



**WPI**



# Air Pollution on Prinsessegade: A Global Problem on an Ultrafine Level

## Interactive Qualifying Project

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Strategies to reduce traffic congestion	Emily, Nicole, Ian	Yao, Emilee
Efforts in Copenhagen to prevent air pollution	Emily, Nicole	Ian, Emilee
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Assessment of strategies	Nicole	Yao, Emily
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Assessment of strategies based on informal observation, public and expert opinion	Emilee	Yao, Nicole
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Finding 2: Poor infrastructure and the city's plan for future developments creates a road with increasing problems.	Emily	Nicole, Ian
Finding 3: Christiania contributes to the traffic congestion in the area and hinders potential solutions.	Nicole	Emily, Emilee, Ian
Finding 4: Political pressure has hindered efforts to implement effective anti-car traffic solutions in Copenhagen.	Ian	Yao, Nicole
Finding 5: Bicycling is the most common mode of transport and there are various factors that influence transport choice.	Yao	Ian, Emily
Finding 6: Providing monetary incentives for alternative transport use is the highest rated solution for reducing traffic congestion	Yao	Ian, Emily
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<b>Recommendations</b>		
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# Abstract

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Traffic congestion is a major contributor to air pollution, which can cause detrimental health effects, especially in children. Traffic congestion and air pollution is a critical issue on Prinsessegade, a narrow through-street with many schools in Copenhagen's Christianshavn community. Our team explored potential strategies to the congestion through interviews with locals, experts, and a community discussion regarding our initial conclusions. We combined our initial research with analyses of these findings to present final recommendations to Miljøpunkt Indre By-Christianshavn.

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# Introduction

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In this section, we establish the central problem this project was intended to address and review the background information that is particularly pertinent and vital to understanding the context of our project. More detailed background information can be found in the section titled “Background” in the supplemental material document.

Air pollution is a contributing factor to cardiovascular disease, which is identified by the World Health Organization European Region as the world’s single biggest health risk and the leading cause of death worldwide (Wichmann et al., 2013). Air pollution is defined as all matter emitted into the atmosphere that can potentially cause harm to humans and the environment (Wu et al., 2012). Diesel vehicles are one of the primary contributors to the air pollution that causes these health problems. Particulate matter (PM) and nitrogen oxides (NO<sub>x</sub>) are among the most significant harmful pollutants within diesel exhaust and cause major health complications (Reşitoğlu et al., 2015).

These complications introduce adverse effects to both the respiratory and cardiovascular systems. Respiratory effects include the exacerbation and potential development of asthma, chronic obstructive pulmonary disease (COPD), lung cancer, airway inflammation, and respiratory infections (Kurt et al., 2016). Cardiovascular effects include various diseases such as vasoconstriction and arterial stiffness, myocardial infarction, myocardial ischaemia, ventricular arrhythmia, and atherosclerosis (Langrish et al., 2012). Mitigating air pollution would spare lives and improve the overall health of people and the environment (Vendelbjerg, 2016).

A major concern in regards to air pollution is the effect it has on children. Excessive exposure to air pollution is dangerous for everyone, but it is especially dangerous for children, who are more sensitive to air pollutants due to their developing lungs (Radim et al., 2013). Figure 1 below also illustrates how air pollution can affect children more severely than adults (Kenagy et al., 2016).



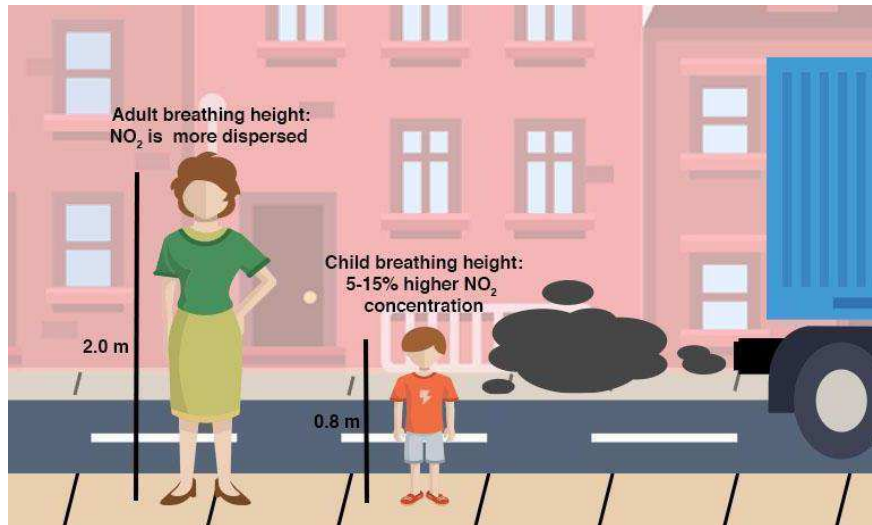


Figure 1: Air pollution has a more severe impact on children than adults

## Road traffic as a major contribution to air pollution

The most significant contributors of air pollution fall within the category of transportation sources, which account for 25% of the particulate matter associated with urban air pollution (Karagulian et al., 2015). All vehicles that run on fossil fuels emit harmful air pollution, although different types of vehicles emit different types of pollutants. In particular, diesel vehicles emit a large amount of particulate matter, which has been linked to respiratory and other related health problems (Bujak-Pietrek et al., 2016).

While transportation is the most significant source of air pollution, the various conditions of traffic flow also influence the concentration of air pollutants produced by vehicle exhaust. Road congestion results in a higher concentration of air pollutants emitted into the atmosphere (Raheem et al., 2015). The lower vehicle speeds associated with high volumes of traffic create longer travel times for vehicles and subsequently result in a higher concentration of pollutant emissions in the associated area (Zhang & Batterman, 2013). Such speeds also reduce the airflow that scatters nearby particles, hindering the dispersion of air pollutants in the atmosphere. This reduction in particle dispersion heavily concentrates air pollutants in high traffic areas on a regular basis (Zhang & Batterman, 2013). Road congestion also disrupts the flow of traffic; the sudden braking and accelerating associated with congestion produces higher emission rates than those of a vehicle traveling without any traffic disruption (Bujak-Pietrek et al., 2016). Several examples around the world have demonstrated that pollutant concentrations drop when urban traffic sharply falls (through voluntary or involuntary means), proving that resolving traffic congestion is vital to combating urban air pollution (Raheem et al., 2015).

## Strategies to reduce traffic congestion

In this section, we will review strategies to mitigate traffic congestion that we have identified through our research. A more detailed version of this information can be found in our supplemental material. Based on our research of these strategies' logistics and various success other cities have experienced with them, we determined these could feasibly reduce traffic congestion, and therefore, air pollution. Below is a description of each strategy we investigated in our project as well as any relevant examples.

### 1. **Road closure**

Research has demonstrated that road closure is an effective method in mitigating traffic congestion, which was exemplified in Paris when the city closed a main road along the Seine and, unexpectedly, the traffic in other locations was minimal, as people adapted to new routes (Gréco, 2016). When the road along the Seine was closed and commuters were forced to seek alternate routes, Mayor Anne Hidalgo announced that "It was thought that it would have been six months to a year before we saw an adaptation of the behavior" (Gréco, 2016), yet the resulting reduced traffic congestion indicates the pedestrianization of this road has had minimal effect on traffic elsewhere (Gréco, 2016). In order to implement a strategy such as closing off the road completely, there needs to be parallel streets or alternate routes that can be taken to get to various locations along the road. This is especially necessary for emergency vehicles and police cars. There are alternative options to closing off the road completely, such as converting the road to bike and pedestrian-only lanes or to block off the road to through traffic. With the latter solution, public buses, residential vehicles and emergency vehicles are still able to pass through. Also, in order to successfully implement a bike and pedestrian-only road, there should be sufficient evidence of existing bike and foot traffic.

### 2. **Improved public transportation options**

Public transportation should be sufficient to get commuters where they need to go. Some places lack enough public transportation options to meet the needs of the cities they serve. If public transportation is limited in certain areas, commuters might be more likely to use private cars to reach their destinations. In this case, it would be best for transportation companies to expand their transportation networks to serve more people. However, there should be a heavy enough flow of traffic in an area to justify implementing more public transport options. Updated public transportation options are only worth consideration if a significant need for improvement exists.

### 3. **Incentivized alternative transit**

An alternative to adding more public transportation options is to attempt to increase the use of existing options. Incentivizing public transport has been implemented in Sacramento, California, where the city provides bonuses to commuters when they switch from a private vehicle to public transportation. One non-profit organization, YOLO Commute, even provides fiscal incentives to those who walk or ride bikes to work (YOLO Commute, 2017). However, studies

have shown that convincing commuters to change their habits is very difficult in practice (Javid et. al, 2016). In order to implement a solution such as this, some education regarding the importance of using public transportation is necessary. In addition, there needs to be funding for providing fiscal incentives.

4. **Reversible lanes**

Reversible lanes are lanes that switch direction depending on the heaviest flow of traffic. In order to implement a solution such as reversible lanes, there needs to be an established higher flow of traffic in one direction. This solution requires that there is an alternative route for the small amount of traffic that still needs to travel in the opposite direction. In order to implement a solution such as reversible lanes, there needs to be an established higher flow of traffic in one direction. Typically reversible lanes are used on large highways where several lanes can be reversible and still enable access for emergency vehicles to travel against the flow of traffic if need be (Trepanier et al., 2011).

5. **Education**

In order to consider education as a potential strategy, there should be an established knowledge gap for the public with regards to traffic congestion and its effect on air pollution. Paris has used this strategy extensively, through online programs that estimate the average number of NO<sub>2</sub> particles emitted by a person's car when they provide information on their daily commute. The same site offers interactive information geared toward children about the severe health effects of air pollution (AirParif, 2010).

6. **Green wave**

In order for signal timing techniques such as the green wave to be considered as a potential strategy to reduce traffic congestion, there are certain requirements regarding the existing road infrastructure. The street should have a series of three or more traffic lights in succession, and therefore the green wave is most applicable to roads with higher traffic volumes. The green wave addresses the issue of traffic lights interrupting a constant flow of traffic. Cars that are continually stopped at red lights emit four times the pollution when compared to cruising (Vos, 2014). The green wave would be applicable when vehicles are unable to travel through multiple intersections without being stopped at various traffic lights.

7. **Stricter policies regarding air pollution**

Implementation of Limited Traffic Zones (LTZ) and stronger policies on Low Emissions Zones (LEZ) are two strategies to try and decrease the air pollution in an area. A Limited Traffic Zone can specifically forbid any non-local vehicles or those with insufficient filters on a specific road or in a particular region, while a Low Emission Zone prohibits vehicles who do not meet specific standards, such as restricting vehicles who are not Euro 4 standard or higher.

8. **Road pricing**

A strategy for reducing road traffic would include road pricing. Not only does road pricing

discourage private vehicle usage, but also provides funding that could be used for transport, infrastructure, and environmental projects. Two examples of road pricing are toll roads and congestion pricing.

a. **Toll Roads**

Road pricing can be found in many different forms; the most popular form of road pricing is the implementation of toll roads. A general characteristic of toll roads is the existence of alternative routes that motorists can use to circumvent a toll booth and still reach their destination. The toll road would serve as the easiest option of travel at a cost, whereas alternative routes would typically involve longer travel distance to reach the same destination (Santos, 2006). To consider toll roads as a solution, the existing infrastructure should have sufficient space to construct a toll booth. Alternatively, if the infrastructure is insufficient, cameras could be used to monitor and charge vehicles coming on to the street.

b. **Congestion pricing**

Another form of road pricing is congestion pricing. Congestion pricing is not associated with any specific road or intersection, instead it encompasses areas with high traffic volume such as the city center. With the use of traffic cameras to record license plates, vehicles would be charged upon entering a specific zone (Santos, 2006).

## The problem with air pollution in Copenhagen

Although Copenhagen is generally perceived as a global leader in sustainability, the city has battled the European Union (EU) on air pollution regulation disputes for nearly a decade. Since 2010 Copenhagen has consistently failed to meet the EU cut-off limits for NO<sub>2</sub>. Even after asking the EU for a 5-year extension until 2015 to reduce the NO<sub>2</sub> levels, Copenhagen proved unable to meet the NO<sub>2</sub> limits. As a result, the EU drafted a letter to the Danish state in April 2016, reprimanding them for refusing to establish and enforce stricter regulations on trucks and diesel vehicles (Weaver, 2016). In addition, while Denmark meets the standard for larger particulate matter values after implementing low emission zones, the country currently lacks any regulations for ultrafine particles (Ministry of Environment and Food of Denmark, 2014). A timeline of events pertaining to this is illustrated below in Figure 2.

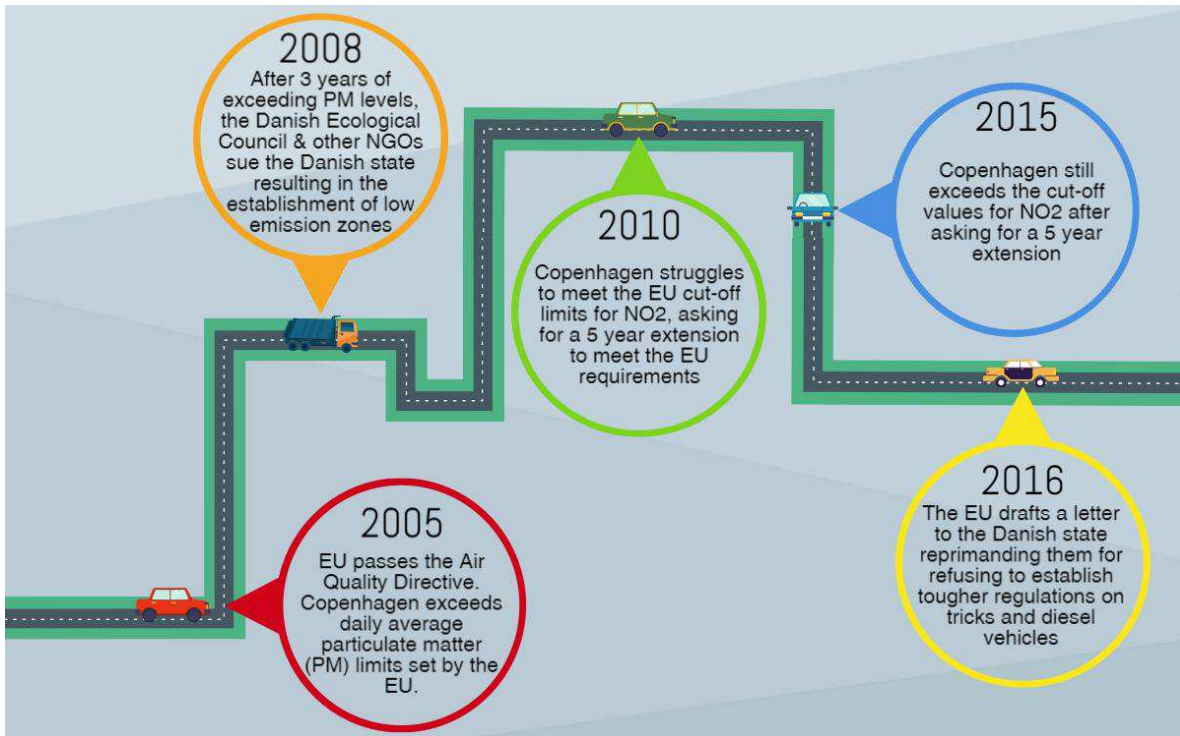


Figure 2: Timeline of Denmark's clash with EU regulations

### The problem in Christianshavn

Christianshavn is a neighborhood on an island within Copenhagen's Indre By (Inner City) district. In this neighborhood, there are two major roads, Torvegade and Prinsessegade, which are used to travel the width and the length of the island (Figure 3). Unfortunately, as these two roads are the primary means of transport, a large buildup of traffic accumulates in the streets (M. Spang Bech, personal communication, March 13, 2017). Christianshavn has also experienced infrastructure changes and a steady increase in population since the 1960s (Das & Jingzhong, 2011), and these developments add to the congestion, and consequently to air pollution. As a direct result of this congestion, Aarhus University and the Danish Centre for Environment and Energy studies have revealed that Christianshavn is ranked the 35th most polluted location out of 98 Copenhagen measuring stations in NO<sub>2</sub> levels (Ellerman et al., 2016).

There are several reasons locals and visitors alike are inclined to travel on Prinsessegade, as illustrated by the points on the map in Figure 3. Popular destinations include a church, schools, the neighborhood of Christiania, and the Opera House. Christianshavn has three public transportation options: a Metro station, a bus line, and a harbor bus (ferry). The Metro station is in southern Christianshavn, and the 9A bus transports passengers north via Prinsessegade. Copenhagen also currently has three harbor bus routes for sailing in both directions through the main harbor

(Havnebusserne, 2015). There are several stops along the way, and one of the stops is the Opera House. The 9A bus and the infrequent harbor bus are the only public transportation routes to northern Christianshavn, and this limits the area's accessibility to commuters or residents departing from the Inner City or Amager. Prinsessegade's narrow car and bicycle lanes produce troublesome road conditions for drivers and cyclists. Travellers wishing to avoid Prinsessegade to reach northern Christianshavn must drive through Torvegade to Amager, traveling on a road around the island to approach Christianshavn's attractions from the north.

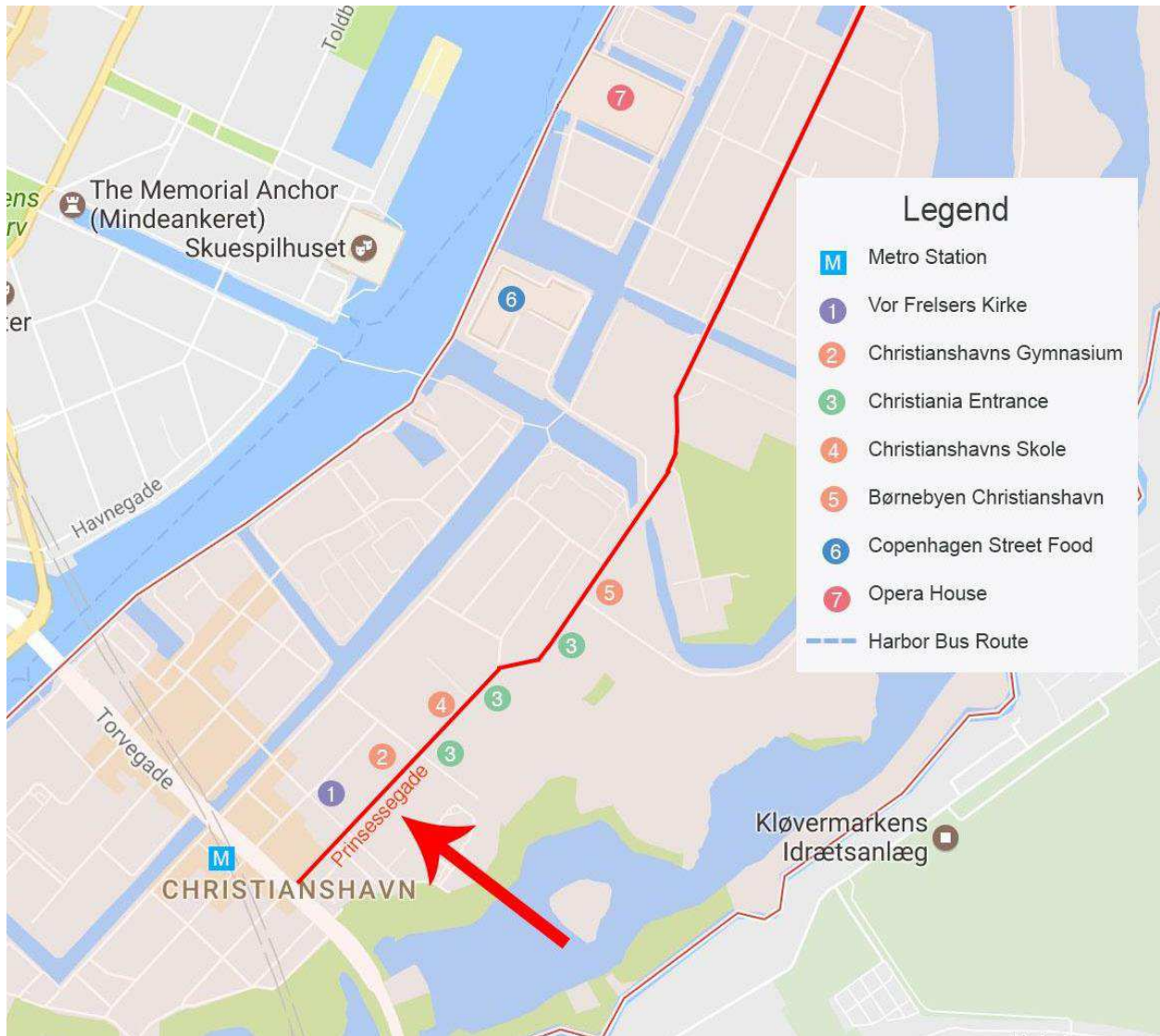


Figure 3: Map of Christianshavn (Google Maps, 2017)



## Efforts in Copenhagen to prevent air pollution

Copenhagen has considered some of the previously stated strategies in an effort to alleviate traffic congestion. The Danish Ecological Council published a report in 2014, “Clean Air Copenhagen,” which discussed programs such as road pricing and green taxes in order to control and decrease air pollution. However, Copenhagen has not yet implemented any of these programs due to media criticism and lack of public support (Press-Kristensen, 2014). Another article summarized a public poll determining that only 35% of drivers supported road pricing and only 12% of individuals reported that the system would convince them to reduce their driving (“Panel Wants Car Owners,” 2013).

The Ecological Council suggested an alternative strategy: tracking citizens’ vehicular travel and charging them per kilometer traveled in their personal vehicles (Press-Kristensen, 2014). Though proposed as a simpler solution, this strategy often lacks public support due to its intrusion into the lives of individual drivers. Nevertheless, Copenhagen has utilized “green taxes,” including a registration tax on new cars. This allows the city to influence “the size, vehicle age, composition and thereby the pollution” and is a disincentive to car ownership (Press-Kristensen, 2014). Many of these actions for decreasing air pollution, as well as establishing low emission zones, have allowed non-governmental organizations (NGOs) to apply pressure on the government (Press-Kristensen, 2014).

Miljøpunkt Indre By-Christianshavn, located within the Indre By district, is one such NGO and one of many Agenda 21 centers across the globe that work towards establishing environmental sustainability (Miljøpunkt Indre By-Christianshavn, 2012). Miljøpunkt Indre By-Christianshavn collaborates with other environmental companies and organizations, as well as the Copenhagen community in this continuous effort (Miljøpunkt Indre By-Christianshavn, 2012). The NGO includes the mitigation of air pollution as one of its most important missions.

## Strategies in Christianshavn

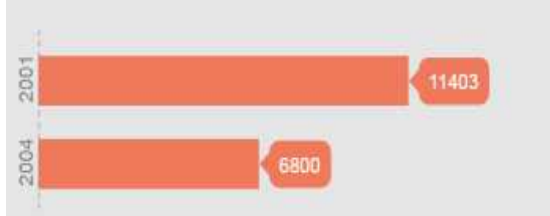
Miljøpunkt has worked to mitigate the air pollution problem in the Indre By and Christianshavn areas through events such as the Car-Free Sunday. They coordinated with the municipality during the Copenhagen Half Marathon in order to extend the hours forbidding cars from certain roads into the evening (Rychla, 2016). As a result, Copenhagen restricted vehicular access to various main roads in the city center from 15.00 to 21.00, and Miljøpunkt worked to extend this restriction to areas of Christianshavn. The city also offered events and activities throughout its streets to encourage citizens to take advantage of



Figure 4: Ultrafine particles per cubic cm on two streets in Copenhagen

and enjoy the car-free roads (Rychla, 2016). The results of the UFP counts on this day are illustrated in Figure 4.

Another example of a municipal effort to relieve traffic congestion in Christianshavn occurred with the implementation of the Prinsessegade bus gate. The bus gate, installed in 2003, was designed to restrict traffic along a section of the street using barriers that only residents, buses, emergency vehicles, and larger vehicles with a waiver could pass. The restriction of vehicular travel on the street proved beneficial to the community, whose residents were concerned about the effects of air pollution from traffic congestion on the children that attend school on Prinsessegade (Ravndal, 2016). The changes in traffic after the installation of the bus gate are depicted in Figure 5.



*Figure 5: Number of cars passing Frelsers Kirke before and after road closure*

Although the construction of the bus gate addressed the traffic concerns of Christianshavn residents, efforts to remove the bus gate still existed. In 2016, the bus gate was removed by the city council of Copenhagen. Lord Mayor Jensen provided two arguments for why the road was reopened: 1) it would link Christianshavn to the new developments better and 2) it would reduce the carbon dioxide (CO<sub>2</sub>) levels that were higher from passenger cars taking the longer route through Amager (Lund, 2015). There were considerations to make the road a one-lane street, but this received opposition from the police who wanted easy access to Christiania.



# Methodology

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The goal of this project was to identify viable solutions to air pollution on Prinsessegade by evaluating the effectiveness of existing strategies in the context of Copenhagen and specifically this street in Christianshavn. In order to achieve this goal, we devised the following objectives:

1. Assess the viability of identified air pollution and traffic congestion strategies within the context of Prinsessegade, a major street in Christianshavn.
2. Explore public and expert opinion on strategies deemed viable for the Prinsessegade context.

The following chapter summarizes our approach to address these objectives and accomplish the goal of the project. An extended version of our methodology can be found in “Detailed Methodology” of the Supplemental Material document.

## Objective 1: Assess the viability of identified air pollution and traffic congestion strategies within the context of Prinsessegade, a major street in Christianshavn.

From our background research, we identified a variety of strategies to mitigate traffic congestion that have been successful in other parts of the world (described in the section titled “Strategies to reduce traffic congestion”). These strategies require certain components in order to be implemented and to be considered successful. We assessed each strategy initially by identifying what factors are necessary for the strategy to be put into effect, and then assessing them within the context of Prinsessegade. Although obtaining public and official approval of these strategies is a vital aspect of determining if a strategy is feasible, we sought to focus on strictly the technical requirements for our initial assessment. In order to achieve this objective, we performed informal observations to determine if Prinsessegade and the region of Christianshavn fit the characteristics that are necessary for each potential solution. Figure 6 details the set of strategies that we included in this initial analysis which are detailed in the introduction.

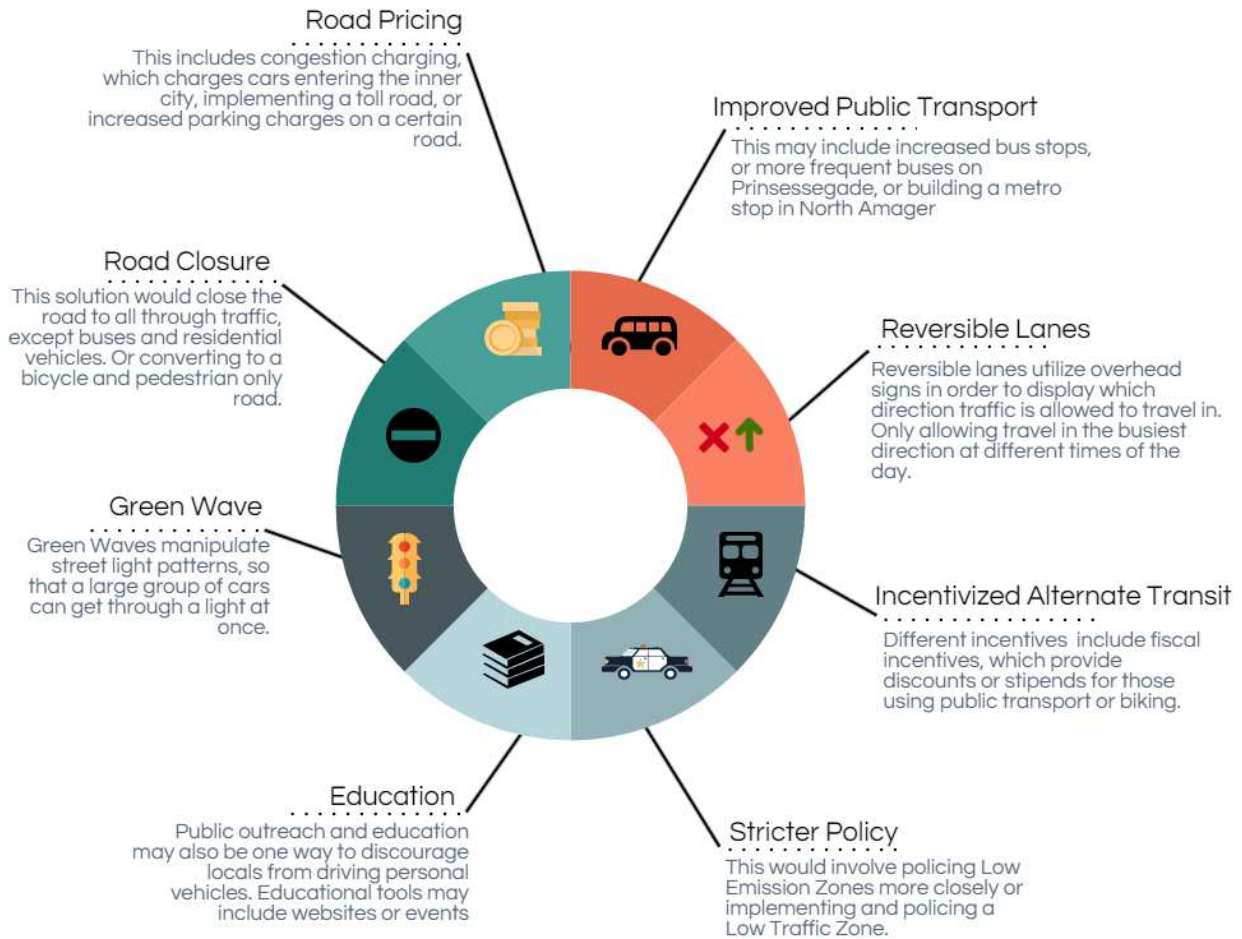


Figure 6: Strategies to Mitigate Traffic Congestion

### Informal observation

During the early stages of our project, we conducted informal observations focusing on the variety of requirements established in the previous section. The strategies that we considered all have factors that need to be considered prior to implementation on a specific street. We also carried out observations in order to determine what destinations in the area are contributing to the traffic congestion problem. We took notes on our observations and took pictures of the intersections and current traffic. We made observations in the areas of infrastructure, traffic, daily life, and existing modes of transportation.

### Assessment of strategies

We applied our informal observations to make initial assessments of whether or not there were any obvious technical barriers to implementing each strategy. We began by identifying the most obvious

constraints and requirements that each strategy had, and compared them with the observations that we made. We kept track of which necessary features Prinsessegade did or did not have in order to use this information and continue to consider these aspects moving forward. We eliminated strategies that did not seem viable based on technical requirements, and retained the remaining requirements for further assessment through Objective 2. In addition, because we were only considering physical restrictions in this assessment, we did not include education and stricter policies in this analysis.

## Objective 2: Investigate public and expert opinion on strategies deemed viable for the Prinsessegade context.

To devise and evaluate potential solutions to traffic congestion that would be well received by local residents and business owners, we gauged the public's opinions of the remaining strategies to traffic congestion and air pollution. In order to complete this objective, we conducted surveys, semi-structured interviews and conducted an open forum. These interviewees included, but were not limited to, professors and researchers from Danish universities and members of the Local Borough Council of Christianshavn, which is the active local committee. The committee's role is to engage the community and ensure that they are informed on local developments, as well as to update politicians on conditions and attitudes of the residents of Christianshavn. In addition to the local committee members, we contacted individuals from the municipality, including urban and traffic planners, and representatives from the Christianshavn Skolebestyrelse (school board). Lastly, to receive collective feedback on our potential strategies for traffic congestion from local Christianshavn experts, we held an open forum dedicated to discussing the possibilities and complications of each approach. We completed this objective from March 13th through April 20th.

### Semi-structured interviews with experts

In this set of semi-structured interviews, we looked for experts on the traffic problem in Christianshavn, as well as experts on traffic congestion and air pollution. This would be considered purposive sampling (Berg & Lune, 2012), as we specifically targeted individuals and groups who are educated on air pollution, traffic congestion, and the link between both major problems. These interviews were an important step in evaluating potential solutions and achieving our mission statement.

We conducted these interviews in a one-on-one, semi-structured fashion, prepared with a list of questions that would launch a discussion with the interview subjects. These questions varied depending on the expertise of the interviewee. We assigned one person to the interview questions and another to record the answers. The research questions we hoped to answer through our expert interviews included the following:

- Which of the traffic strategies we considered have already been researched for use in Prinsessegade, what factors have prevented these strategies from entering usage, and have the

previously attempted congestion mitigation strategies reduced Prinsessegade's daily traffic congestion, if at all?

- What do the locals think is the biggest problem regarding the traffic on Prinsessegade?
- What is the best method to evaluate our strategies and make conclusions about the success of our proposed strategies?
- What sort of strategies will the Christianshavn community support to solve this issue?
- What sort of strategies will the government support to solve this issue?
- What challenges exist when trying to recommend strategies to reduce traffic congestion?
- What strategies work the best to change traffic behavior in Copenhagen?

These broad questions provided more insight into the strategies we have researched and aided our understanding of the local history in the recent years. They also allowed us to understand what did not work and what was more successful in the area, which we then compared to our own list of strategies to determine if any of them were similar to those that had failed, in order to further narrow down our proposed traffic strategies.

After interviewing experts, we analyzed the data via transcripts, which can be found in Appendix A. We utilized the above research questions and highlighted the parts of the interview that answered these questions. Afterwards, we determined the overarching themes that emerged from these interviews and created a visual representation of the individual interviews that provided us with the most useful insight.

### Surveys with the public

Our surveys focused on discovering how members of the public perceive traffic congestion on Prinsessegade and each of the potential strategies to reducing congestion and air pollution that we were considering for Prinsessegade. We chose this method because it was the most direct way to understand the impacts that any strategies might have on the local community, as well as a better understanding regarding what people know about the relationships among air pollution, traffic congestion, and human health. The complete list of survey questions can be found in Figure 11 of the Supplemental Materials document.

We used a combination of in-person surveys of people we encountered near the Christianshavn Metro station, and electronic surveys from a link posted on Miljøpunkt's Facebook page. When conducting in-person surveys, we found that our participants primarily consisted of bicyclists and people who use public transportation and found it difficult to connect with private car users. By posting our survey online, we were able to reach a larger audience but we also recognize that this creates some bias since those interested in Miljøpunkt's work are more likely to exercise environmentally friendly habits such as bicycling or walking.

We asked the participants a set of basic questions in order to categorize the different responses. The questions we addressed in these surveys included what motivates people to use a certain type of

transportation over other types. We also wanted to know why exactly people use Prinsessegade so we could think about how different strategies would appeal to the users of different vehicles.

In addition to this more demographic based information, we asked our survey participants to rate each of the potential strategies that remained after objective 1 on a pre-defined scale of 1 to 5, where 1 was “highly undesirable” and 5 was “highly desirable.” We then used these results to conclude whether public opinion was positive or negative for a strategy, in order to determine if public opinion was a pro or con for each strategy. We calculated an average rating for each solution as well as the standard error. In order to assess whether a potential solution would be well received by the public, we determined that a positive public opinion would be indicated by an average rating of greater than or equal to 3.1, a negative public opinion would be determined by an average rating of less than or equal to 2.9. If the average rating for a strategy fell between 2.9 and 3.1, then we were not able to determine if public opinion could be a pro or con in our final assessment. We analyzed the overall average ratings for all participants, and then analyzed the ratings by various demographics.

### Open forum

We took measures to ensure that we involved the Christianshavn community in our discussion of strategies for reducing traffic congestion on Prinsessegade. To do this, we organized an open forum meeting to publicly discuss our proposed strategies.

Before we conducted our open forum, we took each of the strategies that remained and eliminated additional strategies that did not seem viable based on combined expert interview and survey results. We then created an informational flyer representing the pros and cons of each remaining strategy for use in our open forum, as shown in the Figure 12 of the Supplemental Materials. We did not use the open forum to eliminate any strategies; we instead used it to learn about the strengths and weaknesses of each as seen by the Christianshavn community. Some strategies were eliminated prior to the open forum if our observations suggested they would not be successful. In addition, we eliminated strategies if both the infrastructure seemed unsuitable and our interviews supported that observation.

Our primary aim in hosting an open forum was to present our survey and interview-based pros and cons for each of the strategies to the local attendees. We had the intent of discussing and exposing any complications that could arise from pursuing each possibility and further engaging with residents of Christianshavn to reveal more ideas about the potential strategies. In addition, we hoped to learn more about political perspectives, as everyone was free to agree or disagree with our findings.

The open forum was held on April 19 from 16.30 to 17.30 in Beboerhus, a community meeting space in Christianshavn that provided easy access for Prinsessegade residents and users. We created a presentation and a paper handout detailing the pros and cons of our proposed traffic strategies prepared for the attendees. For simplicity, we combined some of our proposed strategies into four broad categories. These were road closure (including making the road a bicycle and pedestrian only road and closing it to only public transportation and residents), stricter policies (including more enforcement of low emission zones and road pricing), alternative transport options (including improving public

transportation and incentivizing public transportation), and community outreach (educating the public about the dangers of traffic and air pollution).

We began the discussion by presenting information about the traffic problem on Prinsessegade and the health effects of air pollution, emphasizing the potential health threat to children in regards to air pollution and traffic. The beginning of the presentation served to better inform participants of the problem on Prinsessegade and of the importance of the open forum. Then, we presented our information about the traffic strategies that we researched, ending this part of the presentation with an overview slide to remind attendees of each solution. Next, we allowed questions and comments from attendees about their opinions on our proposed strategies and about new ideas for solutions that they had. Two team members gave the presentation, led the forum, and recorded the discussion with a smartphone, two team members took notes, and one took pictures of the proceedings.

We transcribed the open forum notes (the audio recording was low quality) and used a focus group analysis strategy (Hoets, 2017). We first coded the notes according to which research question they answered, as seen in Appendix B, and presented the data in a table to show the attendees' perceptions of the strategies. We then created a final pro-con list, adapted to include the culmination of the results of all our objective.

# Results and Discussion

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The findings described in this section include an analysis of our results synthesized across all objectives. To see the detailed results obtained from each method, please refer to the section titled “Detailed Results” in the Supplemental Materials.

## Finding 1: Improving public transportation options in Christianshavn is infeasible and unnecessary.

Our initial observations of Christianshavn and Prinsessegade suggested a lack of public transportation to northern Christianshavn, with only the 9A bus and the harbor bus providing direct access to the area. However, after conducting our surveys, we have concluded that most locals deem the transportation options as sufficient, even if ridership could be increased to remove more vehicles from the street. We conducted an interview with a traffic planner from Movia, Denmark’s largest transportation company, on March 31, 2017 to learn about the transportation options in Christianshavn. This interview clarified the public transportation layout in Christianshavn, confirming the 9A bus as the only bus on Prinsessegade while also highlighting the 2A bus as a source of transportation through southern Christianshavn. Additional buses with routes through southern Christianshavn include the 350S bus and the 37 bus. Figure 22 in the supplemental material document shows the routes and stops of the Metro, the buses, and the harbor bus in Christianshavn.

This interview revealed that the only current plan to improve public transportation in Christianshavn is an extension of the 9A bus line into northern Amager to account for the new developments in the area, as seen in Figure 7, the representative also emphasized the high expense of constructing a new train or Metro station in the area. Based on this feedback, improvements to the public transportation options in Christianshavn are most likely infeasible and unnecessary at this time. However, as we conducted surveys primarily in southern Christianshavn, we could not predict whether commuters travelling to northern Amager would provide contradicting feedback. In addition, we cannot anticipate the degree to which the developments in northern Amager may create an increased need for public transit, and how opinions of transportation options will change as this area becomes more populated.





*Figure 7: Extension route of 9A bus line*

## Finding 2: Poor infrastructure and the city’s plan for future developments create a road with increasing problems.

After conducting an informal observation of Prinsessegade, we confirmed that the street is completely unsuitable for a significant number of vehicles to use at the same time even though it is the only direct route to northern Christianshavn from southern Christianshavn and central Copenhagen. Not only is the road extremely narrow, with a single car lane in each direction and bicycle lanes on either side, but its daily traffic is also disorganized. Frequent construction on the sidewalks (as seen in Figure 8) combined with heavy foot, road, and bicycle traffic from tourists and locals produces congested and chaotic transportation. According to our surveys and expert interviews, the busiest times of day are in the morning during school commutes (approximately 08.00) and in the evening (approximately 16.00). We observed that the heavy foot traffic, combined with construction on the sidewalks, sometimes encroaches on the already narrow bicycle lanes, forcing cyclists into traffic and therefore further adding to the congestion on the road. This is especially dangerous considering the school traffic due to parents biking or walking their children to school on Prinsessegade, as noted by school board chairman Anja Clausen. Our interviews with residents knowledgeable about Prinsessegade’s issues and individuals actively working on the community’s municipal issues corroborated these conclusions. Inge Hopps, who



has lived on Prinsessegade for a year and a half, agreed with our observations of traffic discord, stating it was “in general, just a pain.” Poul Cohrt and Erling Ekegren, members of the Local Borough Council of Christianshavn (a committee comprised of political representatives and volunteer group liaisons dedicated to connecting Christianshavn residents with the City Council), shared similar sentiments, the latter of whom noted that the street “does everything wrong and nothing right” (personal communication, 2017).



*Figure 8: Road Construction on Prinsessegade*

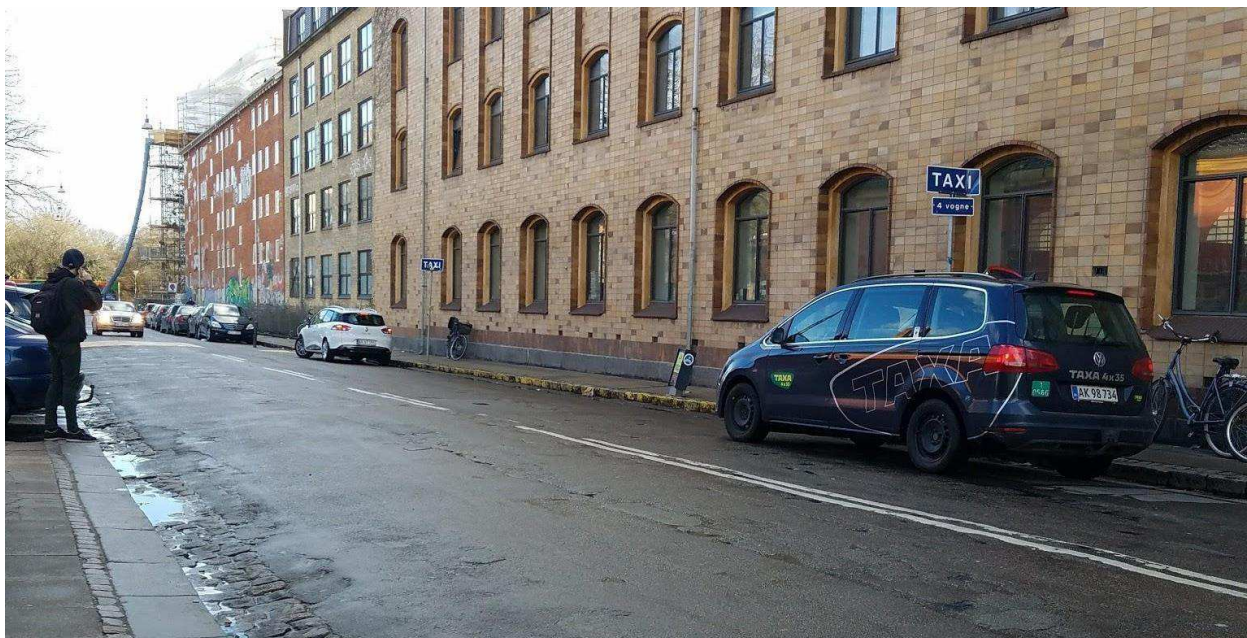
Furthermore, local citizens expressed their concerns with Copenhagen’s expensive public transport, which Hopps has confirmed as a notable issue to many local residents. As such, many of our survey respondents stated that incentives to increase public transport use would have to be substantial to compensate for the high prices.

The Local Borough Council also predicts an increase in traffic, and therefore air pollution, due to major developments north of Prinsessegade. According to Marianne Spang, the city plans to build high-end apartments in northern Amager, as well as a parking garage and other large scale developments on “Paper Island,” which currently contains warehouses holding tourist attractions such as Copenhagen Street Food and Copenhagen Contemporary. Visitors primarily reach these locations by foot and by bicycle (personal observation, 2017). One solution we considered involves closing the road and only allowing motor vehicle access to local residents and buses. However, many locals, including Hopps, emphasized the extreme difficulty in reaching this “up and coming area,” and closing Prinsessegade

would render the northern parts of Christianshavn, where the developments are taking place, almost completely inaccessible.

### Finding 3: Christiania contributes to the traffic congestion in the area and hinders potential solutions.

Travel on Prinsessegade occurs for a variety of reasons, including work, studies and leisure. As a direct result, the street has a high level of car, bike and pedestrian traffic. One such attraction is Freetown Christiania, the first entrance of which is located in the center of Prinsessegade between two of the street's schools. Not only does the autonomous town attract many tourists, but it is also a popular destination among residents of Christianshavn. Many visitors use taxi cabs to reach Christiania, which has created a problem in the past when the taxis obstruct cars along the street, according to Local Committee member Erling Ekegren. Designated drop-off locations for taxis exist on the side street by the first entrance to Christiania, as seen in Figure 9, and police frequently monitor the area to ticket taxis parking illegally. Unfortunately, according to Ekegren, this has failed to stop many taxis from pulling over on the side of Prinsessegade and obstructing car or bike lanes. A similar problem occurs with tour buses blocking traffic in the area and contributing to the air pollution issue by idling (personal communication, 2017).



*Figure 9: Parking spots for taxis outside Christiania on Badsmundsstraede*

In addition, according to Ekegren, the police have had clashes with the drug trade from Christiania in many past conflicts. Cars speed down the street to enter and exit the area. Last year there was an incident where a Christiania drug dealer shot two police officers and a civilian, prompting the removal of the community's open drug stalls on Pusher Street. Ekegren explained that due to mounting tension between the police and residents of Christiania, the police require easy access to all entrances of the community. For this reason, we concluded that we should avoid recommending strategies that would completely block off vehicles from entering, such as a bicycle or pedestrian-only road. Similarly, one-way roads would likely also hinder the police's ability to travel to and from Christiania if they require access in the opposite direction of the current traffic flow.

#### Finding 4: Political pressure has hindered efforts to implement effective anti-car traffic solutions in Copenhagen.

Diverging opinions on the severity of Prinsessegade's congestion between local residents and government representatives have generated considerable friction against strategies aimed at restricting or reducing personal car usage. This is evident in the case of the Prinsessegade bus gate, whose 2016 removal, as Ekegren explained, was almost exclusively due to pressure from national politicians in charge of Christianshavn's municipal infrastructure. Although the working bus gate hindered police from quickly accessing Christiania, local residents remained overwhelmingly in favor of the gate for its success in limiting traffic near schools. While the gate's removal was initially proposed as a temporary measure, Ekegren and Cohrt noted that opaque discussions and deals between the involved politicians have led to the gate's indefinite removal at the expense of resulting traffic congestion.

Another case of governmental obstruction against congestion solutions occurs when Parliament representatives generally favor cars and motor vehicles over greener transportation methods in municipal decisions. Both Ekegren and Cohrt expressed strong dissatisfaction at the approaches to regulating traffic taken by the Folketing's (Danish Parliament) Jutland representatives, who, according to Ekegren and Cohrt, do not effectively represent the views of Copenhagen residents with their full support of cars and motorways. In Denmark, municipality and traffic issues are national matters handled by the Folketing rather than local governments. Since representatives from rural Jutland regions outnumber the Copenhagen representatives 118 to 74, the Jutland representatives maintain control over traffic laws and decisions across the country, including in Copenhagen (Álvarez-Rivera, 2015). This has resulted in other strategies that have effectively reduced congestion and air pollution in various cities across the globe, namely road pricing and congestion charging, receiving very little support in Parliament when proposed by Copenhagen politicians. While members of Parliament have attempted to relieve congestion by fully supporting steps to improve or further incentivize public transport, these measures in practice have not always represented the actual needs of affected residents. For example, Movia attributed the implementation and existence of harbor buses almost exclusively to publicity and

improved city image, but in fact these boats are slow, expensive to run and maintain, and impractical for daily commuting use.

### Finding 5: Bicycling is the most common mode of transport and there are various factors that influence transport choice.

To learn more about the individuals who travel along Prinsessegade and the surrounding area, we conducted surveys with 20 arbitrarily selected individuals from among pedestrians we found at Christianshavns Torv, the Metro square located one block away from Prinsessegade. We received another 40 responses when the survey was posted online on Miljøpunkt Indre By-Christianshavn's Facebook page. One of the first questions pertained to the individual's primary method of travel in Christianshavn. We identified bicycling as the primary method of transportation used in the area, comprising 52% of the 60 survey responses as shown in Figure 10. We also determined that residents of Christianshavn were more likely to bike or walk to reach their destinations when compared to non-residents; 36 out of 43 residents had indicated that their primary mode of transportation was either bicycling or walking, compared to the 5 out of 13 non-residents who had indicated the same.

We received a variety of responses to our prompt regarding why respondents prefer a certain mode of transportation when traveling in Christianshavn. To quantitatively assess these responses, we counted the number of times that a participant had mentioned a subject or keyword from our predefined list when explaining why they used a certain mode of transportation. We identified three common themes that would potentially influence an individual's preferred method of travel based on the frequency of the topics in the responses: travel speed, convenience, and cost.

Speed of travel, mentioned 21 times out of 60 surveys, was the most common theme to appear in the responses. Travelers in Christianshavn prefer to use modes of travel that transport them to their destination in the shortest amount of time. For example, various participants had elaborated that they primarily use travel with public transportation due to the high frequency of vehicle arrivals and fast travel times associated with the Metro or S-train. Participants also reported choosing their method of travel based on convenience. When asked why they used their primary method, 19 participants had noted that their primary mode of transportation was "easy." Convenience is dependent on the individual and their personal opinion; one individual might consider private cars more convenient since

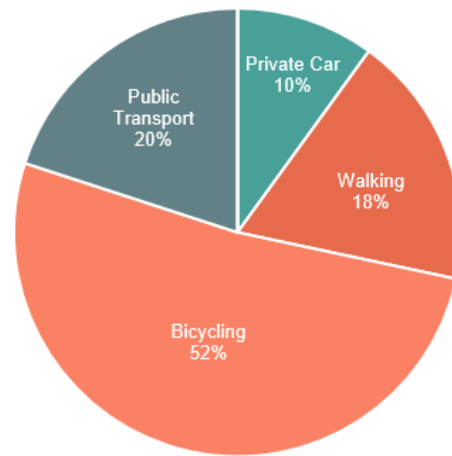


Figure 10: Pie chart of transportation use



they can travel on roads as far and as frequently as their owners prefer, whereas another person could rate the train or bus as most convenient due to the lack of personal driving involved. Lastly, 12 participants considered the cost of travel to influence their method of transport. All 12 of these respondents reported that bicycling is their primary method of transportation, deeming it the least expensive option for travel.

### Finding 6: Providing monetary incentives for alternative transport use is the highest rated solution for reducing traffic congestion.

In order to determine the potential public reception of our researched strategies, we asked the participants to rate each strategy for reducing traffic congestion on Prinsessegade on a scale of 1 to 5 (1 being the least desirable strategy, 2 being undesirable, 3 being neutral, 4 being desirable, and 5 being the most desirable strategy). The average rating for each strategy is shown in Figure 11.

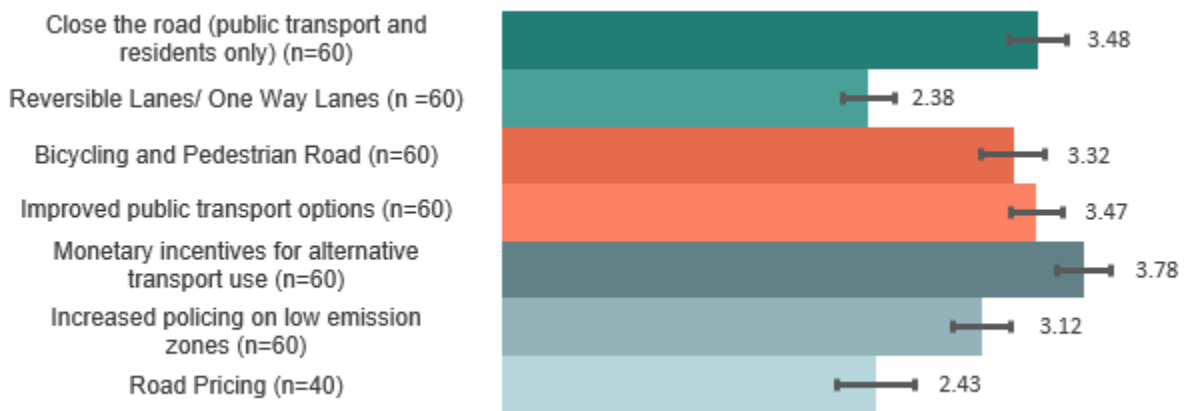


Figure 11: Average ratings for potential strategies. Error bars indicate standard error.

The responses collected from our street surveys highlighted strategies that would likely be well received by the public and those that would be unfavorable by contrast. We then used these ratings to designate public opinion as either a pro or a con in our evaluation of each strategy, using a cutoff point for this distinction. In our methods, we declared an average score rating greater than or equal to 3.1 as a positive public opinion and a rating less than or equal to 2.9 as a negative public opinion. If the average rating for a solution fell between the range of 2.9 and 3.1, we would consider the overall public opinion to be neutral. Using this method, we identified the highest-rated solution as providing monetary incentives in order to encourage alternative transport, with an overall average rating of  $3.78 \pm 0.18$ . Since this solution had an average rating that was higher than 3.1, we considered it well-received by the public and thus listed public opinion as a pro for incentivizing alternative transport in our strategy evaluation.

While generating our surveys, we had brainstormed several factors that may influence a participant's opinion on various strategies. We believed that a participant's place of residence or whether or not they had children impacted how they rated potential strategies to be implemented on Prinsessegade. To assess these relationships, we categorized the data into a series of two mutually exclusive groups (e.g. residents and nonresidents) and constructed column charts relating the average ratings for each solution for each group. After performing a visual assessment of these charts, we found that providing monetary incentives was consistently well-received. Using this method, we determined that neither a participant's place of residence nor whether or not they had children had any impact on their opinion regarding monetary incentives for alternative transport use.

In addition to incentivizing alternative transport, there were several strategies that were "well-received by the public" due to having an average rating greater than or equal to 3.1: closing the road to only allow public transit and residents, converting the street to a bike or pedestrian-only road, improving public transport options, and increased policing on low emission zones. Conversely, two strategies held average ratings below 2.9 and were subsequently labeled as having negative public receptions: implementing reversible and road pricing.

We concluded that no statistically significant relationship existed between a participant's residency and how they rated any of our strategies. Establishing statistical significance in our data was challenging due to having a much smaller sample size of nonresidents compared to residents. We did find that participants with children had differing opinions regarding certain strategies compared to those who do not have children. By performing an analysis of variance (ANOVA), we found that participants with children ( $n=23$ ) and participants without children ( $n=20$ ) answered differently regarding implementing stricter policies. Specifically, participants with children gave this strategy an average rating of 3.87 ( $SD=1.29$ ), while participants without children gave an average rating of 2.85 ( $SD=1.53$ ;  $F=5.618$ ,  $df=1$ ,  $p=0.023$ ). Overall, participants with children had a positive opinion on increased policing whereas the participants without children did not find the solution desirable. By performing another ANOVA, we determined that the ratings for road pricing statistically varied depending on whether or not a participant had children. Participants with children gave road pricing an average rating of 3.00 ( $SD=1.65$ ), whereas participants without children gave an average rating of 1.85 ( $SD=1.27$ ;  $F=6.088$ ,  $df=1$ ,  $p=0.018$ ). The survey responses indicated that participants without children were not in favor of road pricing while participants with children were neutral to the solution. There was no significant difference in how respondents with and without children rated the remaining strategies.

## Discussion of strategies

A full discussion of strategies can be found in our supplemental material in "Discussion of Strategies." After we collected data from our observation, surveys, interviews, and open forum, we synthesized the following table for our traffic strategies. Table 1 is a summary of our process of strategy assessment, including a short discussion of each strategy, which links our above findings with our final recommendations.

Table 1: Summary of Elimination of Strategies

Solution	Objective 1: technical evaluation	Objective 2: evaluation of public and expert opinion	Discussion	Outcome
Green wave	✗	-	There was a lack of need for traffic management.	Eliminated
Road closure	✓	✓	We found that there was considerable foot and bike traffic as well as support from residents. We also identified a viable alternate route for through traffic.	Potential solution
Improving public transport	✓	✗	Interviewees did not see a necessity and it was not feasible to implement.	Eliminated
Incentivizing alternate modes of transport	✓	✓	Many survey participants expressed interest in cheaper forms of public transit, and the existing bike culture could be encouraged further.	Potential solution
Reversible lanes	✓	✗	Interviewees found it confusing, in addition to lack of a need for traffic management.	Eliminated
Education	✓	✓	After surveys, shifted more toward campaigning and public outreach. Would complement other strategies to encourage improved habits and less car use.	Potential solution
Stricter policies regarding air pollution	✓	✓	Open forum revealed that there are many possibilities for different forms of policy that could be effective on Prinsessegade, however it will require more support from the Danish government.	Potential solution
Road pricing	✓	✓	Another form of stricter policy, which has seen success in other cities such as London and researcher Press-Kristensen estimates it would result in a significant drop in road traffic. However, will also require more support from government.	Potential solution

# Recommendations

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Our work has revealed which of the traffic congestion alleviation strategies we assessed are likely to prove most appropriate for Prinsessegade. After performing informal observations, speaking with experts, and surveying locals, we concluded that the problem was not poor traffic management, but rather the number of cars on Prinsessegade, especially when coupled with the chaos of pedestrians and bicyclists from the schools and tourism on the street.

Based on our research and the results of the open forum, we have concluded that the best way to reduce traffic congestion on Prinsessegade will be to combine multiple strategies that we analyzed in order to maximize a reduction of congestion. Changing behavior is a difficult task, and researchers have emphasized that in order to do so, there needs to be a combination of disincentives for car use and incentives for alternative transport use (Javid et. al, 2016). Our interview with Kåre Press-Kristensen also led us to this strategy, as he stated that “incentivizing [alternative transport] is a good idea, but then you need to make it more expensive to have a car.” We predict that a successful combination would be incentives for alternative transport and an awareness campaign coupled with either limited traffic zones, low emission zones, or closing the road again to all traffic excluding public transport and residents of Prinsessegade. The role of each of these strategies is detailed in our 8-step plan below. The following recommendations are actions that our sponsor, Miljøpunkt Indre By-Christianshavn, can take in the future to continue the effort to mitigate traffic congestion on Prinsessegade.

## **1. Complete a detailed traffic study of each of the main intersections on Prinsessegade**

While a full traffic analysis was outside the scope of our project, our investigation does support the importance of having such information for future traffic planning in Christianshavn. Conversations with our sponsor and interviews with local community leaders such as Pohl Cohrt of the Local Borough Council of Christianshavn underscored the large scale of urban development planned in northern Amager. In order to accurately predict how traffic will increase in upcoming years, it is necessary to conduct an in-depth study of both the current technical aspects of Prinsessegade’s traffic and the full extent of proposed development. Such a study would strengthen the argument that strategies to traffic congestion are necessary when presenting the issue to government officials.

This type of study, referred to as a Traffic Impact Analysis (TIA), is usually conducted for a government agency and involves consultants such as traffic engineers and developers (Yarger Engineering, 2017). In the case of Prinsessegade, city planners and private developers would provide the necessary details of the planned developments in Amager. Study locations would include the intersections of Prinsessegade with Torvegade, Bådsmadsstræde, and Sankt Annæ Gade, and city officials would provide sources of current traffic data. Through our surveys, we concluded that 07.00 to



09.00 and 15.00 to 17.00 on weekdays constitute peak traffic hours on Prinsessegade, so the study should focus primarily upon these intervals.

In addition, a traffic study can directly help determine the amount of air pollution on the road, and how various strategies can reduce the pollution levels. From a previous study done by Press-Kristensen on H.C. Andersens Boulevard, a major road in Copenhagen, estimates were made about the average concentration of various pollutants by type of vehicle. The estimates can be found in Appendix C in the supplemental materials. The measurements also confirm that passenger cars make up the majority of the ultrafine particles, and other particulate matter, on the road. This is partly because there is a lack of restrictions on passenger cars to meet EU standards for particle filters. This further suggests that passenger cars should be targeted more than other types of vehicles.

## **2. Conduct additional surveys of community members**

While conducting surveys we were unable to specifically target individuals who rely on private motor vehicles. This was challenging as the only subjects we could directly survey were generally pedestrians, public transport users, and cyclists, all of whom walked in our survey areas. While we managed to obtain some data regarding individuals who primarily use cars after releasing the survey online on Miljøpunkt's Facebook page, the pool of these respondents was very limited.

A past study done in Lahore, Pakistan, surveyed 350 people on their transportation habits and attitudes towards public transport. The results of the survey showed that people are most likely to change behavior if there are fiscal restrictions on car use. In addition, the study concluded that there needed to be an integration of public transport improvement and fiscal restrictions in the area in order to change traveler attitudes (Javid et al., 2016).

A survey with greater outreach specifically targeted to drivers of personal vehicles in Copenhagen would prove more successful for generating accurate, unbiased traffic data and answering the research question, "What would motivate car owners in Copenhagen to convert to alternative transport?"

## **3. Work with city officials to gain support for stricter low emission zone regulations**

Our interviews with experts revealed that the Danish government, specifically the Folketing (Danish Parliament), does not support stricter policies such as road pricing or low emission zones. Folketing maintains control over all Danish municipalities, including Copenhagen. Since a majority of the representatives are from the more rural Jutland area and depend heavily on cars, they generally outvote their Copenhagen counterparts in favor of laws supporting private cars. This presents a challenge to any legislation that would significantly deter people from driving.

Such high levels of political friction constitute a serious obstacle to efforts to reduce Copenhagen's traffic congestion. By collaborating with city officials and presenting the Danish

government with convincing evidence demonstrating an urgent need for traffic reduction, Miljøpunkt Indre By-Christianshavn will more easily be able to tackle this problem. Information and materials to use in appeals to city officials should include traffic studies (e.g., the one outlined above). Such studies, complete with models and data on air pollution levels on Prinsessegade, are likely to demonstrate that traffic (and therefore air pollution) will only increase if no strong control measures are implemented. Other useful information could include the background of the area, specifically highlighting the multiple schools and severe health effects of pollutants such as UFPs on children.

#### **4. Develop Limited Traffic Zones in Christianshavn**

This recommendation, unlike the others, would pertain primarily to the municipality of Copenhagen, as Miljøpunkt would not be able to implement such policies. Limited traffic zones differ from low emission zones in their flexibility with when and what type of cars are restricted on the road. These zones have a variety of possibilities to improve the congestion on Prinsessegade. For example, delivery trucks or non-residential vehicles could be restricted from the street during rush hours, but permitted at other times of day. Cameras would monitor the entrance to the street, and vehicles illegally entering would receive fines. One effective tactic may involve banning all non-electric delivery vehicles (or, failing this, at least Euro VI compliance). A personal communication with our sponsor at Miljøpunkt expressed that any vehicles below Euro VI (the typical Low Emission Zone Standard is Euro IV) still contribute to UFP and the associated health effects. Such a sweeping measure of Euro VI regulation would provide an immediate improvement to the road's air pollutant concentrations. From our open forum, we identified these types of restrictions as possible effective solutions for Prinsessegade. More dedicated research is necessary to determine if Denmark and the city would support these restrictions. An example of this type of program was implemented, and experienced success, in Rome. When cars without sufficient filters were restricted from a railroad ring, the specific area experienced an NO<sub>2</sub> decrease of 23% and a PM<sub>10</sub> decrease of 10% (Cesaroni et al., 2011). This proves that limiting the type of vehicles in a certain area, will decrease air pollution locally. This supports our claim that this strategy would experience success on Prinsessegade, as it would result in less pollution on the street, which is Miljøpunkt's primary goal.

#### **5. Work with Movia and local businesses to develop an alternative transport plan for Christianshavn**

Miljøpunkt has investigated the public buses in Copenhagen and their emissions in the recent past and in this endeavor has successfully caught the attention of the media and forced the public transport company, Movia, to make a change. They have plans to convert the most polluting bus line to run on natural gas, and eventually to change all buses to electric. We recommend establishing further collaborations between Copenhagen's environmental and transportation agencies to ensure the creation and survival of more environmentally sustainable public transportation opportunities. In

addition, we recommend the continuation of Miljøpunkt's collaboration with Movia, with the aim of working together to design and implement an incentive system that encourages car users to seek alternative transport methods. Movia would be able to exhibit greater influence over creating, marketing, and sustaining a legitimate and appealing incentive program than some of the smaller businesses we had attempted to contact, and would therefore be more effective at implementing this type of system.

Other groups, including a team of students at Copenhagen Institute of Interaction Design, have researched other methods of increasing cyclist convenience. However, projects targeting those who will not or cannot ride bicycles are also vital. Our surveys have revealed that many older people, who may be physically unable to cycle, heavily rely upon cars or public transport. Transportation agencies such as Movia can aid in appealing to individuals disinclined to use public transport because of the cost or inconvenience. One way Movia and related organizations can target such individuals is by creating monetary incentives through decreased public transportation fees (while disabled individuals receive a free public transportation ticket, an elderly person over 65 still pays the same 50 kr. as any other adult, however they receive some monthly discounts). Similarly, the agencies can establish a points system that provides discounts to popular local stores or businesses for frequent public transport users. These businesses could include the Opera House, a common destination for Prinsessegade visitors, and convenient retail stores such as grocery stores or restaurants. However, such an incentive system must target both bicycle and public transit users, ensuring that only private car users and not cyclists are encouraged to begin using alternative transportation methods to reap the rewards. An incentive system exclusive to public transport would risk detrimentally converting cyclists into bus or Metro users. While an incentive system would constitute a clear reward for using the bus and Metro, decreasing costs and increasing system reliability would remain preferable, based on the feedback obtained from our surveys and interviews.

## **6. Introduce financial and practical disincentives or obstacles to owning a private vehicle**

This recommendation applies to the municipality instead of Miljøpunkt Indre By- Christianshavn. Decreasing the costs of or incentivizing public transport and bicycling will be most effective when coupled with a system that would strongly dissuade citizens from using cars city-wide. We propose such a disincentive in the form of stricter policy or municipal laws, such as road pricing, limited traffic zones, or low emission zones. Although we acknowledge that these strategies require the support of the Danish Parliament, our interviews and open forum identified stricter policies as the most convincing method of disincentivizing private car use. Our interview with Kåre Press-Kristensen of the Technical University of Denmark, who estimates traffic could decrease by 20% with the implementation of road pricing, particularly supports this recommendation. Furthermore, open discussion and brainstorming in our open forum concluded that the city of Copenhagen is not doing enough in this area. The newest

standard for private vehicles, Euro 6, should be enforced in the city. If this restriction cannot be applied city-wide, that is where the implementation of LTZs is useful. Traffic on Prinsessegade specifically could be restricted to Euro 6 vehicles. Additional disincentives for private car ownership in the area can include increased costs for parking or congestion charging during rush hours.

### **7. Reconsider road closure (public transport and residential use only)**

After discussing with members of the public in regards to the previously implemented bus gate, we believe this approach was highly successful and worth reconsideration. Should the gate return to service upon review, it would prove most effective if coupled with other strategies for incentivizing alternative transport. From our open forum, we identified Kløvermarksvej, the alternative route to northern Christianshavn via Amager, as a promising replacement to Prinsessegade for travel. The route's openness is apparent, swapping Prinsessegade's tall buildings for trees, a canal on the left, and open fields for soccer. These natural features highlight Kløvermarksvej's strong capacity for dispersing and absorbing air pollution. Another consideration for the closure strategy is the placement of the gate. Moving the gate closer to Torvegade, particularly between Sankt Annæ Gade and Bådsmadsstræde, would reduce traffic by the schools and therefore increase the safety of their students. A traffic study in this area would aid in determining the best location for this gate.

### **8. Public outreach and campaigning**

We believe that working with the community and public campaigning will strengthen any other strategies implemented on Prinsessegade. The idea behind this type of outreach is to force people to consider the impacts behind their actions. While our survey results do not demonstrate a severe knowledge gap, community outreach would still be an effective method to promote a sense of civic obligation. Environmental groups exist with this same goal, and many other cities have implemented programs in order to articulate to the broader community how significantly their actions contribute to air pollution. One such campaign titled "soot free for the climate – no diesel without filters!" originated in Germany in 2009 and has since been adopted by many European countries in addition to independent environmental organizations, such as the "Transport & Environment" group (Transport & Environment, 2017). This group produces a number of publications expressing the health effects of vehicular emissions, transportation as a climate problem, and other topics about the sustainability of car traffic. Other cities, especially in the United States, have extensive outreach platforms and use social media to include and update the public on traffic plans. Paris also publishes multiple resources online for both adults and children about air pollution due to vehicle emissions.

# Conclusion

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Due to the severe adverse health effects resulting from high pollutant concentrations, especially those that disproportionately affect children or the elderly, reducing air pollution in a highly residential area such as Christianshavn is of paramount importance to improving the residents' quality of life. In the case of Prinsessegade, a street which melds heavy tourism, children walking and bicycling to school, diesel delivery trucks, and civil construction into a tumultuous mix, the first step to combating the greater-scope issue of air pollution is to effectively restructure the road's transportation into a more manageable form. To this end, we researched the history of Prinsessegade's municipal changes and sought the Christianshavn community's opinion on a variety of traffic solutions implemented around the world, intent on exposing each strategy's pros and cons for all to observe. Our professional interviews with local experts in Christianshavn crafted a telling outline of Prinsessegade's sordid traffic history, while our survey and open forum provided a stream of personal and municipal perspectives about how each possible solution could affect the lives of Prinsessegade's many users. In analyzing each source of information, we combined the interviews' historical accounts, the surveys' personal opinions, and the open forums' logistical assessments to provide a well-rounded assessment of how each solution would be practically implemented, publicly received, and successful in performing its duty of traffic mitigation.

Naturally, no single solution emerged from our evaluation and elimination process as the perfect panacea to Prinsessegade's traffic dilemma, with essentially every strategy suffering from drawbacks on one or more of these fronts. Indeed, the strategies with the highest technical performance ratings known to work effectively in other cities (i.e., road pricing, limited traffic zones) face strong government opposition in implementation, while attempts to specifically remove motor vehicles from Prinsessegade (i.e., road closure, conversion to bicycle road) have historically deteriorated due to police disapproval or political deals. Conversely, solutions with a higher chance of receiving municipal approval (i.e., public transport incentivization, community outreach) face limited public approval and would not provide as drastic pollution results as road closure or pricing. Nevertheless, the path to mending Prinsessegade's troubled traffic situation must involve addressing each potential solution's strengths and shortcomings to determine which approach would ultimately prove most beneficial to Christianshavn. While our results from the surveys and open forum provide an overview of how the four remaining approaches could work on Prinsessegade, a full answer to this question will require completing the rigorous scientific and public studies outlined in Recommendations.

Although any strategies that may be put into motion will likely encounter some form of backlash, either from the public or local authorities, improving Prinsessegade's traffic congestion is vital to protecting the livelihood of Christianshavn and its residents. While the ruinous health effects of ultrafine particles are not well-documented, their potential potency for children provides a critical reason to continue working toward a green solution. Only when the children of Christianshavn can walk

or bicycle to their schools in a safe, clean environment, no longer in immediate or gradual danger from wayward trucks or ultrafine particles, will Prinsessegade and its surrounding neighborhood move forward and become a sterling example of Denmark's green approach to transport. The first step to realizing this ideal is for Miljøpunkt Indre By-Christianshavn to analyze our recommendations and move forward in the most promising direction of implementation.

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