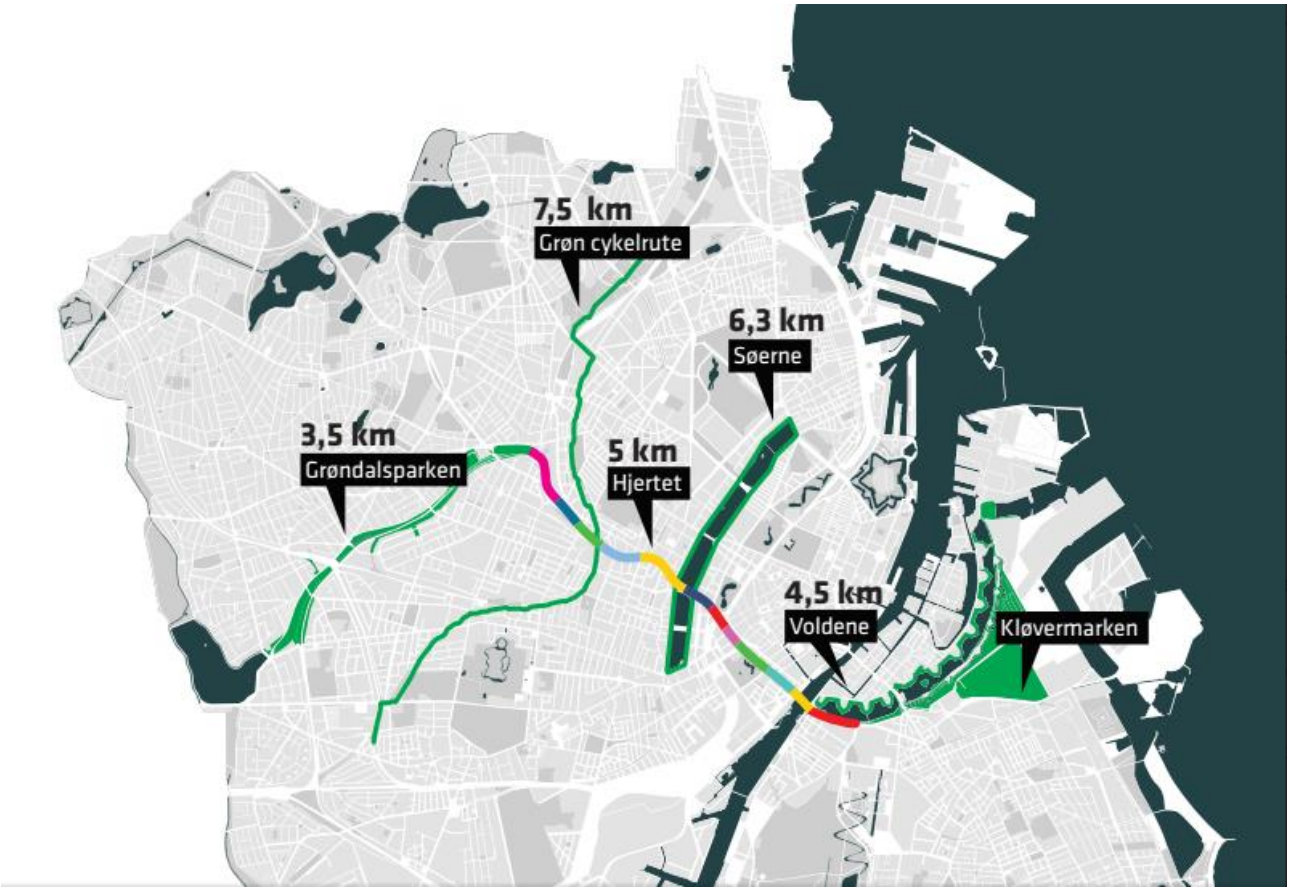

Figure 14. Map depicting Anders Jørn Jensen's tunnel proposal stretching from Nørrebro to Amager
Source: Indre By Revitalisering: Københavns Hjerte Fra Bispeengen Til Amager.

However, in order to thoroughly explore this solution, we must also discuss the disadvantages related to implementing a tunnel under H.C. Andersens Boulevard. To replace a main artery, a large scale tunnel must be constructed in order to handle the traffic capacity. Tunnel specifications must be met in order for it to be effective. If the required number of lanes, tunnel length, or height is shortchanged, this could lead to even more congestion than before (Personal Comm., Jespersen 2015).

The cost factor is also a disadvantage that comes with constructing a tunnel. Tunnels are one of the most expensive traffic infrastructure options and the municipality of Copenhagen currently does not have enough funds to support this project (Personal Comm., Kabell 2015). Furthermore, the Cityringen Metro line that is in progress has a Metro stop located just beside H.C. Andersens

Boulevard, in front of Rådhuspladsen, the town hall square. If a tunnel was constructed, it would have to be deeper underground than the Metro lines which currently sit at 40 meters deep (Copenhagen Municipality, 2015) and digging deeper underground for the tunnel would further add to the cost. The tunnel could not be built above the Metro because there are already train tracks for the intra city and regional trains that take up the space. Another concern with the construction of the tunnel is the unstable ground and the possibility of collapse. During the construction of the Metro, an important consideration was preventing the train tracks above the Metro from caving in (Personal Comm., Jespersen 2015). The same concern holds if a tunnel was built underneath the Metro.

Construction is made more difficult by the high number of pedestrians, cyclists, cars, and public transport lines in the immediate area. Constructing a tunnel will cause a large area to be closed off in an already dense space (Personal Comm., Larsen 2015). Of the public surveyed, 32% believed that implementing a tunnel will not alleviate traffic congestion and some people in that percentage, stated that it would make traffic worse during the period of construction. They believe that construction will have a contradictory impact because it will create barriers for traffic and pedestrians, similar to what they have experienced with the construction of the Rådhuspladsen Metro station.

It is evident that the addition of a tunnel will improve the continuous flow of traffic. However, this advantage of a tunnel can be perceived as a disadvantage for other criteria. If the tunnel makes using a car more practical and faster, it will provide an incentive for people to use private cars instead of public transportation or bicycles. Therefore, the tunnel would attract more car users into the Inner City. While a tunnel might alleviate traffic on H.C. Andersens Boulevard, it could lead to traffic in another part of Indre By (Personal Comm., Pedersen 2015).

The addition of a tunnel might attract more car users into the Inner City, due to its accessibility. With possible traffic building up in a different part of the city, air pollution will still be generated. This also might encourage people to buy cars because the tunnel would make traffic easier. Incentivizing car ownership would contradict the city's goal to be carbon neutral by 2025. Furthermore, the added green space on the surface might not be enough to improve air quality. Green spaces might help with macromolecules such as NO and CO_2, however they will not help reduce ultrafine particles that come from vehicle exhaust and black carbon. These ultrafine particles are the pollutants that are carcinogenic and lead to premature deaths and cardiovascular diseases (Press-Kristensen, 2015). Although most of the public surveyed believes that green spaces will help

air quality, 14% of the public do not think that green spaces will be enough to combat the air pollution in the area.

It is important to note that the tunnel and green space solution aims to move the traffic faster instead of discouraging private car use. Therefore, although this solution has the possibility to alleviate some traffic congestion, it will not reduce the number of private cars in central Copenhagen.

Finding 4: Other solutions have been proposed which focus on changing incentives for transportation in central Copenhagen by discouraging car usage and promoting public transportation

Evidently, the current situation in the Indre By and Christianshavn area is less than ideal. Aside from tunnels, which would be effective in improving air quality but not necessarily reducing traffic, other solutions must be examined. These solutions must be focused on improving transportation. This means that car usage must be discouraged and public transportation promoted. Solutions that have been proposed include a light rail system, congestion pricing, and reducing car access to the Inner City. The main complication with all of these solutions is the price of public transportation. Of the people surveyed, approximately 80% felt that the public transportation in the city is too expensive. It is currently more favorable to travel long distances by car than by train, especially when commuting from outer areas to Greater Copenhagen for work (Personal Comm., Pedersen 2015). This is because private cars are getting increasingly cheaper (Personal Comm., Larsen 2015). This is a problem because no matter what solution is implemented, a strong price incentive will influence ridership more than convenience. Furthermore, public transportation has an insufficient impact on traffic congestion when implemented alone. The new Metro lines will mostly attract people already using the public transportation system and only about 1% of car users (Personal Comm., Larsen 2015). When these car users are removed from the road, more space is created, attracting private car users from outside the city (Personal Comm., Pedersen 2015). As long as there is space on the road, there will be cars that fill in, and thus, any public transport solution that is proposed must be coupled with methods to lessen the incentive to drive (Personal Comm., Jespersen 2015).

One important solution is improving public infrastructure for bicycle users. This may mean improving light signals and extending the bicycle lane, thus lessening space for cars. With almost 50% of commuters in Copenhagen using bicycles (Denmark, 2011), it is likely that more people are willing to convert to bicycles if the routes and lanes are improved.

Another important solution that has been suggested is a light rail system. A tram system was implemented in Copenhagen in the past, but was closed in the 1970s. The system was shut down because it was not considered modern transportation and was being replaced by buses and private cars (Personal Comm., Jespersen 2015). With the increasingly negative impacts of vehicular traffic, the light rail system was proposed again in 2006 and is now in the planning stage. While almost all major European cities have a light rail system, Denmark is still lacking this infrastructure. The newly proposed light rail system will extend 27 km long with 27 stations and will connect 11 outer municipalities with the Greater Copenhagen area. This system is expected to serve approximately 14 million passengers a year and will be completed by 2021 (Kjaer Jensen, 2014).

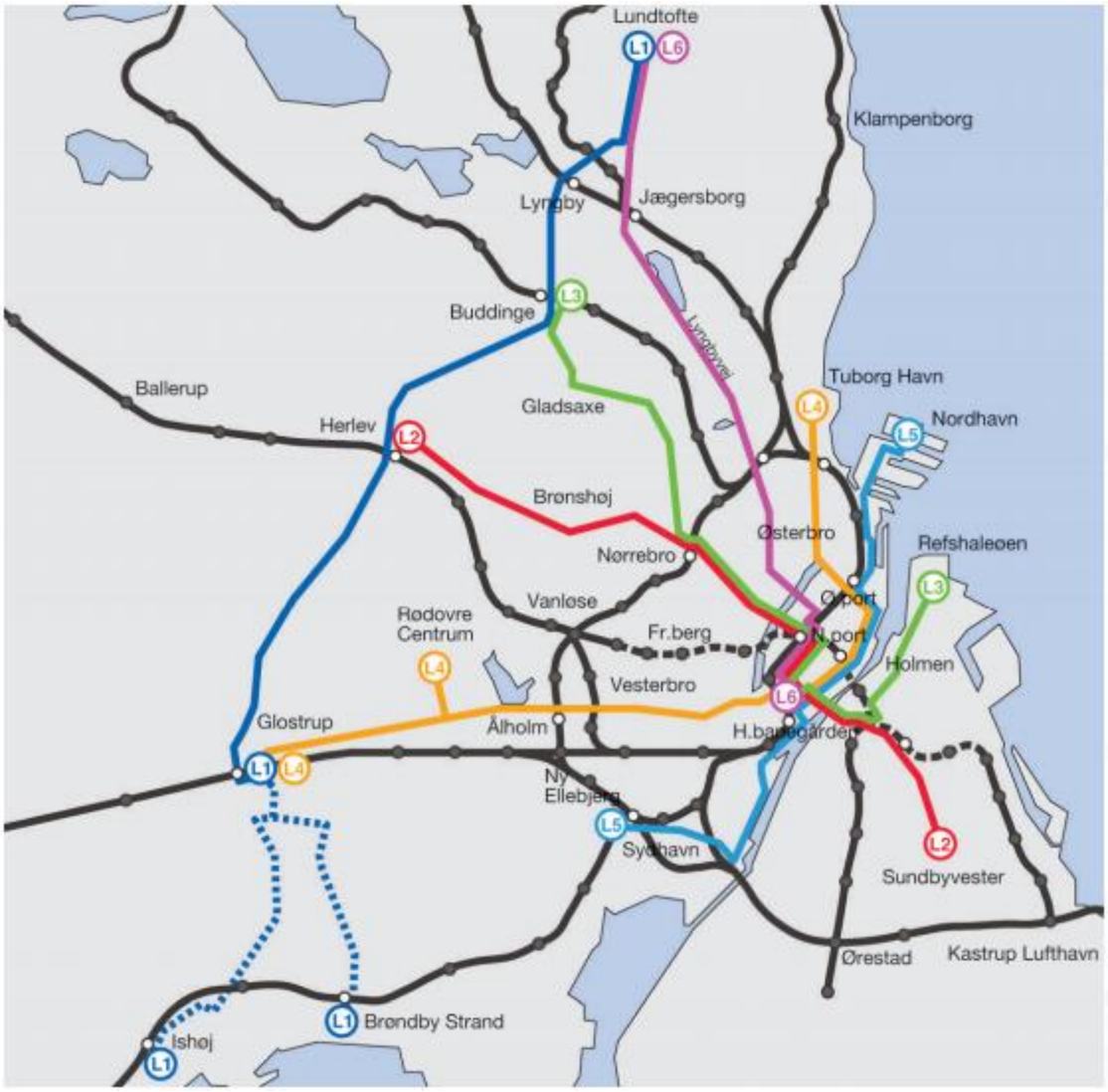

Figure 15. Proposed light rail system represented by dark blue line L1
Source: Letbaner.dk

With frequent services and improved connections between the Metro and the trains, the light rail could contribute to resolving the traffic congestion issues in the central area. This effect could be strengthened if the system had another line in Indre By with stations on H.C. Andersens Boulevard. Not only is it cheaper to build compared to a tunnel and metro infrastructure (Personal Comm., Larsen 2015), the system would reduce space for cars on the road and could potentially replace the bus lines which are plagued by traffic delays (Personal Comm., Kabell 2015). According to Morten Engelbrecht, implementing the system could cause a 20-50% drop in car traffic. Light rail systems are also attractive because the stations, just like bus stops, are all on the surface. For older passengers and passengers with children, this means that they don't have to go down several flights of stairs and thus, the accessibility of the system will cater to wider range of passengers (Personal Comm., Larsen 2015).

As mentioned earlier, it is important to consider ways to make private car usage more difficult along with making public transport easier. There are several possible ways to create disincentives. Congestion pricing on H.C. Andersens Boulevard was proposed in 2012. Though the idea is technically feasible and effective, there are several political and economic factors in the way of its implementation. When proposed in the past, congestion pricing was rejected because many politicians from the municipalities in the outskirts were afraid of not being reelected considering that many of their voters were car users (Personal Comm., Jespersen 2015). Many car users are against road pricing because of the high expenses they incur from private car usage. Taxation on cars in Denmark is 180% which means that people pay almost three times more for a car than if they purchased it overseas (Personal Comm., Larsen 2015). According to several private car users who were surveyed, car users feel that they are taxed enough already and do not want to be charged to use certain roads.

Technically speaking however, congestion pricing would be effective in reducing traffic volume as fewer people will want to use H.C. Andersens and unless drivers are willing to pay the fee, getting through Indre By by car will become more difficult (Personal Comm., Larsen 2015). Thus, congestion pricing will promote public transportation and bicycle usage.

Furthermore, if a tunnel was implemented, there is the option to combine it with a road pricing system so that car users are required to pay a fee for using the tunnel. While congestion pricing on a main road alone may not be appropriate for Copenhagen, another possibility lies in the combination of congestion pricing and a tunnel. For example, in Seoul, South Korea, a congestion pricing system was implemented in 1996 for personal cars traveling in two of the Namsan tunnels.

The traffic in the two tunnels at the time consisted of 90% private vehicles, most with only one occupant, which is very inefficient use of space and fuel. The charges were 2000 South Korean won, which is equivalent to $1.50 USD, and were in effect on weekdays from 7:00 to 21:00, and Saturdays, 7:00 to 15:00. These charges exempted cars with three or more occupants, and all non-private vehicles. In the first month, traffic volume decreased by 25% and thus, the congestion pricing was successful in changing incentives so that private car users switched to carpooling, public transportation, or other routes (Son & Hwang, 2002). Considering the success of this concept in reducing private car use in South Korea, Copenhagen could explore this option.

Another possibility is to make it more difficult to park a car in the Inner City. This can be done through reducing access to parking or making parking more expensive. This would be especially effective because if there are limited spaces to park, it would discourage people from using their car to enter the city and opt for other forms of transportation. As a result, this would reduce car usage in the area and increase car turnover rates (Personal Comm., Jespersen 2015). On the other hand there also several disadvantages to this solution. Shorter average parking times may generate more vehicles in the area and increasing parking fees may be met with the same resistance from car lobbyists against congestion pricing. Another possibility is the concept of 'park and ride' parking lots placed outside the Inner City. These parking lots would provide commuters with direct connections to public transportation into Indre By.

There are, however, other methods to lessen the incentive to drive. For example, eliminating lanes on major roads may discourage drivers from using the road (Personal Comm., Jespersen 2015). Although it may initially cause increased congestion, the inability to quickly move through an area will divert car users to other roads or may encourage people to switch to public transport or bicycles. An example of the success of lane removal is the Cheonggyecheon River in Seoul, South Korea. To overcome the flooding from the river, the government chose to cover it and convert the space into one of the largest arterial roads in the city. However, about 40 years after the construction of the road, problems of air and noise pollution and traffic congestion began to arise. Furthermore, the infrastructure proved to be insufficiently stable and thus posed safety hazards for users. In response, the government decided to restore the river and make the road a green belt in October, 2005. As a result, the average daily traffic volume in the city decreased by 170,000 cars and air pollution decreased by 35% (Rutherford, n.d.). This solution was paired with a new bus rapid transit (BRT) system and reduced parking spaces, all of which have contributed to a more environmentally friendly and less congested city center. If this principle was applied to H.C. Andersens Boulevard in

Copenhagen, similar effects may be observed. Obviously, instead of a river restoration, the road would be converted to a green space with plenty of room for pedestrians and bicyclists, and with a lack of lanes for traffic. If this solution was coupled with a light rail system, Copenhagen could be put on a promising path towards meeting their sustainability goals for carbon neutrality and urban planning. In the following chapter we discuss our recommendations for implementing a light rail system with several solutions to discourage car usage and our conclusions.

Figure 16. Before and after the restoration of the Cheonggyecheon River in Seoul, South Korea
Source: http://www.nclurbandesign.org/wp-content/uploads/2015/01/Cheonggyecheon-Stream-Before-After1.jpg

Chapter 5: Recommendations and Conclusion

Over the course of the past weeks, we have collected public opinion, interviewed experts, conducted direct observations, and other forms of research to come to a conclusion regarding air pollution and traffic congestion on H.C. Andersens Boulevard. There are significant problems with air pollution and congestion on H. C. Andersens Boulevard, and these problems are likely to get worse over time if no actions are taken. Air and noise pollution cause health problems, and traffic congestion lowers quality of life by introducing travel delays and creating barriers for movement.

In our opinion, implementing a tunnel would not be an appropriate solution for congestion alleviation on H.C. Andersens Boulevard because the disadvantages outweigh the benefits. Even though a tunnel will improve the flow of traffic, it will attract more car users to the tunnel and encourage drivers to enter the Inner City. Increasing car traffic will interfere with the city's goal to reduce carbon emissions and eventually reach carbon neutrality, thus we concluded that a tunnel would not be appropriate for Indre By. However, considering the tunnel proposal that stretches from Nørrebro to Amager, we recognize that a tunnel might be the preferred solution in order to promote continuity through the three areas. If a tunnel was to be constructed in Nørrebro and Amager, the exits into Indre By would cause more congestion and as a result, continuing the tunnel may be necessary. In this scenario, we recommend implementing congestion pricing to use the tunnel. We recognize that congestion pricing has been proposed and rejected in the past due to political complications. However, the only way the tunnel can reduce the number of cars in Indre By is in combination with congestion pricing. Furthermore, we also recommend the addition of a green space on the surface to better the commute for bicyclists and pedestrians as well as improve the air quality and aesthetics on H.C. Andersens Boulevard. We believe that only with the addition of congestion pricing and a green space will the tunnel solution work well for Indre By.

Furthermore, we think that constructing a light rail is a very effective solution. The current proposal only places the system in the outer neighborhoods. In order to be beneficial, the system must extend into Indre By. Implementing a light rail system on H.C. Andersens would reduce car lanes and replace bus lines since the system runs on exclusive lanes 90% of the time. Currently, the buses are plagued with delays and the car-free lanes for the light rail would allow faster and more direct transportation. Reducing car lanes would discourage car usage. This solution would only really be useful if public transportation prices were lowered. We found that approximately 80% of survey respondents believed that public transportation was expensive and therefore, lowering prices will

encourage more people to utilize the transportation systems. Considering that the light rail would improve the connections between other forms of public transport, it is important to ensure high ridership before putting further work into the system. It is also important to improve bicycle infrastructure in order to incentivize bicycle use. We recommend that bicycle lanes be extended, though we recognize that this is difficult to do in a highly dense area like H.C. Andersens Boulevard. It may be more effective to extend the bicycle lanes on the roads leading to H.C. Andersens which would discourage car traffic and encourage bicycle traffic into the Inner City.

We also recommend that steps be taken to reduce parking in Inner City. Reducing parking places in Indre By would provide disincentives for car usage. However, this may be difficult due to the new construction of several parking structures around H.C. Andersens such as Scala, a new building containing 180 parking spots on Axeltorv square (. If the structure was to be taken down, it would be lost of investment. Furthermore, the price of parking could be increased, but it may be infeasible due to similar political complications experienced by congestion pricing. The most effective option would be to implement a "park and ride" structure in an area outside Indre By and provide light rail connections into the city center.

Although we have provided several solutions to Miljøpunkt Indre By as seen in our recommendations in Appendix D, there are steps that need to be taken before these solutions can be considered. We recommend that Miljøpunkt Indre By propose their plan with this report as a supplement to the Copenhagen Municipality. The Copenhagen Municipality's budget should be taken into consideration when moving forward with these proposed solutions. Meanwhile, Miljøpunkt Indre By can take other approaches such as informing the public of high pollution rates on H. C. Andersens Boulevard. With the support of the public, the Copenhagen Municipality might be inclined to take further action.

It is clear to us that the actions that are being taken by the Copenhagen Municipality to combat air pollution at this time are not sufficient. Currently, the air pollution emitted on H. C. Andersens Boulevard exceeds the EU's limit. We therefore conclude that action must be taken to improve the air quality and congestion on H. C. Andersens by incentivizing less private car use and more public transportation. Hopefully, the solutions we proposed will push the city of Copenhagen one step closer to its goal of carbon neutrality in 2025.

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Appendices

Appendix A: Interview Questions for Kjeld Larsen and Ivan Lund Pedersen

1. Could you tell us a little bit about what you do and why is this project of relevance to you?
2. What do you believe are the main causes of the traffic congestion in the area?
3. How well or poorly is Indre By's traffic infrastructure handling the current patterns of traffic?
4. How does the traffic impact people who live, work or visit the area?
5. How will the construction of the Metro system impact traffic in the area?
6. How will the Metro impact the decision to implement a tunnel?
7. To what extent would a tunnel reduce the traffic congestion in the area?
8. Have roundabouts or congestion pricing been used in other parts of the city to alleviate traffic? If yes, where and how? Would these solutions be appropriate for Indre By?
9. Other questions that may be asked according to the interviewees' response.

Appendix B: Interview Questions for Expert

We are a group of students from Worcester Polytechnic Institute in the USA. We are working with Miljøpunkt Indre By-Christianshavn to understand the traffic situation in Indre By and Christianshavn and its impact on the air quality of surrounding areas by conducting interviews with the public. Our focus area is **H.C. Andersens Boulevard**.

One possible solution that we are researching is the implementation of a car tunnel beneath Åboulevarden/H.C. Andersens Boulevard and the development of a green space on top to reduce traffic congestion and improve the air quality. Our ultimate goal is to assess the appropriateness of a tunnel and your insights will be extremely useful. Your participation in this interview is **completely voluntary** and you may **withdraw at any time**.

Questions for Professor Per Homann Jespersen

1. Could you tell us a little bit about what you do and why is this project of relevance to you?
2. In your opinion, what do you think is the main causes of traffic congestion in the area?
3. What are the complications about building a tunnel with the metro in the area?
4. Do you think that the tunnel will improve air quality?
5. Where do you think all the private cars that are on H.C. Andersens Boulevard originated from?
6. Other solutions that we have researched include reducing parking in the inner city, light rail system, and congestion pricing. What is your opinion on these solutions?
7. In terms of air quality, would a green space around H.C. Andersens Boulevard reduce air pollution? Do you have other solutions in mind?
8. From our public surveys, we have discovered that the public is concern about construction if a tunnel was built under H.C. Andersens Boulevard. What is your opinion?
9. Other questions that may be asked according to the interviewee response.

Questions for Kåre Press-Kristensen

1. Could you tell us a little bit about what you do and why is this project of relevance to you?
2. What is the history of air pollution in the inner city, specifically H.C. Andersens Boulevard area?
3. Which areas in Copenhagen is the air pollution particularly problematic?
4. How is air quality impacting the health of central Copenhagen inhabitants?
5. If a tunnel was implemented under HC Andersens Boulevard, would it reduce both air pollution and noise pollution? To what extent would it improve air quality?
6. If a tunnel was implemented, would the construction worsen the air quality?
7. Do you know of any methods that could be used to filter the air pollution gathered inside the tunnel?
8. What are ultrasmall particles? Are there any known methods to dispose or filter those?

9. In your opinion, where should the tunnel begin and end?
10. Other questions that may be asked according to the interviewee response.

Questions for Mayor Morten Kabell (Email Interview)

1. What is your position in the Copenhagen Municipality?
2. What is your opinion on the current traffic condition in the Indre By and Christianshavn?
3. What changes do you want to see for the traffic in the area?
4. Some solutions that have been proposed include tunnels, light rail systems, reduction of parking, and congestion pricing. What is your opinion of these solutions?
5. What are some political complications that would arise if a tunnel was proposed?

Appendix C: Structured Questionnaire

We are a group of students from Worcester Polytechnic Institute in the USA. We are working with Miljøpunkt Indre By-Christianshavn to understand the traffic situation in Indre By and Christianshavn and its impact on the air quality of surrounding areas by conducting interviews with the public. Our focus area is **H.C. Andersens Boulevard**.

One possible solution that we are researching is the implementation of a car tunnel beneath Åboulevarden/H.C. Andersens Boulevard and the development of a green space on top to reduce traffic congestion and improve the air quality. Our ultimate goal is to assess the appropriateness of a tunnel and your insights will be extremely useful.

Your participation in this interview is **completely voluntary** and you may **withdraw at any time**. Your comments will be **anonymous** however we will ask you certain demographics question that will determine the purpose of people's commute in the area.

This survey will take **less than 5 minutes**.

Demographics

1. What is your gender?
   ▢ Female ▢ Male ▢ Other

2. In which age group do you belong?
   ▢ 18-25 years old ▢ 26-40 years old ▢ 41-60 years old ▢ >60 years old

3. In what area or district do you live?
   ▢ Nørrebro ▢ Vesterbro ▢ Østerbro ▢ Indre By
   ▢ Christianshavn ▢ Amager Øst ▢ Amager Vest ▢ Other
   If other, please specify _____

4. What is your main mode of transportation?
   ▢ Bus ▢ Private Car ▢ Walking ▢ Metro ▢ S-Tog
   ▢ Regional Train ▢ Bicycle

5. Why do you use HC Andersens Boulevard?
   ▢ Commuting to work ▢ Other
   ▢ Entertainment (ex. tourist attractions, shopping, eating)
   ▢ Commuting to school
   If other, please specify _____

Traffic Conditions

6. In your opinion, what time of day is H.C. Andersens Boulevard most congested?

▢ 6:00 - 9:00 ▢ 9:00 - 12:00 ▢ 12:00 - 15:00
▢ 15:00 - 18:00 ▢ 18:00 - 21:00 ▢ 21:00 - 24:00

7. In your opinion, how is the traffic condition of H.C. Andersens Boulevard?

▢ No problem ▢ Sometimes congested ▢ Always congested

8. The Cityringen Metro station is currently in construction and is scheduled to open in 2019. Do you plan to use the new Metro lines in place of other modes of transportation?

▢ Yes ▢ No ▢ Sometimes

9. In your opinion, do you consider current prices of public transportation (ex. Metro, regional train, S-Tog, buses etc.) to be…?

▢ Expensive ▢ Reasonable ▢ Inexpensive

Air Quality

10. To what extent does the air pollution generated from automobiles on H.C. Andersens Boulevard impact you?

▢ Never ▢ Rarely ▢ Sometimes ▢ Often ▢ All of the time

11. To what extent does the noise pollution generated from automobiles on H.C. Andersens Boulevard impact you?

▢ Never ▢ Rarely ▢ Sometimes ▢ Often ▢ All of the time

12. Do you think implementing a green space around H.C. Andersens Boulevard would improve air quality?

▢ Yes ▢ No

Tunnels and Other Solutions

13. If you are a private car user, would you use a tunnel built under H.C. Andersens Boulevard and where would you exit? Multiple answers possible.

- ▢ Not a private car user
- ▢ Yes, and I would exit in Indre By or Christianshavn
- ▢ Yes, and I would exit outside Indre By to _____
- ▢ No, I would not use it

14. If you are not a private car user, how would your commute be with the implementation of a tunnel under H.C. Andersens Boulevard?

- ▢ Much Worse
- ▢ Worse
- ▢ About the Same
- ▢ Better
- ▢ Much better
- ▢ I am a private car user

15. If there was a fee for using the tunnel, would you use it?

- ▢ I would not use the tunnel regardless
- ▢ I would not use the tunnel if there was a fee
- ▢ I would use the tunnel if there was a fee, and I would be willing to pay ___

16. Do you think a tunnel would improve air quality and reduce noise pollution?

- ▢ Yes
- ▢ No

17. Do you think a tunnel would reduce traffic congestion?

- ▢ Yes
- ▢ No

Appendix D: Table of Recommendations

Solutions	Benefits	Drawbacks	Impact on H.C. Andersens Boulevard
Tunnel and green space	• Reduces air and noise pollution on the surface • Increases traffic flow	• Construction of a tunnel involves high costs and creates barriers for pedestrians and bicyclist • Worsen traffic congestion during construction • Encourage car drivers to enter the city	Implementing a tunnel under H.C. Andersens Boulevard would reduce air and noise pollution but in the long term it will impede the city's goal of becoming carbon neutral by 2025 because it will not reduce the number of cars entering the area.
Reducing public transportation prices	• Commuters more likely to use public transport • Decreases private car use	• Overcrowding of public transportation • Less revenue for the government	80% of survey respondents think that the current prices are expensive. Reducing the prices would encourage more commuters to utilize the public transportation system on H.C. Andersens Boulevard.
Light rail system	• Discourage car use by reducing car lanes • Lower in cost compared to tunnels • Easier access compared to the Metro • Replaces bus lines	• The reduction of car lanes might cause more traffic congestion • Reduces street parking for car users	There is currently a proposal to implement the light rail system in the outskirts of Copenhagen. If the light rail could be extended into the city, it would connect the outer neighborhoods with the Inner City. It would also reduce lanes for car users within Indre By. This could replace existing bus lines, which would further help the city in reaching its climate goal.
Reducing lanes	• Discourage car use	• Possibility of creating congestion	Technically speaking, lane reduction has a high possibility in discouraging car use. However, since H.C. Andersens is a main artery, reducing lanes might increase congestion if it is not coupled with another solution, such as improving public transportation or bicycle infrastructure around the Inner City.

Reducing incentives to park by reducing spots or increasing prices	• Discourage car owners to drive into the city	• Less revenue for the government • Political opposition	Although technically this solution would discourage car use, it would be difficult to implement in Indre By because of the current construction of the parking structure, making it a lost investment if the parking structure would just be demolished. Instead, a park and ride system constructed outside Indre By coupled with a light rail system that provides transportation into the city would be effective.
Improving bicycle infrastructure by extending bicycle lanes	• Encourage biking as a form of transportation • Reduces lanes for private car use	• The reduction of car lanes might cause more traffic congestion	This solution would not be suitable for H.C. Andersens Boulevard because the area is already highly dense and there would not be enough space however, extending bicycle lanes in the roads leading to H.C. Andersens may be effective.
Congestion pricing	• Discourage car use • Promote public transportation use • Creates revenue	• Increase costs for car users • Political opposition	This solution has been brought up before but due to political complications, it has not been implemented. The solution may be effective to couple with a tunnel, if it was constructed.