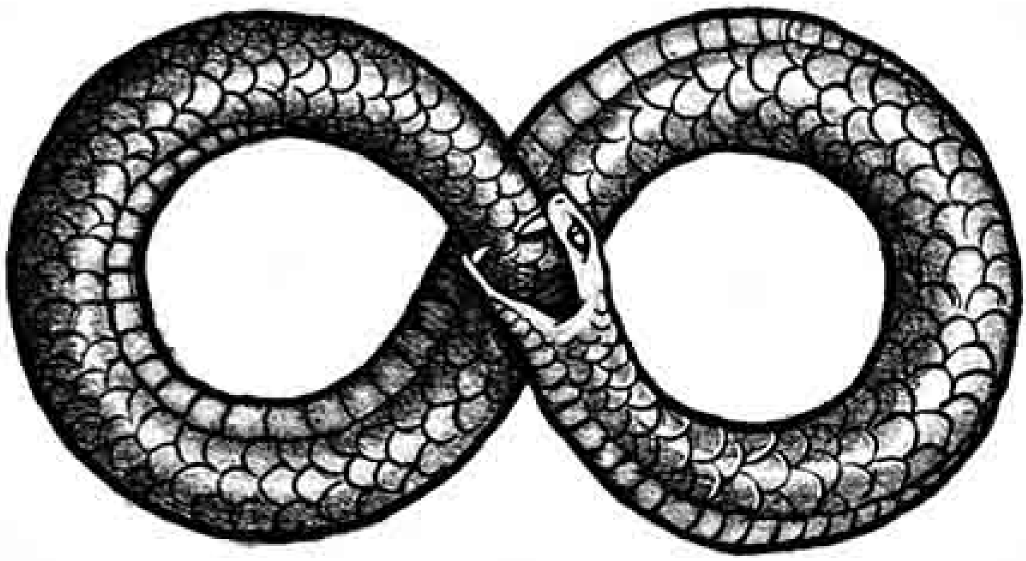

# Ignoring Induced Traffic

**-An Empirical Study of Induced Traffic**


*Master Thesis*

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# Title Sheet

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**Synopsis:**

The objective of this report is to find empirical evidence of induced traffic in a Danish context. This is done through corridor analysis of 45 road projects with appertaining before and after traffic counts. The traffic counts that have been collected are taken over a four year period after opening of each of the case projects. The report has found that induced traffic does occur when the road capacity of the road network is increased. Furthermore, the report has also found that the magnitude of induced traffic that occurs is very context-dependent of the type of road constructed. It is also found that the effects of induced traffic are not limited to an initial "jump" in traffic after the opening of a road project. The effects of induced traffic continues over a longer time period after the opening, however, this is also very context dependent on the type of road project build. Lastly the report concludes that there are large difficulties in obtaining data regarding ex-post evaluation of road projects.

# Preface

This study is carried out in the period between the 2nd of February 2012 and the 9th of January 2013 by John Christian Twitchett, Urban Planning and Management 9th and 10th Semester at Department of Development and Planning, Aalborg University. The main theme of this semester has been "Transport evaluation" and the theme of this study is induced traffic.

The report is written as an inspiration to municipalities, planning professionals, researchers and others who work with planning as well as lectures, supervisors and students who have an interest in the subject.

The report is divided into four levels so that overall chapters have numbers and paragraphs have two numbers. In the main part of the paragraphs, there are headlines marked with bold and underlined and another headline only marked with bold. The two headlines which do not have numbers are not included in the Table of Contents.

All pictures, graphs and figures are called Figure, and are numbered. All tables are called tables and numbered separately from figures. The number does not refer to the numbers of the chapters, but are in numerical order throughout the report.

Source references are marked with a bracket and are mentioned with the author and year, e.g. (Cockburn 2011). The full source is to found in the List of References.

I would like to thank Professor Petter Næss, PhD Morten Skou Nicolaisen, for their support, help and inspiration during the process of making this report.

I would furthermore like to thank Niels Erik Moltved from the Road Directorate for help with access to Mastra, the interview and answering the many questions I had, regarding the Road Directorate and data collecting, during the process of this study.

# Contents

# 1 Introduction

Construction and maintenance of road infrastructure constitutes a large part of infrastructure planning in Denmark. Denmark has a well-developed road infrastructure network, with ca. 74.171 km of public road in Denmark compared to 2.667 km of railway (Statistics Denmark 2011). In 2001 The Danish Environmental Protection Agency (EPA) published a study aiming to quantify the area used for transportation purposes the results are shown in ***Figure 1***.

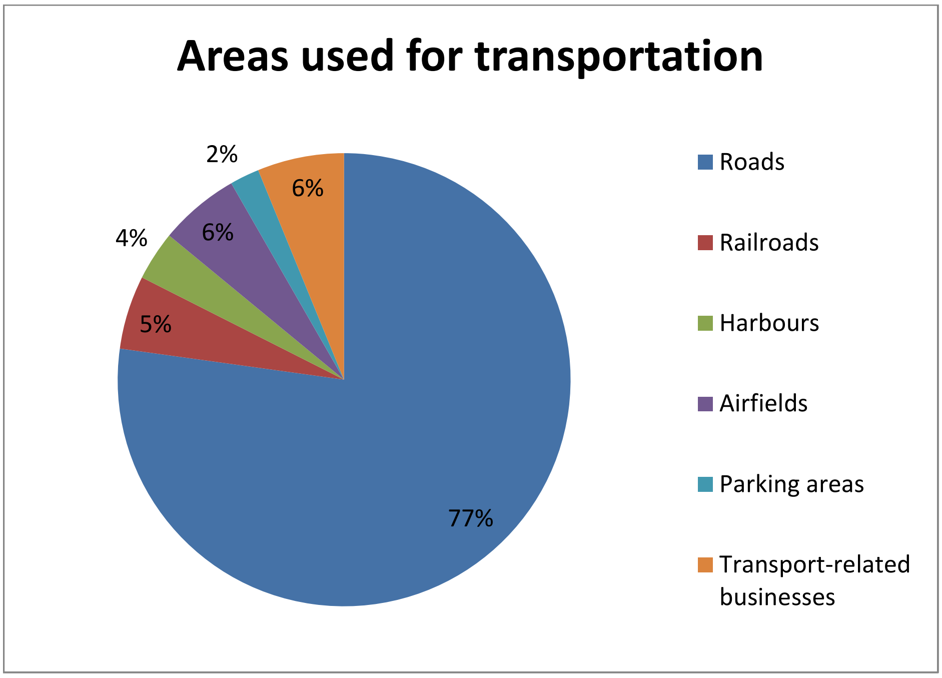


***Figure 1: Total area used for transportation purposes classified by transportation mode and use.(The Danish Environmental Protection Agency 2001)***

The total area used for transportation purposes in Denmark was 1276 km² in 2001, which is roughly the size of Lolland; a mid-sized island in Denmark. This means that 3 % of the land area in Denmark is used for transportation purposes and as ***Figure 1*** shows, 77 % of this area constitutes roads (The Danish Environmental Protection Agency 2001).

Road infrastructure is furthermore the single largest recipient of infrastructure investments from the Danish government. The Danish government invested 5.045 million DKK in road infrastructure in 2010 compared to rail infrastructure where the Danish government invested 1.580 million DKK in 2010.(Statistics Denmark 2011) Below in ***Figure 2*** a map of Denmark and the major Road infrastructure in Denmark is shown.


***Figure 2: Map of the Major roads in the Danish road network.***

This well-developed road network means that the need for building a road in order to reach a city or place is almost no longer present.[1] Nowadays the main political reasons for expanding the existing road-network are; relieving congestion, a wish for increased speeds on roads (motorways) and economic growth and regional development. The current practice of expanding road capacity in order to relieve congestion is a consequence of the "predict-and-provide" paradigm which is based on extrapolating existing traffic trends and then providing the capacity in order to accommodate future traffic volumes (Owens 1995). The predict-and-provide paradigm has reigned in most of the western world for some time and has

[1] Small access roads facilitated by cul-de-sac development and the continuing sprawl of cities are not considered in this report.

started to cause problems in traffic planning, environmental planning and other areas of planning. This approach has worked well in the post-World War II era were the road network needed to be developed, but in today's context the predict-and-provide approach has been criticized for not being adequate to handle the modern mobility and environmental problems (Banister 2011; Owens 1995).

Resent transportation research suggests that this predict-and-provide approach, which not unique to Denmark, is not adequate to solve the problem of congestion (Næss et al. 2012; Nielsen & Fosgerau 2005; SACTRA 1994). According to research on road congestion, providing additional road capacity to congested roads usually in itself facilitates even more traffic, thus fuelling the fire of congestion (Phil Goodwin 1996; Næss et al. 2012; Litman 2011; SACTRA 1994). This additional traffic is called induced traffic and the main focus of this report is on induced traffic in Denmark.

Induced traffic is resulting from a mechanism that is triggered when you follow the predict-and-provide paradigm and allocate additional road capacity to a congested road. Specifically, induced traffic is the additional traffic that arises when adding road capacity to a road network. Induced traffic occurs for the most part on congested roads, it can however also occur on uncongested roads if travel speeds are significantly increased. A further elaboration on induced traffic will be given later in the Theory chapter.

In an earlier study by the author, it was found that there were some difference/confusion in how the definitions and wordings around the concept of induced traffic were used by researchers and professional planners. This was both in regard to what was considered to be included in the definition of induced traffic and the use of words travel and traffic. It is therefore specified in this report that, ***traffic*** is used about all forms motor vehicle travel that is allowed on the Danish motorways. This means that traffic is generated form travel in cars, bus, trucks and so on, but walking, mopeds and bike travel are not generating traffic. The definition of induced traffic that will be used throughout this report is stated below. (Twitchett 2012)

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***Definitions:***

***Induced traffic:*** is additional motor vehicle kilometres that are undertaken on the entire road network as a result of added road capacity, e.g. new roads and/or road expansions.[2]

***Generated traffic:*** consists of motor vehicle traffic that is diverted from other streets, times or transportation modes to the new or expanded road, as well as the induced traffic on this specific road.

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In today's transport planning, models and forecasts are extensively used as planning and decision making tools. If these tools are to be used they must also strive to be as correct as possible and therefore include effects like induced traffic.

[2] Intelligent traffic management systems that can improve road speeds without adding road capacity to the road network could induce additional traffic, but are not considered in the report.

However this is rarely the case in Danish traffic planning. Up until recently induced traffic was not included in the traffic models used for new infrastructure projects and it was only the Ørestad model (OTM), which is used in the Capital region, which was capable of including some limited short term effects of induced traffic. It is only recently that the Road Directorate has introduced an elasticity factor in order to compensate induced traffic. However, this elasticity is based on guesses and estimations not the multiple international empirical studies done in England and USA.(Nielsen & Fosgerau 2005; Twitchett 2012)

The effect of induced traffic is well documented by international studies, see for example (Litman 2011; Hills 1996; SACTRA 1994; Duranton & Turner 2011; Phil Goodwin 1996; Noland 2000). Litmand (2011) provides a table over the short- and long term effects of induced traffic in relation to road capacity found in different studies (cf. ***Table 1***).

| Author | Short-term | Long-term(+ 3 years) |
|---|---|---|
| **SACTRA** | | 50 - 100% |
| **Goodwin** | 28% | 57% |
| **Johnson and Ceerla** | | 60 - 90% |
| **Hansen and Huang** | | 90% |
| **Fulton, et al.** | 10 - 40% | 50 - 80% |
| **Marshall** | | 76 - 85% |
| **Noland** | 20 - 50% | 70 - 100% |

***Table 1: Portion of New Capacity Absorbed by Induced Traffic.(Litman 2011)***

The table above shows, that after a short period of three years most of the added road capacity is filled with traffic that the added capacity itself has induced. This means that the act of increasing road capacity for the sake of relieving congestion is almost meaningless, and may in fact increase congestion on the connected roads.

Although the effect of induced traffic is well documented and has been known for the last 60 years in the academic community (Jorgensen 1948; Downs 1962), there still seems to be some reluctance to fully incorporate induced traffic into the existing traffic planning methods and procedures. This reluctance to incorporate induced traffic in traffic planning has some significant environmental and economic effects on the outcome of the traffic planning carried out.

In traffic planning, cost benefit analysis (CBA) is a very central part of the decision making process. CBA is used to assess the economic viability of proposed projects and as a tool for comparing different project proposals. If induced traffic is omitted in the traffic modelling used in a CBA comparison, road projects may appear more favourable than they actually are. This is because of the large emphasis on travel time savings in CBAs. On average, travel time savings made up 90% of the total benefits of the CBAs performed as a part of the environmental impact assessments (EIA) published by the Danish Road Directorate in 2011. (Nicolaisen & Næss 2011)

By not including induced traffic no congested roads in traffic modelling the travel time savings may appear larger than they actually are. This is because the travel time savings gained will appear larger if the road capacity is not occupied with induced traffic. ***Figure 3*** below illustrates how road capacity is filled when including induced traffic and without including induced traffic.

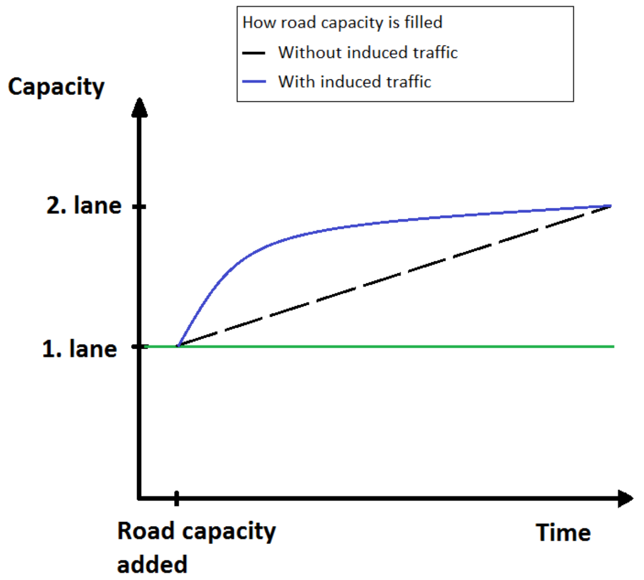


***Figure 3 Illustration of how road capacity is filled with and without induced traffic.***

***Figure 3*** shows that the road capacity is filled much faster if induced traffic is considered, than if it is ignored. This has the implication that congestion sets in much faster than if induced traffic is ignored and this also has an effect on the road speeds gained form the road expansion.

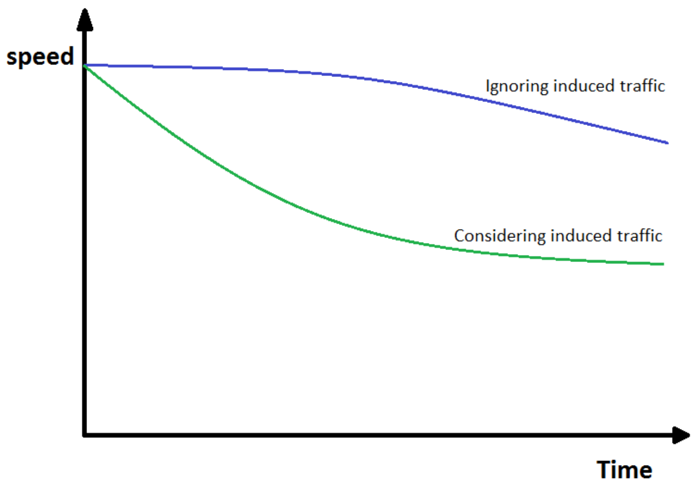


***Figure 4 Differences in projected traffic speeds when respectively ignoring induced traffic and considering induced traffic. Adapted from*** (Litman 2012)**.**

***Figure 4*** shows that traffic speeds will be overestimated if induced traffic is ignored and this will then again lead to overestimation of travel time savings which constitutes a major part of the benefits in CBAs. So ignoring induced traffic in traffic modelling can lead to a systematic bias in the assessments of the viability of the road infrastructure projects considered.

Ignoring induced traffic does not only have some consequences for economic viability of proposed road projects, but it also has some environmental consequences. When a road project is in the preliminary stages of planning, traffic forecasts are made in order to predict future traffic volumes and to assess travel time saving and the economic viability of the project. But these traffic forecasts are also used in the EIAs. This means that the traffic forecasts are used when assessing noise pollution, air pollution, traffic mortality and so on. So an underestimation of traffic volumes because of ignoring induced traffic will not only produce biased traffic forecasts, but also bias assessments of noise and air pollution, thus producing a biased EIA (Twitchett 2012). This means that the error made by ignoring induced traffic is multiplied in a CBA and EIA through the multiple uses of the bias traffic forecasts.

Some critics will argue that that the increased traffic flow/speeds gained from a road expansion will reduce emission and thereby be better for the environment. This is initially true if the speeds do not exceed speeds above 80 km/h (Strand et al. 2009), but if the road expansion generates new cold start trips, then these reduction benefits will disappear after some time. A similar argument is also heard when traffic restricting initiatives are implemented as for example reallocating road space for bus lanes. Critics argue that the increased congestion will entail increased emissions, however studies show that this is not the case over a longer period. (Stathopoulos & Noland 2003)

As argued in the introduction above, including induced traffic in traffic planning is vital in order to achieve correct and honest assessments of the viability and consequences of propose road projects. Furthermore, since billions of DKK are used every year on road infrastructure it is in the best interest of the public and the government to ensure that this money is used most efficiently. However empirical studies of induced traffic in a Danish context are very limited and there is a need for more studies on induced traffic in contexts other than the Anglo-American. (Nielsen & Fosgerau 2005) This leads to the research questions of this report:

## 1.1 Research Questions

Main research question:

- **To what extent does induced traffic appeared when building new roads or expanding roads in Denmark?**

This is a very broad question and it would be interesting to see if the occurrence of induced traffic could be determined more precisely. Other studies have indicated that the level induced traffic which occurs is dependent of the classification of the road (road type), so the objective of the first sub-question is to determines if certain road types generate more induced traffic than others.

1. Do different road classifications generate different levels of induced traffic?

In several international studies it have been suggested that the effect of induced traffic increases over time (Litman 2012; Phil Goodwin 1996; Noland & Lem 2002; SACTRA 1994). However the causal relationships and effect of these becomes increasingly difficult to prove over time. Therefore is would be interesting to investigate if these long term effects of induced traffic can be measured.

2. Does the level of induced traffic increase over time?

It should be specified that the objectives of research sub-question 2 is not to uncover the specific mechanisms that occur in the long term development of induced traffic. It is simply to find empirical evidence of the increase of induced traffic over time and if possible estimate the magnitude of this increase.

# 2 Theory

This chapter will explain the concepts, definitions and theory used in the current study. The subject will be state-of-the-art research on induced traffic and rationales behind transport behaviour, published by the leading researchers in this field. The chapter will go through the theory of how traffic manifests itself under certain conditions which will then be supported by theory about rationales behind transport behaviour.

## 2.1 Induced Traffic

Induced traffic is the additional traffic that occurs when traffic flow is improved on a road network. Induced traffic can be facilitated by many different initiatives such as intelligent traffic management systems, road expansions, improving road surface on old roads, increasing speed limits, relieving congestion, building new roads etc. Since the objective of this study is to examine the link between road network capacity expansion and traffic volume, this study is only concerned with induced traffic that is facilitated by road capacity expansions in the form of new or widened roads. Road expansion is defined to be increasing the number of lanes on an existing road and construction of new links in the road network. Below the definition of induced traffic use throughout this report is presented.

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***Definition:***

***Induced traffic:*** Are the additional motor vehicle kilometres that are undertaken on the entire road network as a result of added road capacity, e.g. new road links and/or road expansions.[3]

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One way of looking at induced traffic is that induced traffic arises from a lot of different behavioural responses when people's accessibility patterns are changed. The following will describe these different behavioural responses.

Induced traffic appears when there is a latent demand for traveling by car, i.e. trips that are not undertaken by the user, because the perceived cost of traveling by car is too high. The perceived cost is the actual cost of the trip including the operational cost of the transport mode, as well as the effort, inconvenience, risk, time etc. (Næss et al. 2001). Latent demand occurs when congestion sets in and affects the travel speed, meaning that some trips are suppressed because of the congestion i.e. the users will therefore forego the trips or divert the trips to other times, routes or modes. The travel speed on a road is affected by the level of usage as shown below.

[3] Intelligent traffic management systems that can improve road speeds without adding road capacity to the road network could induce additional traffic, but are not considered in the study.

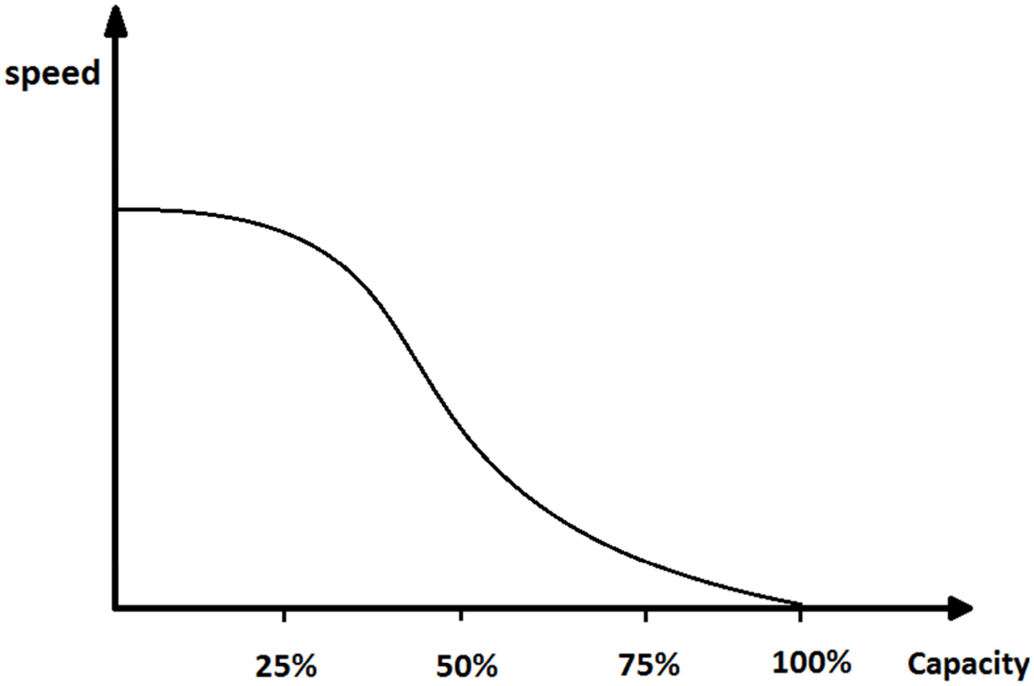



***Figure 5: Graph showing how road speeds are affected by the level of usage. Adapted from*** (Ammoser 2012)**.**

***Figure 5*** illustrates how traffic speeds are affected when congestion sets in. As the travel speeds decrease so does the users' willingness to undertake the trip because the perceived cost of traveling increases.

If the road capacity on a congested road is expanded, the traffic will flow freely and traffic speeds will increase. This increase in travel speed is perceived by the users as a decrease in travel costs and some users may now be willing undertake some of the trips that they were unwilling to undertake before the road expansion. This means that, in addition to the general traffic growth, there will occur some trips that are brought on by the more free flowing traffic and the increased speeds. These additional trips, that the users are willing to undertake after the capacity is expanded, are called induced traffic. This means, that the benefits of the road expansion, in for example traffic models, EIA, CBA etc., may be less if induced traffic is included, because the road capacity of the newly expanded road will start to fill faster and congestion will also set in again faster, than if induced traffic was not included.

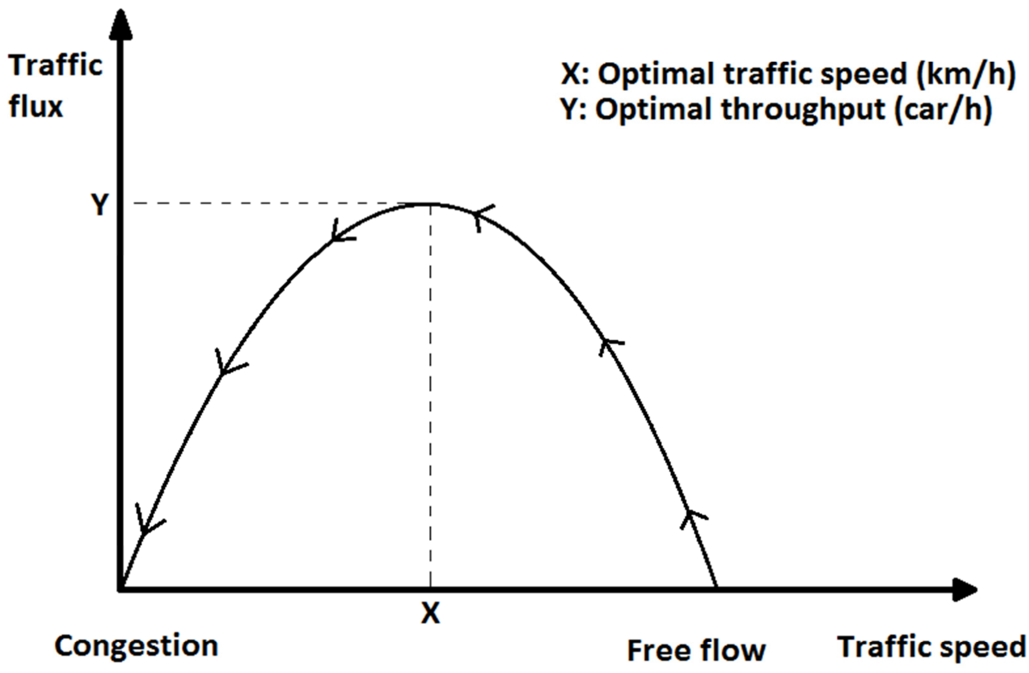



***Figure 6: How increase in the number of cars on a road affects traffic speeds and traffic flux. Adapted from*** (Ammoser 2012)**.**

***Figure 6*** illustrates how the traffic flows freely after a road expansion and travel speeds are at maximum. As the number of cars increase on the road, the traffic speeds decrease as shown in ***Figure 5***. At the same time in ***Figure 6*** the traffic flux increases until it reaches Y while traffic speeds decrease to X. At Y the optimal amount of throughput of cars per hour is achieved and this is the optimal operation level of the road. As even more cars use the road and congestion sets in the flux then starts to decrease while the traffic speeds continue to decrease. If induced traffic is not considered in ***Figure 6***, the speed with which the curve goes from free flow to congestion following the arrow would be more uniform and steady paced, following the development of the general traffic growth. It should be noted that the general traffic growth can be negative in which case the arrows should be inverted and the curve would go from congestion to free flow. However if induced traffic is considered in ***Figure 6*** then there will "jump" in traffic i.e. the speed with which the curve goes from free flow to congestion will be faster and not uniform and steady. This is because of the extra travellers that are suddenly prepared to undertake the trip. In regards to the benefits of a road project it is the area at and around optimal operation level that increases the benefits of a project. This means that, when induced traffic is included the benefits are lower because the curve reaches congestion level faster.

In the case where there is no congestion, it is also a decrease in travel time that may cause additional traffic to occur. However in this case, the increase in travel speeds is caused by increase in speed limits that arise from an upgrade of the roads functional classification or straightening of a road with a lot of bends etc. So the users may be willing to undertake more trips or drive longer for a given purpose.

In ***Figure*** *7*, a person-trip per day matrix is shown. This trip matrix is used in the SACTRA[4] (1994) report to define induced traffic and is used in the current study to identify and explain the different behavioural responses that occur when expanding road capacity (SACTRA 1994).

[4] SACTRA (The standing advisory committee on trunk road assessment) is an independent committee appointed by the Secretary of State for Transport in the 90s, to document the effect of induced traffic, did a large scale study of 151 road projects.

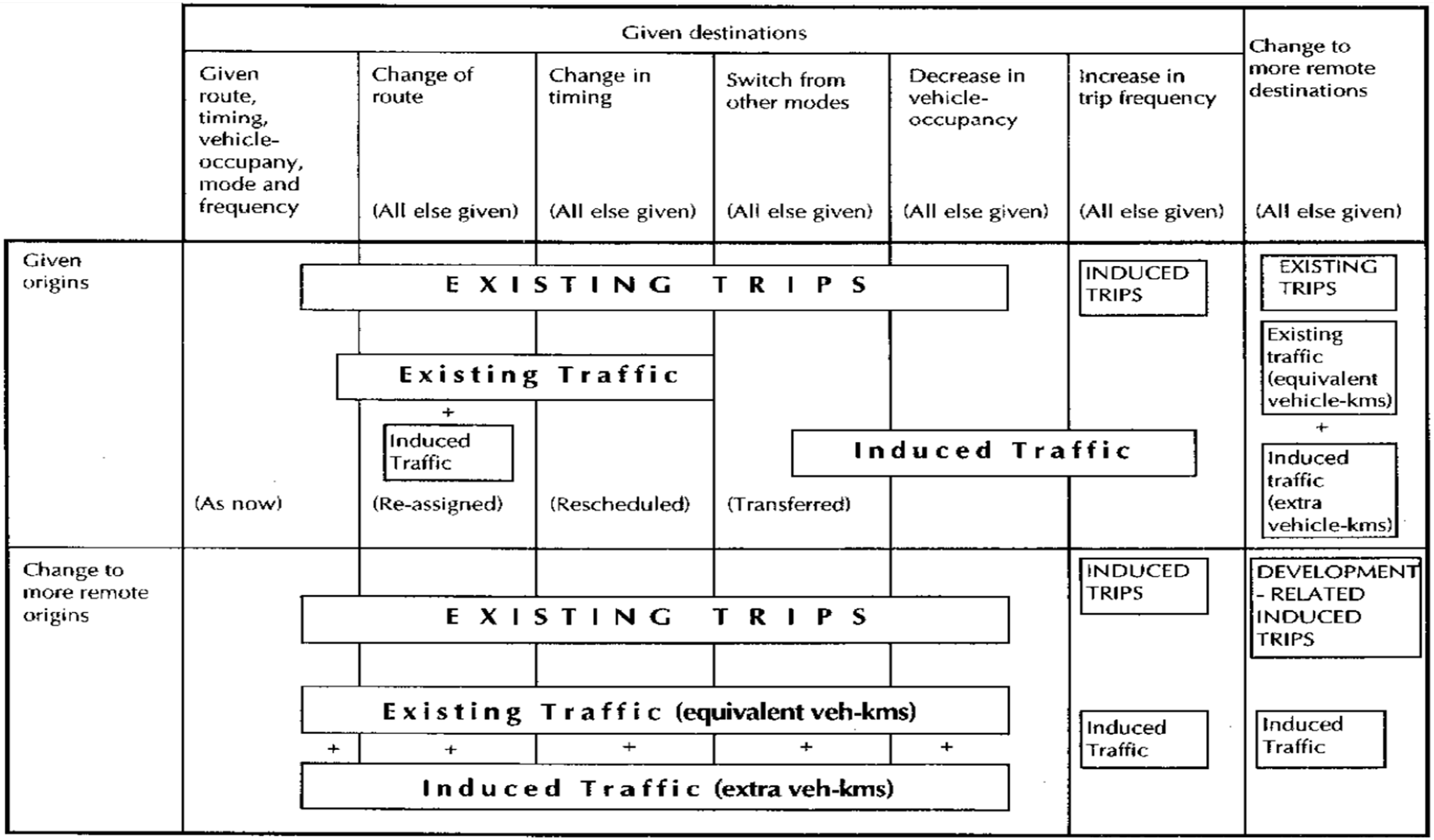



***Figure 7: Person-trip matrix taken from*** (SACTRA 1994)***.***

Overall the matrix is arranged after whether the origin and/or destination have changed after the capacity expansion.

- Fixed origin and destination: The top left six responses[5] all have fixed origin and destination and are called fixed trip matrix.
- Fixed origin, new destination: In the top right response, the capacity expansion has facilitated a relocation of the destination further away than before the capacity expansion, but still with a fixed origin.
- Fixed destination, new origin: The bottom six responses are where persons have changed to more remote origins after capacity expansion, but with a fixed destination.
- New origin and destination: Lastly the bottom right response is where the both the origin and destination have moved to more remote locations

In the following each of the responses will be explained.

## Fixed origin and destination

There are six different responses in the fixed-trip matrix; no-response, change in route, change in time, change in transportation mode, change in vehicle occupancy and change in frequency. Below in ***Figure 8*** an illustration is shown as example of how induced traffic affects the road network and to help explain the six responses.

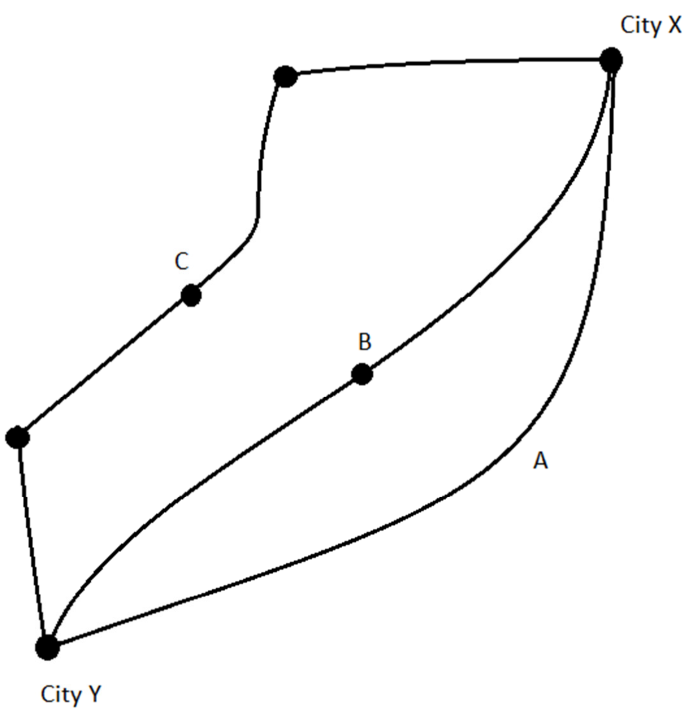



***Figure 8: Model of how induced traffic affects the road network.***

[5] Increased frequency can occur in all categories, but are explained in this category.

Imagine road A is a highly congested motorway, B is a medium congested road and C is an uncongested country road and this road structure has been the same for some time. Then equilibrium is said to have set in, meaning that drivers have chosen their preferred route between city X and city Y because they feel that this route is the most cost-efficient and maybe fulfil some specific objectives such as shopping, picking up children from kindergarten, family visits, nice scenery while driving etc.

If road capacity expansion is made to the road A in order to relieve congestion, then the traffic will flow more freely and thereby increase road speeds. This means that route A is now viewed as more cost-efficient than route B and route C. The drivers will then reconsider their mobility patterns and this is where the six responses are used.

### No response

In the no-response (as now) category it is important to note that this is a person-trip per day matrix and not a vehicle-trip per day matrix. In a vehicle-trips matrix some of the areas in the table in ***Figure 7*** would have been different e.g. the switch from other modes response is existing trips in a person-trip matrix, but in a vehicle-trip this response would be an induced trip (SACTRA 1994).

There are a group of the people affected in cities X and Y for which the road expansion has no effect and does not facilitate any direct changes in their mobility patterns, such as children, people who cannot afford a car, people who chose to not own a car, etc. These people's mobility patterns can however be affected indirectly by increased car-dependency, changed land-use patterns, sprawl, etc. meaning that their mobility patterns can be forced to change without the individual's own whish for change. There are also those who choose to drive on road B and C because the route fulfils some specific purposes like dropping children of at kindergarten, shopping, family visits, etc. They will still not see A as more cost efficient than the two other options road B and C.

### Change in route

Changes in route will usually affect drivers on route B and C. The trip distribution is affected because route A now is perceived by an additional number of travellers to be more cost-efficient compared to route B and C, so drivers who chose to take route B or C before the road improvement may now consider route A. This means that a portion of drivers from route B and C now will choose route A and thereby reduce congestion on road B and C. This will again make route B and C seem more cost-efficient and attractive to new drivers. It should be noted that changes in route are not categorised newly induced trips, but simply existing trips that are redirected. However there is a possibility that a small amount of induced traffic occurs if the driving distance is longer on the new route A than the previous routes B and C, but the opposite can also occur. Furthermore if route B and C become faster and more cost efficient because some drivers move from B and C to A, then there is a possibility that these routes may produce induced traffic from new drivers.

In regards to the time frame of the different effects of induced traffic a distinction is generally made between the short time frame (usually from zero to three/five year after the opening of the new/improved road) and long time frame (from three/five years and on) (Litman 2012). However time frames for the different effects vary dependent of context. Change in route or trip distribution is one of the short term effects of road capacity expansion. This can occur almost immediately after opening of a new project.

## Change in trip scheduling

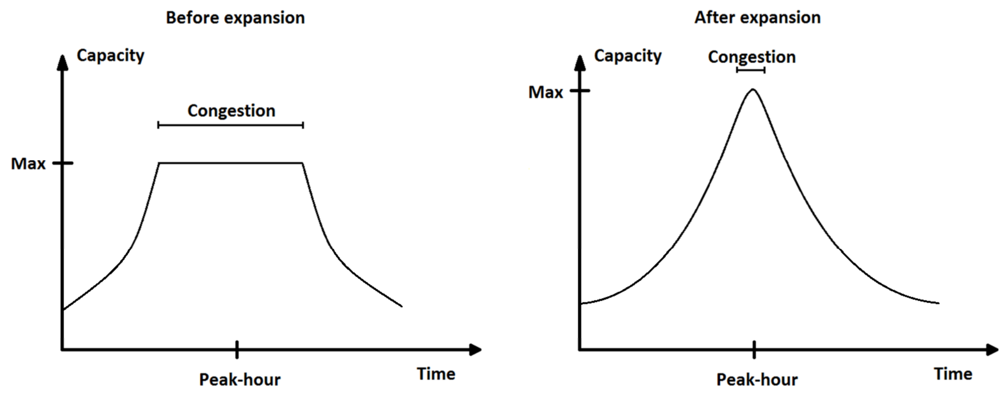



***Figure 9: Road capacity vs. traffic, around peak-hour.***

Time distribution of trips is affected around peak hour because drivers who before the road improvement had chosen to travel times outside of peak-hour traffic because of congestion, may after the road improvement be tempted to travel in or close to peak-hour traffic again. ***Figure 9*** illustrates how the capacity around peak-hour is fully utilized and the link thus heavily congested. People are therefore inclined to undertake travel outside peak-hour travel time. After capacity expansion the congestion around peak-hour has decreased and it is possible to travel in peak-hour again. This will again leave the time around peak-hour even more attractive and maybe induce new trips in this time frame. The re-timed travel is also not categorised newly induced trips, but only existing retimed trips. Change in time distribution can occur immediately after opening of the capacity expansion so this is also categorised as one of the short time effects.

## Change in transportation mode

Changes in transportation mode occurs when e.g. a person who used to take the bus, train, walked or cycled before the road improvement decides to take the car after the road improvement, because the perceived cost of driving a car now seem less than the cost of taking the other modes respectively. It should be noted that these trips are trips that would have been undertaken no matter if the capacity expansion was made or not. This means that they are not induced trips, but they are induced traffic since they shift towards less spatially efficient modes of transport, which in compliance with the definition of traffic used in this report.

The effects and time frames for change in transportation mode can be both short term and long term effects. The short term effects may be a shift from train to car, but in the long term the effects could develop into increased car dependency and diminished public transport services. One of the obvious effects of transport mode shift is added cars on the road network and it is also categorised as induced traffic. There are also some long term effects that follow change in transport mode. The shift form public transport to cars may not in the short run effect the public transport system, but in the long run public transport services could be diminished because of the decrease in passenger numbers and revenues and in the long run the cost of taking the car can also increase. This is called the Downs-Thomson paradox.

The Downs-Thomson paradox occurs in congested urban regions and is concerned with the interaction that happens between the cost of driving cars and the cost of public transport, when improving the flow of cars by e.g. expanding road capacity on congested roads. The premise for the Downs-Thomson paradox is that increased urban travel has opposite consequences for cars and public transport respectively. The cost of car driving increases as the number of cars increase on the road. This is because of congestion and increased travel time. However public transport costs decrease with increased usage. The increased patronage will increase revenues which again can lead to increased frequency of departures and improved public transport services in general.

The Down-Thomson paradox is grounded in the Downs equilibrium which is illustrated in ***Figure 10***. In the Downs equilibrium the flow of traffic on the network is held constant. This means that cars and public transport each holds a proportion of the total traffic on the road network.[6] The relationship between these two proportions is determined by the Downs equilibrium. Downs argued that the relationship between the two proportions would be determined by the cost of traveling with these two modes of transport respectively and that they would eventually find an equilibrium where there cost of taking the car would be the same as the cost of taking public transport (Mogridge 1997). This equilibrium is the Downs equilibrium as illustrated in ***Figure 10***.

[6] It is important to note that the Down-Thomson paradox and the Downs equilibrium are only concerned with the relationship between car and public transport.

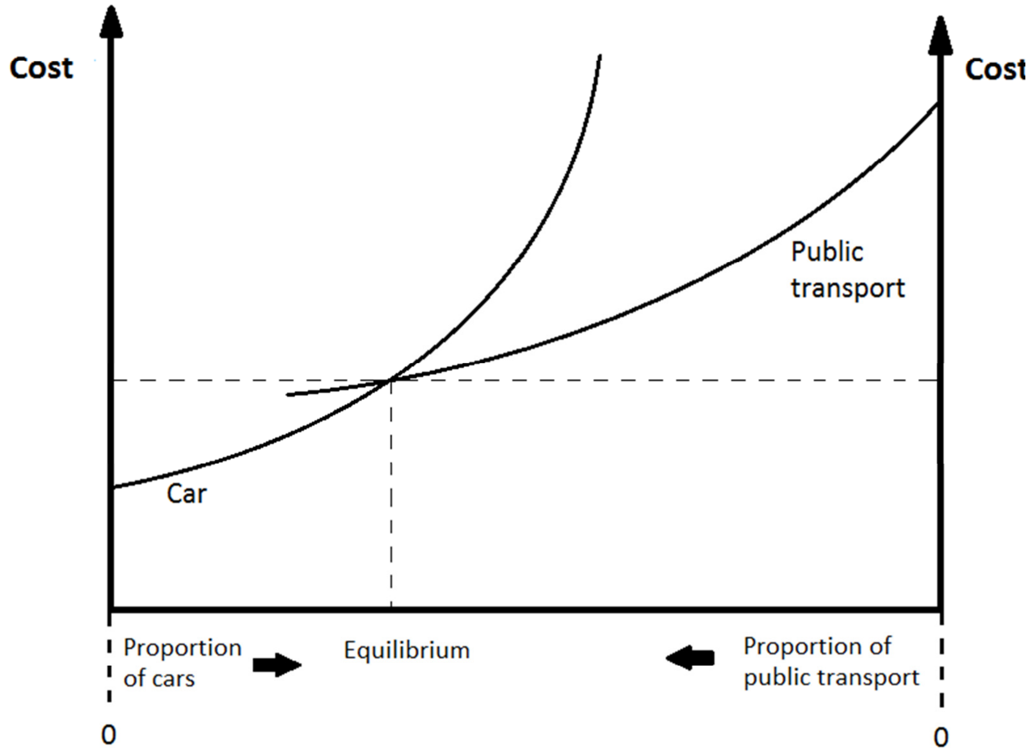



***Figure 10: The Downs equilibrium.*** (Mogridge 1997)

The Down-Thomson paradox occurs when expansions are made to the road network in order to relieve congestion. If the conditions are as before in Downs's equilibrium, then the flow is constant and the network has reached a congested equilibrium. If road capacity is increased then the cost of traveling by car will decrease for a fixed amount of traffic and the slope of the cost curve will level of as illustrated in ***Figure 11*** (Næss et al. 2001). A consequence of this is that the Downs equilibrium has moved further to the right. This is because car driving has become more attractive compared to public transport and thus more travellers will chose the car. Furthermore if one accepts that the cost of travelling with public transport increases as patronage decreases, then the equilibrium also moves upward because more people now take the car rather than public transport. This means that the act of relieving congestion and making it easier to travel has been counterproductive. A consequence of this is that attempts to improve congested urban traffic will be futile unless conditions for public transport are improved (Mogridge 1997).

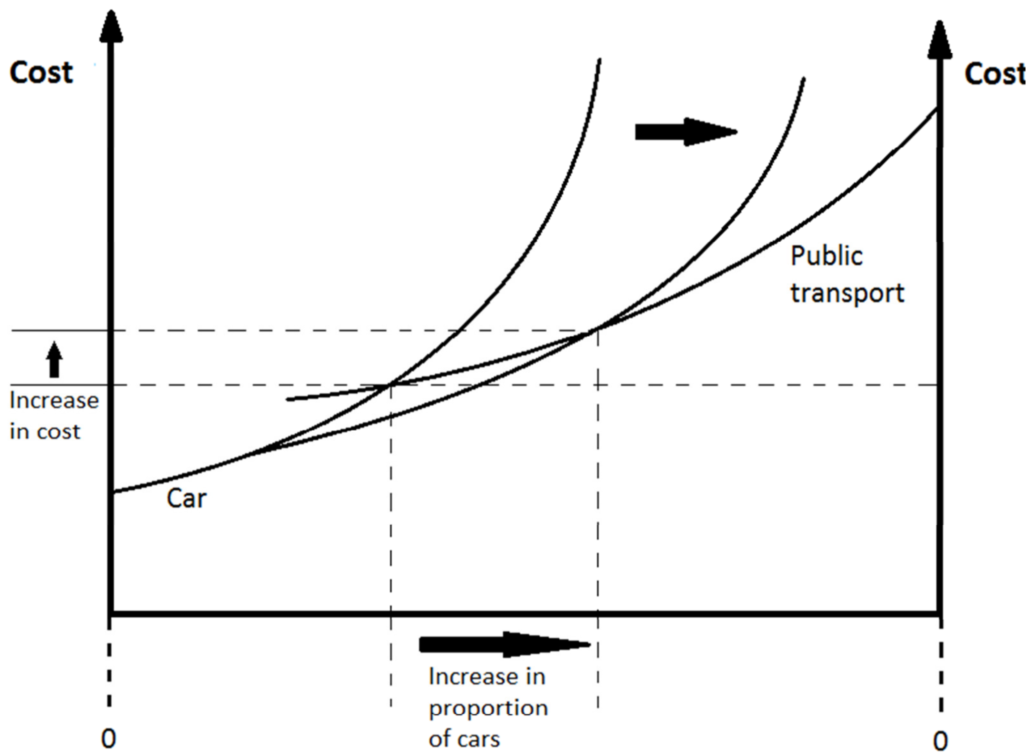



*Figure 11: The Downs-Thomson paradox* (Mogridge 1997)**.**

It is however not only on the roads the shift in transport mode has an effect in the urban area. The increase in the number of cars also has some consequences in the urban space: increase in the car fleet means that more urban space is allocated for car parking; conditions for pedestrians and cyclists are worsened and travellers by these modes feel unsafe; increased noise and pollution in cities; increased barrier effect; increase in accidents; and decrease in urban public transport services. While the shift from public transport to car may happen over a relatively short period, some of these other effects may accumulate over a longer period and cause future problems.

Another downside to the shift from public transport to car is the increased car dependency. The increase in car ownership can facilitate lower public transport services which then again facilitate an overall increased car dependency and increased car dependent development.

### Change in vehicle occupancy

Change in vehicle occupancy refers to the case were the cost of driving a car becomes so low that the difference between taking your own car and riding in a carpool or with others becomes negligible. So people who ride in carpools or with others decide to take their own car instead of a shared car or the carpool.

The time frame for changes in vehicle occupancy is short term, since it can start to take place immediately after opening of the capacity expansion. In a longer term, it may also increase car ownership and car dependency as in the case of change in transportation mode.

**Change in frequency**

Change in frequency can be an increase from zero to a single trip a year, and it can be an increase from 150 to 200, the important thing here is that these trips are totally newly induced trips. All the other five responses in the fixed trip matrix are already existing trips in one form or another.

Change in frequency occur because people who did not undertake a trip between X and Y before the road improvement, might now consider undertaking the trip since there now is an even more cost-efficient route between X and Y, namely A. This means that by improving traffic flow on A between X and Y there are induced some totally new trips on road A.

How new drivers decide to make the trip can be modelled by use of the economic theory supply and demand. This approach is often used to determine the time benefits of the road expansion (Nielsen & Fosgerau 2005).

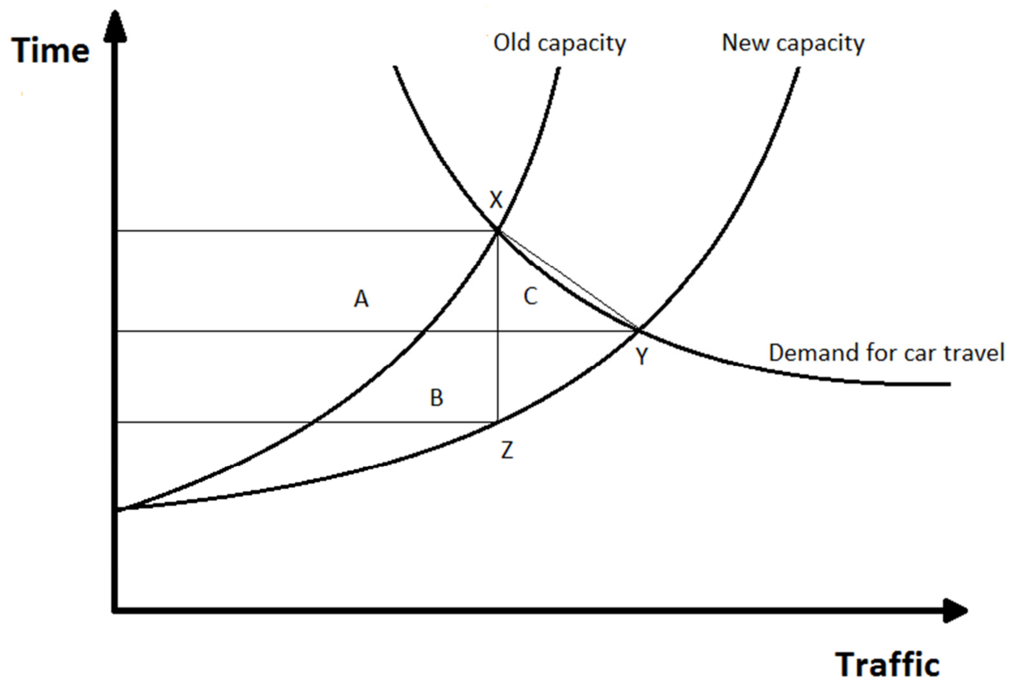



***Figure 12: Supply and demand model*** (Adapted from Nielsen & Fosgerau 2005).

If the premise that "people will travel more if the cost of traveling is reduced" is accepted, then ***Figure 12*** shows that traffic is dependent of the travel time if induced traffic is included in the model. To illustrate the differences between including induced traffic and not including induced traffic, the difference in travel time savings for both cases will be explained / shown.

If induced traffic is *not* included in a traffic model the travel demand line would be a vertical line at some point on the traffic-axes. That would mean that traffic was totally independent of travel time and no matter the travel time there would be the same amount of traffic. This will also mean large time benefits for existing drivers if the capacity then is expanded. The point X in ***Figure 12*** is the travel time on the old capacity. If then the capacity is expanded to the new capacity and congestion is relived, then the travel time decrease to Z. This means that if you do not include induced traffic the travel time savings of the capacity expansion is the area A+B.

If induced traffic *is* included the demand curve is as illustrated in ***Figure 12*** and in this case the travel demand line and new capacity intersect in the point Y instead of Z. This means that the travel time savings for existing drivers are the area A. But the travel time saving for the newly induced drivers shall also be calculated. This is usually done by the "rule of half" (Nielsen & Fosgerau 2005). "Rule of half" means the benefits of these newly induced trips are on average only worth half the benefits of an existing trip. This is because the "last" additional trip is made by a drivers who are almost indifferent about whether or not to undertake the trip, so the value is only marginally above 0, whereas the "first" additional trip is made by a person who was very close to carrying it out even before the road expansion, and for whom the new trip therefore gives nearly full utility value. The average for all the new drivers will then be half the utility value of existing drivers. This is illustrated by the triangle C in ***Figure 12***. The travel demand line between X and Y is usually approximated by a straight line as shown.

So the difference in travel time savings between not including induced traffic A+B and including induced traffic A+C is B-C. Since travel time makes up a large part of costs in CBAs, the difference in travel time savings is not negligible.

The time frame for increased frequency is short term, since it can start to take place immediately after opening of the capacity expansion. It can also increase car ownership and car dependency as in the case of change in transportation mode.

It is important to note that all these different responses do not work independent of each other but rather in synergy and eventually the road network will again reach equilibrium.

This ends my review of the different responses to a road improvement with fixed origin and destination. A change in perceived costs can, however, also bring about some changes in the origin and destination, which will be addressed in the next section.

### Fixed destination/new origin and fixed origin/new destination

The fixed destination/new origin and fixed origin/new destination responses can both be short term and longer term effect. An example of people who fall in the fixed destination/new origin response category will typically be people who are willing to travel further in order to get a job because of the decrease in travel time or people who travel further to visit large shopping centres instead of shopping at the local marked. For the fixed destination /new origin response a typical example will be people moving further away from their workplaces, to a more desirable dwelling location. These trips are of course all existing trips, but there are bound to be some induced traffic since the mobility of the persons in question has been improved and it will be easier to travel longer for them. It seems implausible that people will travel less if their travel costs are decreased. Below in ***Figure 13*** an illustration of the two responses is shown.

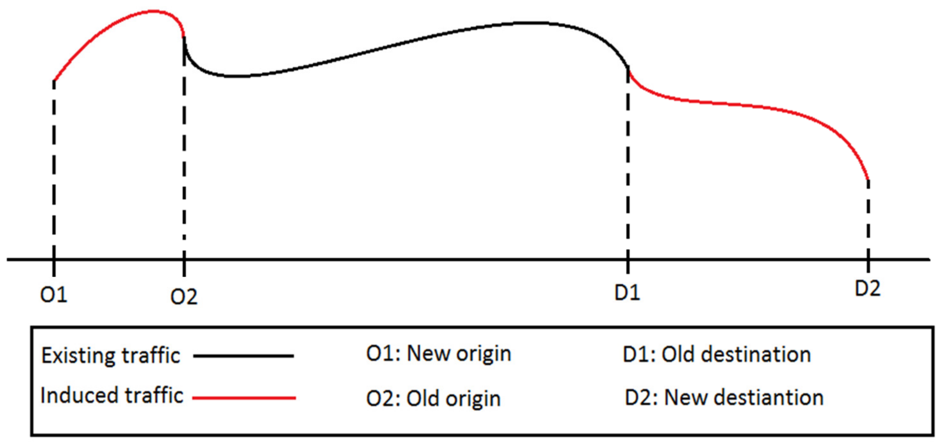



***Figure 13: Map showing change in destination and/or origin.***

On the map in ***Figure 13*** two cases are shown; the origin O2 that has moved to O1 and the destination D1 that has moved to D2. Note only one of the two responses occur in this response category. When a change in origin occurs it is the red part of the trip between O1 and O2 that produces induced traffic and the remaining part of the trip from O2 to D1 is the old part of the trip and existing traffic. For change in destinations it is the red part of the trip between D1 and D2 that is the induced traffic and the black part of the trip between O2 and D1 is the existing traffic.

These responses to capacity expansions are usually long term effects since they involve change in land use. However in the case of new motorway construction changes in land use can occur quickly after opening. It is often seen that companies that have a lot of logistics are placed close to motorways and there are of course all the businesses and workplaces in rest stops that are built along with the motorway like hotels, petrol stations, restaurants, cafés and kiosks. All these developments happen quite quickly after opening of a motorway, but new land use development and speculation in land can happen as soon as project is announced if the market conditions are suitable (Litman 2011). In the medium to long term people will start to look for work and homes in a larger radius than they would if the expansion was not build. After a while this may also start to reflect on land use development such as more dispersed development and more car dependent development (Litman 2011).

### New origin and destination

When there is a change in both origin and destination there is usually talk of long term effects and it becomes more difficult to determine if the move is facilitated by the change in accessibility or if it is facilitated by other factors such as new development or change in life structures such as change from work to retirement or a young person who has finished school and has to start work and leave home. In ***Figure 13*** changes in both origin and destination are comprised in the red part of the trip from O1 to O2 and the red part of the trip from D1 to D2, which are both induced traffic. The black part of the trip is the existing trip.

The time frame of new origin and new destination is long term since in most cases this category involves major restructuration of people's accessibility patterns and in the case of commuter trips, the restructuration entails that the person finds a new location for dwelling and a new workplace. Since both origin and destination have changed in this response it becomes more difficult to determine if it is an existing trip or it is an induced trip. SACTRA (1994) found that the best way to approach this is to determine whether the purpose of the trip in question is related to existing development that predates the new road expansion or if the trip relates to new development that has been built after the road expansion (SACTRA 1994).

In the case where the purpose of the trip relates to existing development, the trip is an existing trip and only the extra vehicle kilometres travelled (i.e. red parts of ***Figure 13***) is regarded as induced traffic, since the shorter trip (i.e. the black part of ***Figure 13***) also was carried out before the new road construction. In the case where the purpose of the trip relates to new development that was not present before the road construction, the whole trip is regarded as induced traffic (i.e. both the red and the black part of ***Figure 13***) since the trip would not have been carried out if the new road project had not been carried out.

Below in ***Table 2*** all the different responses are listed along with their time frame effects and traffic impacts.

| Response | Time frame | Effect | Traffic impacts |
|---|---|---|---|
| **No change** | - | - | None |
| **Change in route** | Short term | Diverted traffic | Small increase or reduction in traffic |
| **Change in time** | Short term | Diverted traffic | None to small increase in traffic |
| **Change in transportation mode** | Short and long term | Induced traffic / diverted travel | Increase in traffic / Car dependency / Reduced public transport services |
| **Change in vehicle occupancy** | Short term | Induced traffic / diverted travel | Increased traffic / increased car ownership |
| **Change in frequency** | Short term | Induced traffic | Increase in traffic |
| **Change in origin** | long term | Induced traffic | Increase in traffic / land use |
| **Change in destination** | Short and long term | Induced traffic | Increase in traffic / land use |
| **Change in origin and destination** | Short and long term | Induced traffic | Increase in traffic / land use |

***Table 2: Type, impact and Time frame of the different responses to road capacity expansion*** (Adapted form Litman 2011)**.**

## 2.2 Behind the theory of induced traffic

It is important to note that the theory and the behavioural responses mentioned above are rooted in the assumption that the individuals wish for travel time savings; an assumption that could be said to be based on the rationality of an "economic man". The ideal type of an "economic man" will strive to reduce the general travel costs when under taking a trip. This assumption means that travel time is heavily weighted in modelling and evaluating of travel behaviour and implies that people's travel behaviour is governed by the wish to optimise travel time savings. This is of course not always how real humans behave. Other rationales for traveling and modal choice are also present as found in a study by Næss & Jensen (Næss & Jensen 2005; Næss 2005; Næss 2006) referred to by Næss & Møller (2004). Below followed the rationales for travel mode choice referred to in Næss & Møller (2004):

- constraints and possibilities set by the person's mobility resources
- time consumption
- monetary costs
- bodily constraints and a wish to avoid physical efforts
- flexibility and freedom
- a wish for physical exercise
- environmental considerations
- lifestyle signalling
- habits and customs inherited through adolescence, and to some extent

- social norms.

This means that people do not always or only behave as the “economic man” choosing the most time- and cost-efficient mode of travel. For example, some people insist on taking the car through peak hour traffic even though public transport or cycling would have been quicker and more time efficient. And some people decide to cycle or walk in order to get exercise even if car travel is faster and more time efficient.

The above theory on induced traffic is then not a description of how the behaviour responses are in real life, but a model designed to simplify and help simulate behavioural responses that can help in the analysis of these responses. In real life behavioural responses are much more complex and context-dependent. The behavioural responses have different time frames and depend much on the specific situation. Some of the response may be short term in one context and be long term in another context or they may not even happen. The different responses also have different consequences in different contexts so generally one should be careful to have a predetermined set of determinants that follow a road capacity expansion. It is important to note that the different responses can be added together and work simultaneously e.g. a person could leave a carpool scheme in order to attend a new job further away. This would then be an example of change in car occupancy + change in trip destination, which is an existing trip that produces induced traffic + induced traffic because of the longer trip. This means that the behavioural responses and their effects can work in synergy and be cumulative. It should also be noted that the effect of inducing traffic by expanding capacity and increasing flow also work the other way around, so that reducing traffic flow will lead to a decrease in traffic. In a study by (Cairns et al. 2002) is was found that reallocating road space from cars did not create traffic chaos. The traffic problems that occurred in connection with the reallocating of road space were usually far less than predicted. They also showed that by reallocating read space from cars overall traffic levels can be significantly reduced.

# 3 Methodology

Presented in this chapter, are the methods used for data collection, the methods of analysis, data availability and considerations that were associated with choices made in the current study. The aim of this chapter is to create clarity and reflect on the chosen methods, starting with a general description of the research design.

## 3.1 Approach to Research Design

The aim of this study is to obtain empirical evidence of induced traffic in Denmark and if possible get an estimate of the magnitude of this induced traffic. The approach and methods chosen in order to answer the research questions are described in the following.

In order to help answer the research questions of this study and to structure the research design, a table was constructed in the preliminary stages of the study. This table is shown in ***Table 3***. The table was constructed to help clarify which theory, empirical information/data, methods and resources was needed to answer each research question. The table is pretty self-explanatory, but will be described briefly below. In the first column the research questions of the study were stated. In the next column, the theory needed to answer the concerned research question is stated. In the third column the empirical data needed were noted. In the method column the approaches to answering the research questions were chosen. Lastly in the fourth column, the different resources needed for applying the methods and obtaining the data were noted. When completed, the table gives an overview over the whole study and clarifies data, theory, methods and resources needed.

| Main Research Question | Theory | Empirical Information | Method | Resources |
|---|---|---|---|---|
| -To what extent has induced traffic appeared when building new roads or expanding roads in Denmark? | -Theory about induced traffic and by which causal mechanisms it is produced. (SACTRA 1994; Litman 2012; Phil Goodwin 1996; Næss et al. 2012; Hills 1996) | -Traffic counts from as many road projects as possible, before and one, three and five years after project opening.<br>-General traffic growth since 1980 | -Corridor analysis one, three and five years after opening. | -Technical traffic reports<br>-Mastra<br>-Before and after reports published by the Road Directorate<br>-Vejman.dk |
| **Sub Questions** | | | | |
| -Does the magnitude of induced traffic differ between different geographical areas? | -Theory about induced traffic and by which causal mechanisms it is produced. (SACTRA 1994; Litman 2012; Phil Goodwin 1996; Hills 1996) | -Geographically dependent information on development in factors that might induce more traffic in some regions than in others, such as; traffic, population, income, car ownership, public transport accessibility and so on.<br>-Information on the level of induced traffic in the different regions of Denmark. (obtained from the main RQ) | -Comparing level of induced traffic on similar road projects in different regions of Denmark. Controlling for factors that may induce more traffic in some regions than in others. | -Danish statistics.<br>-Empirical data on induced traffic nationwide (own empirical study).<br>-Articles and studies on induced traffic |
| -What is the difference in the level of induced traffic between road expansions on congested and uncongested roads? | -Theory about induced traffic and by which causal mechanisms it is produced. (SACTRA 1994; Litman 2012; Phil Goodwin 1996; Næss et al. 2012; Hills 1996) | -Data on the level of induced traffic on road projects.<br>-Information on the level of congestion on the selected road projects. | -Comparing the level of induced traffic between road projects with different level of congestion. | -Empirical data on induced traffic nationwide (own empirical study).<br>-Empirical data on congestion levels on the selected road projects (Mastra? Road directorate?) |
| -What is the difference in induced traffic between different types of road projects? | -Theory about induced traffic and by which causal mechanisms it is produced. (SACTRA 1994; Litman 2012; Phil Goodwin 1996; Hills 1996) | -Information on the level of induced traffic on different types of roads. | -Dividing the road projects in to categories of similar types and comparing the level of induced traffic.<br>-Maybe controlling for geographical differences (sub-question above) and congestion level. | -Empirical data on induced traffic nationwide (own study).<br>-Articles and studies on induced traffic |

***Table 3: showing the basic structure of the research design in the preliminary stages of the study.***

It should be noted that ***Table 3*** in not a final list of theory, method and resources used in this study e.g. under theory there are only mentioned a few articles. The articles mentioned in the table are only used to give an indication of the theory that is to be used in the study and several more articles are used. Furthermore new articles, methods and resources have been discovered during the course of the study and are not noted in the table, since the table was made in the preliminary stages of the current study.

## 3.2 General research design

The aim of the current study is to obtain empirical evidence of induced traffic in a Danish context, and to determine the magnitude of this induced traffic if possible. Since the objectives of this study are quantitative in nature, the method chosen to answer the research questions is also quantitative in nature. The main method of analysis for determining whether or not induced traffic occurs is corridor-analysis. In order to obtain a valid estimate of the magnitude of the induced traffic it was the aim of this project to collect information about as many road projects as possible with appertaining before-and-after traffic counts from one to five years after the opening of the project. Firstly the aim was 150-200 road projects, but the number of projects has since been lowered, since the availability of data has not been as first expected. When the road projects had been selected, a corridor-analysis was performed to get an estimate on how much induced traffic has occurred as a result of each road project. After having calculated the magnitude of induced traffic for each case, analyses were performed on all the projects in order to get a result regarding the existence and the magnitude of induced traffic among the total sample of projects. Furthermore the projects were divided in categories according to geography and type of road in order to clarify if there is a geographical difference in the occurrence of induced traffic and on which types of road it appears.

### Approach for measuring induced traffic

The specific method for calculating induced traffic in this report is by using before and after traffic counts, counted at one or more screenlines. This approach is called corridor analysis and the aim of this approach is to measure changes in the throughput of motor vehicles in the corridor in question. Screenlines are lines placed to mark where the traffic is to be counted in the corridor, both on the main road in question and on the connecting parallel roads included in the analysis. An example of screenlines is shown in ***Figure 14*** below. In relation to the opening of each of the 45 projects used in this study, the Road Directorate has published a before and after report, describing the traffic development by means of traffic counts from before and after the opening of the project. It should be noted that traffic counts are taken before and after the opening of the project and adjusted to one reference year, furthermore, this first traffic count from the same year as the opening of the project is called the immediately after traffic count. This means that there will be collected traffic counts; before the opening, immediately after the opening, one, two, three, four and five years after the opening. These before and after reports have been collected and used as the basis for the immediately after traffic counts and the placement of the screenlines. For the traffic counts one to five years after project openings other source had to be used, since the Road Directorate's ex-post evaluation only covers the year of the opening of a project. The potential sources for one to four year traffic counts are Mastra, the technical traffic reports published by the road directorate, the archives at the municipalities and Vejman. However, not all of these sources were used in the present study. The different data sources and the reasons for choosing among them will be described later in this chapter.

Below in ***Figure 14*** is an example of a case-project with appertaining traffic counts before and after the opening of the project, made by the Road Directorate. The screenlines are placed by the author.

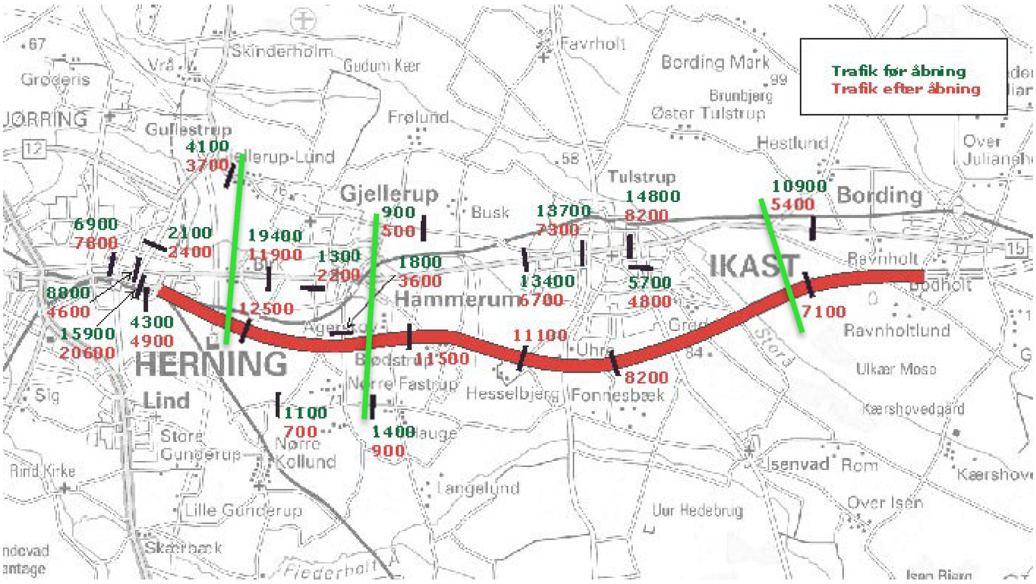



*Figure 14: Example of a case-project and placement of screenlines.*

For each project the traffic counts before and immediately after opening of the project will be noted in a spreadsheet along with the traffic counts one, two, three, four and five years after opening, where the growth also will be calculated. The general traffic growth is also noted in the spreadsheet, since the general traffic growth is to be subtracted from the traffic growth of the road projects in the given year. The general traffic growth in Denmark for the period 1980 – 2010 was found in the StatBank Denmark[7]. The magnitude of induced traffic can now be calculated and this has been done for all the 45 projects.

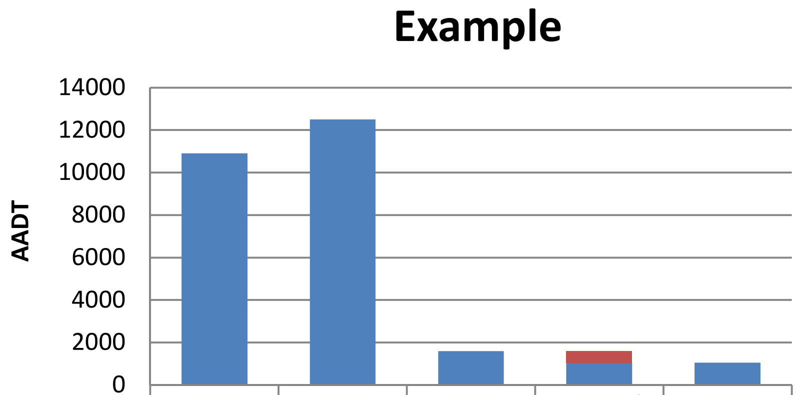
### Example of how induced traffic is calculated

If the project is a new stretch of road that opened in 2000, then traffic counts before and immediately after the opening of the road is needed. These traffic counts are obtained through the before and after reports, furthermore the traffic counts for the five year period are needed. This would then be traffic counts from 2001, 2002, 2003, 2004 and 2005. The following example will show how induced traffic is calculated one year after opening 2001. In this example the before traffic counts are taken immediately before opening and the after traffic counts are taken exactly one year after opening of the project. How the time periods between traffic counts are determined and why the before and after method are chosen will be discussed later in the chapter. The difference between the traffic counts at the screenline in year 2000 and 2001 can then be found. This difference is then an expression of how much the traffic has increased in the given time period at the screenline. However, this increase in traffic is not all induced traffic. The general traffic growth has to be subtracted from this difference since not all the difference can be attributed to induced traffic.[8] Furthermore it should be noted that what is commonly known as general traffic growth also consists to some extent of induced traffic facilitated by the general improvements to the overall road

[7] StatBank Denmark contains detailed statistical information on the Danish society. http://www.statistikbanken.dk/statbank5a/default.asp?w=1920

[8] In the case of the registration immediate after opening the general traffic growth has not been subtracted, since the before and immediate after traffic count are taken in the same year and any variations in general traffic growth has been adjusted by the Road Directorate.

network. This "generally" induced traffic should ideally be filtered from the general traffic growth so all the induced traffic is accounted for. This will be discussed later in the chapter. Below in ***Figure 15*** is shown an illustration of how induced traffic has been calculated.




| | Before, Year 2000 | After, Year 2001 | Increase in traffic 2000-2001 | General traffic growths part of increase in traffic | induced traffic |
|---|---|---|---|---|---|
| General traffic growth 5 % | | | | 545 | |
| traffic counts | 10900 | 12500 | 1600 | 1055 | 1055 |

***Figure 15: This graph illustrates how much of the traffic growth between year 2000 and year 2001 can be contributed to general traffic growth, when the general traffic growth is set to 5%, and how much can be attributed to induced traffic.***

In ***Figure 15*** above, it is shown that the increase in traffic after the opening of the road project is

$$Increase\ in\ AADT = After - Before = 12500 - 10900 = 1600$$

This gives an increase in traffic of

$$Increase\ in\ traffic = \frac{1600}{10900} * 100\% = 14{,}7\%$$

in the period 2000 to 2001. But as mentioned above, there is a general growth in traffic in that period, which in this case is set to about 5% (The general traffic growth will be retrieved from Danish Statistics or the Road Directorate). This means that 5% of the traffic growth on the road in the period 2000 to 2001 are coursed by general traffic growth and should be subtracted from the 14.7% increase in traffic, leaving the traffic that is induced by the new road.

$$Induced\ traffic = After - before * (1 + g_n)$$

Where $g_n$ is the general traffic growth in the specific period $n$.

$$Induced\ traffic = 12500 - 10900 * (1 + 0{,}05) = 1055$$

This gives an increase in induced traffic of

$$Induced\ traffic = \left(\frac{Induced\ traffic}{Before}\right)100 = \left(\frac{1055}{10900}\right)100 = \underline{9{,}7\%}$$

Note here, that the part of general traffic growth that is induced by general improvements to the overall road network is not subtracted from the general traffic growth, leaving a conservative estimate of the induced traffic.

## 3.3 Reflection on methods

The following will reflect on the method and the different choices made in this study. The sources for data will be discussed. The method will be related to the theory in order to clarify how good the method is to fulfil the research questions.

### Corridor Analysis

In Denmark there have been performed semi-systematic traffic counts in relation to most new larger road projects and on main roads in most of the country over the last 40 years. This means that before and after traffic counts for some of projects have already been done in pamphlets published by the Road Directorate. These pamphlets with appertaining traffic counts have been collected in order to obtain the traffic counts and other relevant information about the projects. This data has then been complemented with traffic counts from the Mastra database and the technical traffic reports in order to obtain traffic counts for the whole four year period after the opening of the projects. After having collected as much data as possible covering the four year period, a corridor analysis was performed as explained above.

The reason for choosing corridor analysis is that it is an effective way of measuring the changes in throughput through a corridor. In regard to induced traffic, this is interesting because this gives an indication of whether or not the road improvement has facilitated an increase in frequency of cars passing through the corridor. There are however some reservation when using corridor analysis. A road improvement may for example facilitate more small shopping trips in-between the screenlines that are not detected and fewer local shopping trips outside of the corridor included in the analysis. This means a further discussion of the methods applicability is warranted for and will be presented in the following.

### Method in relation to theory

The following will try to link the theory of induced traffic presented in the theory chapter with the method of corridor analysis chosen in this study. A qualitative discussion, of corridor analysis' applicability to capture the behavioural responses to changes in accessibility, will be given. This is done to emphasise the weakness and strengths of the method and illustrate the difficulty of capturing the effects of induced traffic.

As mentioned above, the method of corridor analysis has a limited geographical area in which the analysis is performed. This means that changes in behavioural responses that occur outside of the chosen corridor will not be detected by the method. So the following is concerned with assessing how good the method is at detecting changes in the different behavioural responses **within** the corridor chosen for the analysis.

As mentioned in the theory chapter, the behavioural response matrix shown in ***Figure 7*** is arranged after whether the origin and/or destination have changed after the road projects has been completed. This gives the four possibilities shown below

- **Fixed origin and destination**: The top left six responses[9] all have fixed origin and destination and are called fixed trip matrix.
- **Fixed origin, new destination**: In the top right response, the road project has facilitated a relocation of the destination further away than before the road projects completion, but still with a fixed origin.
- **Fixed destination, new origin**: The bottom six responses are where persons have changed to more remote origins after the road projects completion, but with a fixed destination.
- **New origin and destination**: Lastly the bottom right response is where the both the origin and destination have moved to more remote locations

### Fixed origin and destination

Within the fixed origin and destination sub-matrix there are six different responses that occur.

- No-response
- Change in route
- Change in time
- Change in transportation mode
- Change in vehicle occupancy
- Change in frequency

#### *No-response*

There are no changes to detect

#### *Change in route*

Theoretically the method of corridor analysis would be good at detecting changes in the rout choice within the corridor. I.e. if all the roads within the corridor where covered by screenlines, all the changes in rout could be detected. However, there are seldom more than two to three roads in a corridor analysis for which there exist traffic counts, this being the new road and the old main road and maybe one or two byroads. And usually only one to four screenlines are placed. If the changes in route should be detected perfectly the whole road network within the corridor should be covered by a screenline, which would be unmanageable. However, the present study is only concerned with changes in the total throughput of the corridor and not where in the corridor these changes occur. The current study is thus only concerned with the possible increase or decrease in frequency that the changes in route might facilitate by relieving some of the old roads. This frequency will be discussed in the increased frequency category.

It should be noted that, this method ideally should not detect any changes in induced traffic if only the "changes in route" behavioural response occurred. However, since not all roads in the corridor are included there can occur instances

[9] Increased frequency can occur in all categories, but are explained in this category.

where a change in route is registered as an increase in induced traffic, even though changes in route is existing trips. This can occur if a driver change route from a road which is included in the corridor analysis, to a road that in not included. The frequency of cars will then decrease affecting the induced traffic registered in the corridor. The same is of course true if the driver changes from a road not included to a road included in the corridor, only the effect would be an increase in induced traffic. However, it is the authors believe that the effect of this to the overall result of the corridor is relatively small, since this occurs only at the smaller roads.

### *Change in time*

The method chosen is not capable of registering changes in timing of trips, since it is using aggregated values of AADT over the whole year. However, changes in timing dose not directly cause any changes in induced traffic. The indirect effect, of facilitating induced traffic by making traveling easier on certain times, is included in the induced frequency category.

### *Change in transportation mode*

The method of corridor analysis is very good at capturing the behavioural response of change in transportation mode within the corridor. It is of course implicit that the change in transport is from walking, cycling or public transport to car, i.e. adding an additional vehicle to the corridor in question. There is the case where a person changes from public transport to take the car on a road that is not included in the corridor analysis. However, these low level roads are usually placed some distances away from the new road project and will thus represent a considerable detour. Furthermore the congestion levels on these byroads would be very low if not none and thus the effect of the new road project would be very limited.

### *Change in vehicle occupancy*

The method of corridor analysis is good at capturing the change in vehicle occupancy, i.e. changes where a person goes from carpooling to taking his or hers own car. As in the case of change in transportation mode there is the case where the person goes from carpooling to taking the car on a road which is not included in the corridor analysis. However, as argued above the effects of this to the overall result is very limited.

### *Change in frequency*

Corridor analysis is designed to register changes in frequency so it is no wonder it is very good at detecting changes in frequency within the corridor, there are however some reservation. In a corridor analysis the traffic is measured at screenlines as mentioned earlier. These screenlines are placed with some distance apart, so if the trip is small enough to be carried out in between the screenlines the trip would not be registered. These unregistered trips would most likely occur in highly congested urban areas, where there are short distances between the different services. It is the authors believe that, “missing” these short trips could have a small effect on the overall results of the study, thus leaving a conservative result.

### Changes in origin and/or destination

The three last cases where the origin, destination or both origin and destination changes are a little more difficult to assess. Within a corridor analysis changes in origin and/or destination would be registered in the case where the change crosses a screenline. However, if the change is brought on by increased mobility one would think that the distances, with which origin and/or destination have moved, would be fairly significant, because otherwise the changes would be possible without the increased mobility and the move would thus not by induced by the new road project. Because of this, it is estimated that the method captures most of these behavioural responses within the corridor analysis.

In addition to these behavioural responses within the corridor come the responses which occur outside the corridor. This could be for example upstream or downstream bottlenecks, affecting the traffic and travel behaviour outside the area included in the corridor analysis. This means that one has to be careful in choosing the size of the corridor that is to be analysed. In this study the size of the corridor is chosen to be the same as used in the before and after reports published by the Road Directorate. This means that corridor analysis cannot hope to capture the complexity of the behavioural responses described in the theory chapter and this should also be kept in mind when interpreting the results.

There are of course other approaches to registering induced traffic and another method that could have been used is GPS-data on a large sample of cars in the area affected by the road improvement. This method would be able to detect changes in existing drivers' route-choices and trip-chains. However this method also has some shortcomings. This method would not detect any additional new cars to the road network and it would also not detect behavioural responses as changes in car-occupancy. Also questionnaires on origin-destination data, before and after opening of a project, are another method to obtain information about the behavioural responses. This method also has some shortcomings due to difficulties in finding people willing to participate and the long time span between before and after questionnaires. However, a combination of two or three of the methods may be beneficial since they may complement each other. This has unfortunately not been possible in this study because of data and time constraints.

### General Traffic Growth

General traffic growth is affected by the general improvements and expansions to the overall road network as well as fuel prices, increase in populations and increases in car ownership. This general traffic growth shall of course be subtracted from the growth found at each of the projects, since it is not induced by the road project itself but by these other factors. The values used in this study are national values for general traffic growth, found in Statistics Denmark which is the central authority on Danish statistics (Statistics Denmark 2012). After an interview with the Road Directorate it has come to the author's attention that values for general traffic growth could have been received upon request on a regional level and that this might have been beneficial to the current study. However, it has not been possible to change these values because of time restraints.

It is important to note that part of the general traffic growth mentioned above is induced by general improvements to the overall road network and should ideally be subtracted from the general traffic growth and counted as induced traffic, since it is induced traffic generated by other road projects. However, there do not seem to be any estimations of this part of general induced traffic in the literature. So it has not been possible to do so. Furthermore by not subtracting this general induced traffic part from the general traffic growth, the estimate of induced traffic facilitated by new roads or road improvements will be a conservative estimate.

## Screenlines

Different considerations have to be made when screenlines are to be placed. Data availability and which nearby roads are affected are the two main factors in placing the screenlines. The placements of the screenlines are mainly determined by where available traffic counts are taken. Since traffic counts are only performed a few places along a road and not carried out for this specific study the placements of screenlines are limited.

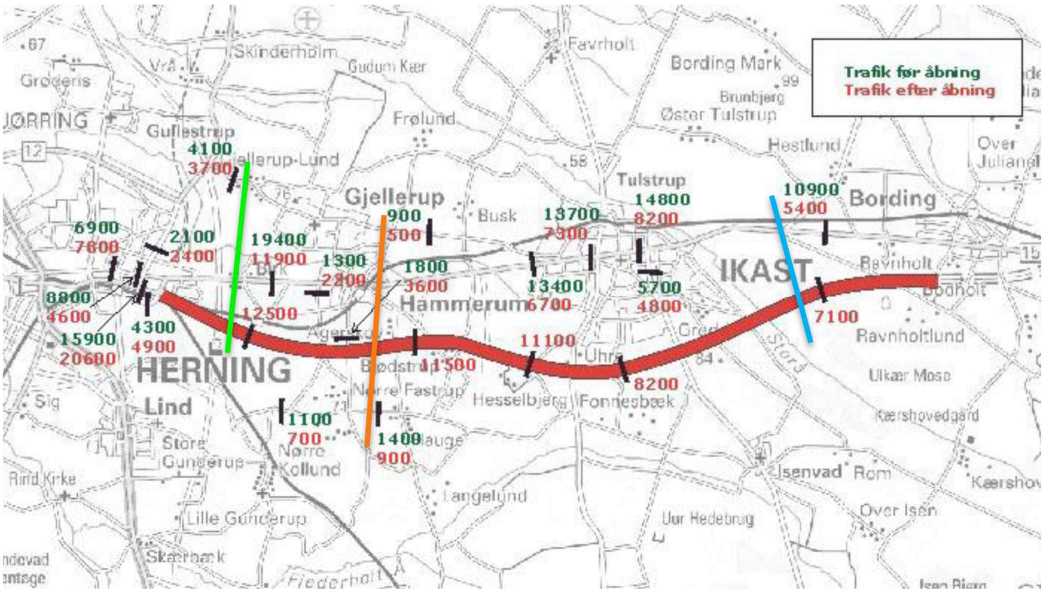



***Figure 16: An example of how screenlines are placed.***

Above in ***Figure 16*** is shown an example of how screenlines are placed. The blue screenline is placed beside the 7100 and 5400 "after" traffic counts mainly because the traffic counts are placed between the small towns of Bording and Ikast. The screenline also only covers two roads, namely the old highway and the new motorway. This is partly because these are considered the most affected roads and partly because this is where there are traffic counts available. Ideally the smaller roads further out should have been included, but traffic counts were not available. The orange screenline is placed between Ikast and a village called Hammerum, but this time it covers four roads instead of two roads as in the case of the blue screenline. Here the traffic counts are available and the two additional roads added are larger roads that follow the main roads closer, thus being more likely to be affected by the opening of a new road. The green screenline is placed between the town of Herning and the village of Hammerum. At the green screenline there are three roads that have traffic counts. I.e. the three screenlines are placed between the larger settlements in the area. This is done mainly to see how the traffic is affected on the entire stretch of new road and to get a more precise measurement of the induced traffic.

It should be noted that the two fixed link motorway connections are special cases. Since there are no byroads on which to measure the before traffic, the before traffic counts are taken to be the car traffic which uses the ferry routs over the connection. The after traffic counts are of course the traffic on the new fixed links bridges and the traffic which uses the ferry connections in question. The determining factor, to which ferry routes are included in this study, is the Road directorates' before and after reports. However, as far as the author can tell all car carrying ferry connections are included in both cases

## Timespan between Traffic Counts

This study is mainly concerned with the development of induced traffic in the first five years after the opening of a project. All the road projects included in this study have a year one traffic counts that is taken immediately after opening of the project. This data was fairly easily available since the Road Directorate over a long time has period performed traffic counts on new road projects before and after the opening. These first-year traffic counts will give an idea of how fast induced traffic sets in and how large the immediate jump in traffic is. But the short term effect of induced traffic is not limited to the first year. Litman (2012) has set a mark at three years, where the short-term effects fall inside the first three years and the long-term effects start to appear three years after the opening of a new road. Below in ***Table 4*** is a list of studies that have examined long term effects after three years.

| Author | Short-term | Long-term (+3 years) |
|---|---|---|
| SACTRA | | 50 - 100% |
| Goodwin | 28% | 57% |
| Johnson and Ceerla | | 60 - 90% |
| Hansen and Huang | | 90% |
| Fulton, et al. | 10 - 40% | 50 - 80% |
| Marshall | | 76 - 85% |
| Noland | 20 - 50% | 70 - 100% |

***Table 4: Short and long - term results for proportion of new capacity absorbed by induced traffic, found in different studies.*** (Litman 2012)

In other studies long-term effects are set to appear after five years. It is of course not so simple to determine where the short-term effects end and the long-term effects begin. It is a fluent and also very context dependent transition.

In the present study there are six registrations of traffic; before, immediately after, one, two, three and four years after opening of the projects, where induced traffic is calculated at immediately after, one, two, three and four years after opening. This was chosen in order to be able to follow the development in induced traffic because some effects of induced traffic first occur after a period of time. The reason why the registration period is limited to four years is that data becomes increasingly difficult to obtain, the longer away from the opening it is and some considerations in regards to the time limits of this study had to be taken.

## Data Availability

This study relies on traffic counts taken over the last 30-40 years. This means that there is a lot of data and that it has to be collected from a lot of different places. There are three data sources used in this study, namely; Mastra, technical traffic reports and before and after reports. Originally also the municipality's archives and Vejman were considered as sources for obtaining data, but after an interview with the Road Directorate and a small phone survey amongst the municipalities these two sources were discarded. The different sources are described below.

## Mastra

A lot of the data is collected from the Mastra database. Mastra is an internet-database used by the Road Directorate and the municipalities for storage and handling traffic counts. However, not all municipalities have joined this database. Below is a map over the municipalities that have joined Mastra.

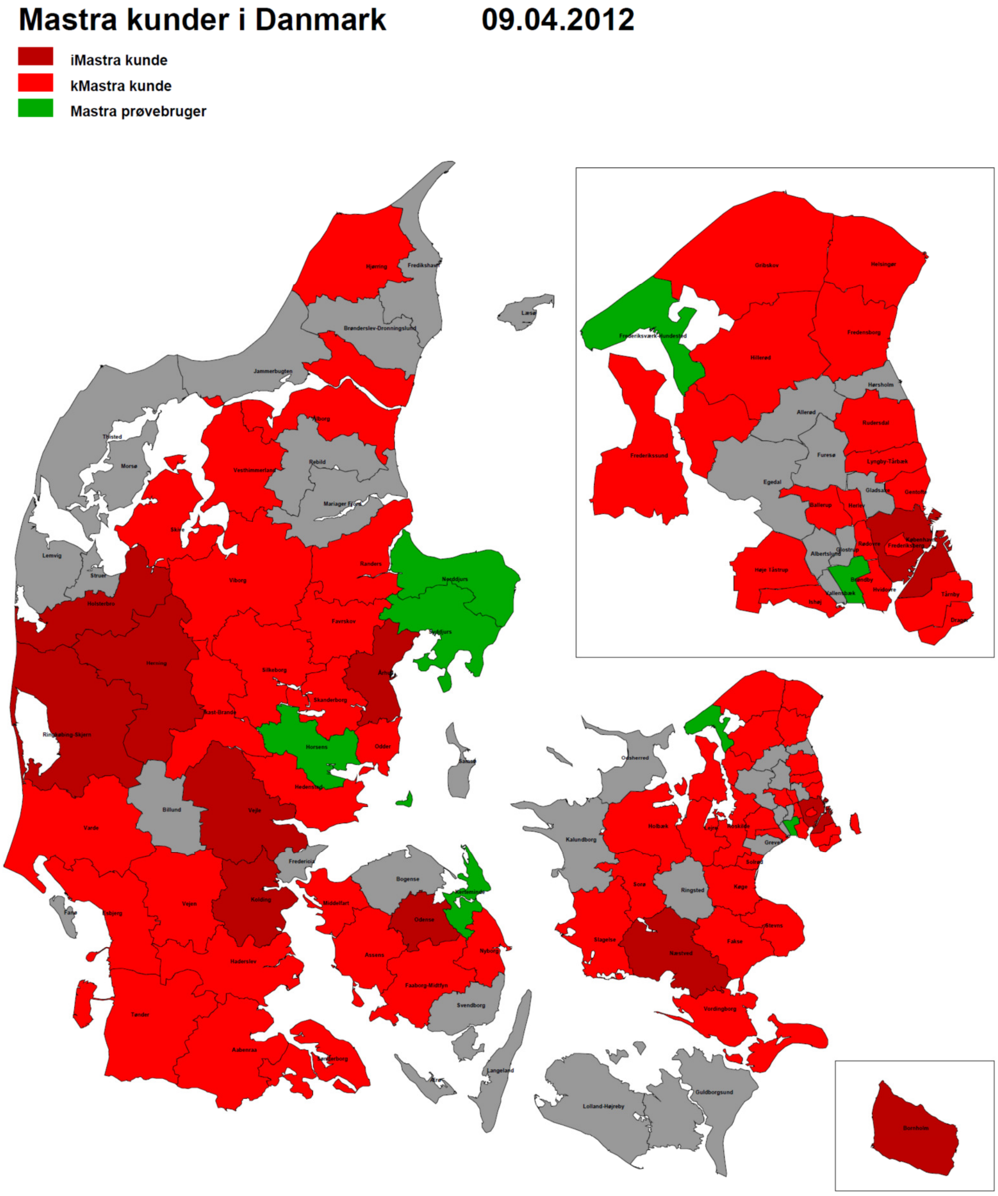



***Figure 17: Map showing the municipalities that have joined the Mastra database. The Red, Dark red and green are Mastra users. The greys are non-Mastra users. (The Road Directorate 2012)***

As can be seen from ***Figure 17*** there are 66 of the 98 municipalities that have joined Mastra. The municipalities marked with red and dark red are Mastra users. The difference between the municipalities marked with red and dark red are the level of membership to Mastra. The municipalities marked with dark red have more options for processing the data register in Mastra. The municipalities marked with green are trial users and the municipalities marked with grey are not using Mastra. Altogether this means that a lot of the data could be collected from

Mastra. Even though the Mastra database has been a great help and made it easier to collect data, not all the data needed was available within the municipalities that had joined Mastra; e.g. the earliest data registered in Mastra are from 1990 and very limited, so data from before 1990 had to be retrieved from other sources.

**Before and after reports**

The before and after reports are reports published by the Road Directorate after the opening of a new road project. The reports contain information about: the date of opening of the road project, illustrations of the precise location of the road in question and the location in Denmark, type of road and type of construction i.e. whether it is a new road or a road expansion, traffic counts before and after on a map for the year of opening and some of the reports also contain traffic forecasts. Since these reports are published by the Road Directorate the author has assumed that the traffic counts are correct and valid. It should be noted that there can be errors in these reports. It is furthermore these reports that determine which byroads the corridor analysis covers. This is because the author acknowledges the Road Directorate's assessments of which byroads that are most likely to be affected and also because it is more likely to obtain traffic counts for these byroads from other souses since the Road Directorate has included them.

**Technical traffic reports**

The technical traffic reports are reports published by the Road Directorate, concerning the traffic development in Denmark. The reports contain traffic counts at specific locations from the whole of Denmark, along with some statistical information on the overall development of the traffic. The reports where published each year in a period from the 1950´s to 2003, from then on most traffic registration where done in Mastra as described earlier.

For data obtained through the technical traffic reports, the author has set a lower limit of 20 counting days, in order to get a valid estimate on the AADT at the specific location where the traffic counts are taken.

## 3.4 Data Collection

This sub-chapter will concern the actual process of collecting data. Whereas the methodology chapter were concerned with describing the methods used for data collection this chapter will concern how the data were actually collected and all the reservation that had to be taken in the data collection process.

As described earlier, the objective was from the start to obtain traffic counts from one, two, three and four years after opening. In the early stages of the study the author naively expected to collect somewhere between 150 to 200 road projects with appertaining traffic counts for evaluation. However, it quickly became evident that this was not at all possible. As a starting point pamphlets containing road projects, published by the Road Directorate, were collected. These pamphlets contained the basic information about the projects such as location, date of opening, maps, and traffic counts. The traffic counts in these pamphlets were only from before and after opening of the projects, so the traffic counts for one, two, three and four years after opening had to be obtained elsewhere.

Some of the projects were received from a colleague who previously had collected some of these before and after reports on road projects in Denmark, others were collected from the Road directorate's webpage and other places. However, in the following months the author only managed to find ca. 15 additional road projects with appertaining traffic counts. All in all this resulted in 45 road projects viable for evaluation. This is not to say that more before and after reports do not exist, only that the author was unable to find them even after inquiring within the Road Directorate which is the author of these before and after reports.

After having collected and checked the data about the 49 projects, the work on laying out the screenlines started. The screenlines were placed in accordance with the procedure described in the method chapter. In this process some of the projects had to be discarded because of the nature of the projects' layout and the nature of the corridor analysis. Corridor analysis is designed to measure the throughput of traffic along a corridor, however in some of the projects the layout made it difficult to space the screenlines in a meaningful way and the projects had to be discarded.

When all the screenlines were placed the next step was to find traffic counts for one, two, three and four years after opening. The traffic counts for one, two, three and four years after were to be found in Mastra and in the Technical Traffic Reports. This meant identifying where each traffic count was taken and identifying a usable traffic counting station in either Mastra or the Technical Traffic Reports where the traffic counts for one, two, three and four years could be taken. However, it was far from always that the traffic counts were taken by a permanent traffic counting station. Many of the traffic counts listed in Mastra and the Technical Traffic Reports were manual traffic counts and not always preformed in the same location or in every year. Thus some of the traffic counts for some of the screenlines are not taken at the exactly same location in the four years measured. If there were traffic counts at different locations and there only were very small roads in between the location of the two traffic counts stations, the author assessed that not that many cars would take this road and affect the flow of the main road and therefore the two stations could be used as the same point of counting.

After checking for traffic counts at one, two, three and four years after, it became clear that not much data was available. The two main sources (Mastra and the Technical Traffic Reports) for traffic counts in year one, two, three and four after opening, did only produce one projects fully accounted for over the whole period of four years. This severe lack of data meant that new sources for obtaining data had to be investigated.

One option that had been revealed in the preliminary stages of the study was that the municipalities could have traffic counts archived locally. In the preliminary stages of the study the author had talked with a researcher at Alborg University regarding data arability and he had mentioned that there was a possibility that the municipalities had some data stored in their archives. So a phone survey was performed in order to clarify if there was possible data to be obtained in the municipal archives. The municipalities contacted were both Mastra and non Mastra municipalities. Not all municipalities were contacted. However the phone survey showed that there was little data to be obtained through this source. The municipalities that were using Mastra reported that that their data had already been entered into Mastra, also the older data. The municipalities that did not use Mastra reported that they did not perform systematic traffic counts and that before the municipality reform this task was performed by the county authorities and that this data was given to the Road directorate or entered into Mastra.

All in all

- 684 screenlines where collected and checked.
- There is one project were all screenlines were accounted for in all the six registration intervals.
- 282 screenlines where accounted for in all, of which 54 were from technical traffic reports produced by the Road Directorate and the traffic database Mastra, and 228 where from the Road Directorate's before and after reports.
  - All 114 screenlines accounted for at before opening
  - All 114 screenlines accounted for at immediately after opening
  - 18 screenlines accounted for one year after opening
  - 17 screenlines accounted for two years after opening
  - 10 screenlines accounted for three years after opening
  - 9 screenlines accounted for four years after opening

### Summery & Reflections on Methodology and Data Availability

As mentioned above there is quit a difference between the data I expected to collect and the data actually collected. The lack of data in the years from one year after and up to four years after opening has some implications for the results of this study. As stated in the beginning of this chapter, the research questions are somewhat quantitative nature. This has been a deliberate choice by the author from the start of the study, however the severe lack of data experienced in the data collecting process will have some implications for the quantitative approach and especially for the analysis of the long term development of induced traffic.

I believe that the data collected before and immediately after opening will be applicable for the short term effect analysis of induced traffic and give a fairly god estimates of the magnitude of the initial induced traffic experienced by the road projects. However the lack in data obtained in the following years will hamper the quantitative long term analysis of the development of induced traffic. It might be possible to conclude on the direction on development of induced traffic after the first registration, but statements on the magnitude would be difficult with such small sample of road projects and the results must be interpreted with some caution.

# 4 Analysis

This chapter will contain the analysis of the data compiled for this study. The data will be presented and analysed in order to help answer the research questions stated in the introduction.

## 4.1 The Data

This study is comprised of 45 road projects from all over Denmark[10]. The locations of the 45 project are evenly distributed over the whole of Denmark and are shown on the map in ***Figure 18*** below.


***Figure 18: Locations of the 45 road projects included in the current study.***

[10] There were no road projects on the island of Bornholm, so Bornholm is not shown on the map.

Furthermore the 45 road projects are distributed between the four road type classifications as follows

- Motorways: 20
- Highways: 8
- Bypasses: 15
- Fixed link motorway bridges: 2

## 4.2 Analysing data

The method chosen in this study is corridor analysis with traffic counts from the four years after opening of the road projects. This will enable an analysis of long term as well as the short term effects of induced traffic. The overall result from the 45 projects is presented below in ***Table 5*** Here the average induced traffic experienced, by all the projects accounted for each year, are shown.

| | Immediately after | 1 year after opening | 2 years after opening | 3 years after opening | 4 years after opening |
|---|---|---|---|---|---|
| **Number of projects** | 45 | 5 | 3 | 2 | 2 |
| **Induced traffic** | 9% | 8% | 15% | 12% | 32% |

***Table 5: Overall average induced traffic in the four registration years.***

***Table 5*** shows that there is that there is an increase in average induced traffic over the whole four year period. However, there is a sharp drop in the number of projects evaluated after the first registration and the results can be a bit misleading. The average induced traffic measured fluctuates over the four year period and this is because it is not the same projects that are accounted for at the different registrations, as shown in ***Table 6*** below.

| Kolonne1 | Immediately after | 1. Year | 2. Year | 3. Year | 4. Year |
|---|---|---|---|---|---|
| **Amagermotorvejen** | 5% | 2% | 2% | | |
| **Brønderslev - Nørresundby** | 13% | | 33% | | 45% |
| **Guldborgsundtunnelen** | 0% | 7% | 9% | 15% | 18% |
| **Kolding - Vejlefjordbroen** | 9% | 9% | | | |
| **Odense motorvej** | 22% | 17% | | | |
| **Rønnede - Udby** | 0.00% | 5% | | 8% | |

***Table 6: Projects with accounted for screenlines at the four registration intervals after the first registration.***

In ***Table 6*** are shown the six road projects which have all screenlines accounted for in one or more of the registration intervals after the first. The number of projects, where traffic counts for all screenlines in a project are accounted for, drops from 45 immediately after opening, to five, three, two and two projects over the following four years. The reason for this drop in fully accounted for projects is difficulty in obtaining all traffic counts for some of the screenlines in the project at the given years. In fact there is only one project where all screenlines are accounted for in all of the five registration intervals, namely the Guldborgsundtunnel. The low number of projects fully accounted for after the registration immediately after opening and the fact that it is different projects that is registered, is the cause for the fluctuations in the readings in the ***Table 5*** above.

At the first registration immediately after opening, there are 45 projects with an average increase in traffic of 9%. Since there is a population of 45 projects this result is pretty robust, but at the remaining four registrations there are a limited number of projects fully accounted for and the results are thus more uncertain. However if the results from ***Table 5*** are compared with the theory of induced traffic, the increase in induced traffic over time seem to follow the development of induced traffic predicted by the theory of induced traffic albeit a little on the low side.

There are projects where some, but not all screenlines are accounted for at one, two, three and four years after opening. It is of course not ideal that all screenlines are not accounted for in some of the projects, but since the method used in this study is corridor analysis, the screenlines are placed perpendicular to the corridor and the flow of traffic in order to measure changes in the throughput of traffic and they will give an indication of whether there is an increase or decrease in traffic. This means that some but not all screenlines in a project can still be used to give an indication of whether or not there is an increase or decrease in induced traffic, although it might be a little more indicative/uncertain than if all the screenlines where accounted for. In ***Table 7*** below all screenlines accounted for, at the five registration intervals in this study, are included.

| | **Number of screenlines** | **Average Induced traffic** |
|---|---|---|
| **Immediately after opening** | All screenlines | 9% |
| **1 Year after opening** | 18 screenlines over 10 projects | 10% |
| **2 Years after opening** | 17 screenlines over 11 projects | 18% |
| **3 Years after opening** | 10 screenlines over 7 projects | 11% |
| **4 Years after opening** | 9 screenlines over 6 projects | 30% |

***Table 7: Average induced traffic over a five year period counted on screenlines.***

When all of the screenlines are accounted for, as shown in ***Table 7,*** there is an average increase in induced traffic over the whole four year period after opening. This supports the readings found in ***Table 5*** though with slight variations in induced traffic, but still in line with theory of induced traffic. The fluctuations found in ***Table 5*** also appear in ***Table 7.*** The reason for these fluctuations is again that it is not the same screenlines and projects that are registered at the respective years. I.e. the screenlines registered in year one are not the same as the screenlines registered in year two and so on. This means that it is difficult to examine the long term effects from the tables above. However, in ***Table 6*** there seem to be a tendency that induced traffic is increasing if projects are examined individually, especially the projects with registrations three and four years after opening. This tendency will be discussed later in the chapter.

## Overview of the first year registrations

Below in ***Table 8*** all the 45 projects included in this study are listed along with the induced traffic found at each of the projects immediately after opening.

As seen below, induced traffic ranges range between 0% - 20% for most of the projects. There are several projects with 0% induced traffic and there are a few projects that generate a very high level of induced traffic.

Two projects that immediately stand out are the Ørresunds Bridge and the Storebælt Bridge. They generate very large amounts of induced traffic, however, the Ørresund and Storebælt Bridges are fixed-link bridges and it was somewhat expected that they would generate a large amount of induced traffic. Another project that stands out is the Guldborgsundtunnel which generates 0% induced traffic the first year of opening. This seems unlikely since it provides time savings on a somewhat heavily trafficked stretch of road.

In order to further examine the deviations in induced traffic between the projects as well as the long term effects, a more case orientated evaluation of the projects with screenlines containing traffic counts in all of the five years of registration are performed in the following, as well as a further examination of if the road type influences the level of induced traffic generated in the different projects.

| Project | Induced Traffic | Projects | Induced Traffic |
|---|---|---|---|
| **Amagermotorvejen** | 4,61% | **Kværndrup omfartsvej** | 0,00% |
| **Bellinge omfartsvej** | 10,00% | **Løgten - Tåstrup** | 0,00% |
| **Bramming omfartsvej** | 0,00% | **Låsby - Århus** | 13,63% |
| **Brande Omfartsvej** | 0,00% | **Nr. Herlev - Herredsvejen** | 7,85% |
| **Bredsten Omfartsveje** | 0,30% | **Ny Nibevej** | 11,22% |
| **Brønderslev - Hjørring** | 14,11% | **Nykøbing Falster omfartsvej** | 19,25% |
| **Brønderslev - Nørresundby** | 12,79% | **Odense motorvej** | 21,90% |
| **Christiansfeld - Sønderborgvejen** | 8,95% | **Overby - yderby Omfartsvej** | 2,00% |
| **Esbjerg - Vejen** | 25,40% | **Randers nord - Hobro syd** | 13,38% |
| **Farøbroen** | 6,54% | **Ringsted - Slagelse Ø** | 16,76% |
| **Flauenskjold omfartsvej** | 0,00% | **Rise-Hjarup - Skovby** | 1,50% |
| **Gammelby omfartsvej** | 0,00% | **Rudkøbing - Halsted** | 3,42% |
| **Guldborgsundtunnelen** | 0,00% | **Rønnede - Udby** | 0,36% |
| **Hadsund omfartsvej** | 0,00% | **Slangerup omfartsveje** | 2,77% |
| **Hasle- og Vejlby Ringvej** | 7,92% | **Solrød omfartsveje** | 0,43% |
| **Herning - Bording** | 20,16% | **St. Lyngby omfartsvej** | 0,00% |
| **Hjulby - Langeskov** | 4,68% | **Storebælt** | 66,09% |
| **Hjørring - Hirtshals** | 20,00% | **Tarm omfartsvej** | 0,00% |
| **Hobro syd - Aalborg syd** | 8,21% | **Vejle - Horsens** | 6,67% |
| **Horsens - Skanderborg** | 5,51% | **Vestre Boulevard** | 3,50% |
| **Jyske Ås - Syvsten** | 10,58% | **Øresund** | 47,06% |
| **Kirkeåsvejen** | 5,31% | **Århus syd - Randers syd og Lillebælt - Vejle** | 7,47% |
| **Kolding - Vejlefjordbroen** | 9,47% | | |

***Table 8: List of induced traffic found at all the 45 projects included in the study immediately after opening.***

## 4.3 Long term effects of induced traffic

As mentioned above there were some fluctuations in the registrations of induced traffic over the four year period. The reason for this was that it was not the same screenlines registered at each registration year. In one year there might be a lot of motorways registered with high levels of induced traffic and the next it might be mostly bypasses with low levels of induced traffic. This makes it difficult to draw any conclusions about the development of induced traffic. So to further examine the long term effects and the development of induced traffic, the screenlines for which the traffic counts are accounted for over the whole five-year period, are studied in more detail in the following. In the data collection process, data was collected for each year in a four year period after opening of the projects. The four projects which contain completed screenlines are Brønderslev-Nørresundby, Kirkeåsvejen, Guldborgsundtunnel and Farøbridge. There are six completed screenlines in total; the Brønderslev-Nørresundby and Kirkeåsvejen projects each have one completed screenline, The Guldborgsundtunnel and Farøbridge projects each have two completed screenlines. In the projects where there are two completed screenlines, the average value of the two screenlines has been used, since they both measure the throughput in the same corridor. In ***Figure 19*** below, the development in induced traffic for each of the four projects is shown for the five year period after the opening of the projects.

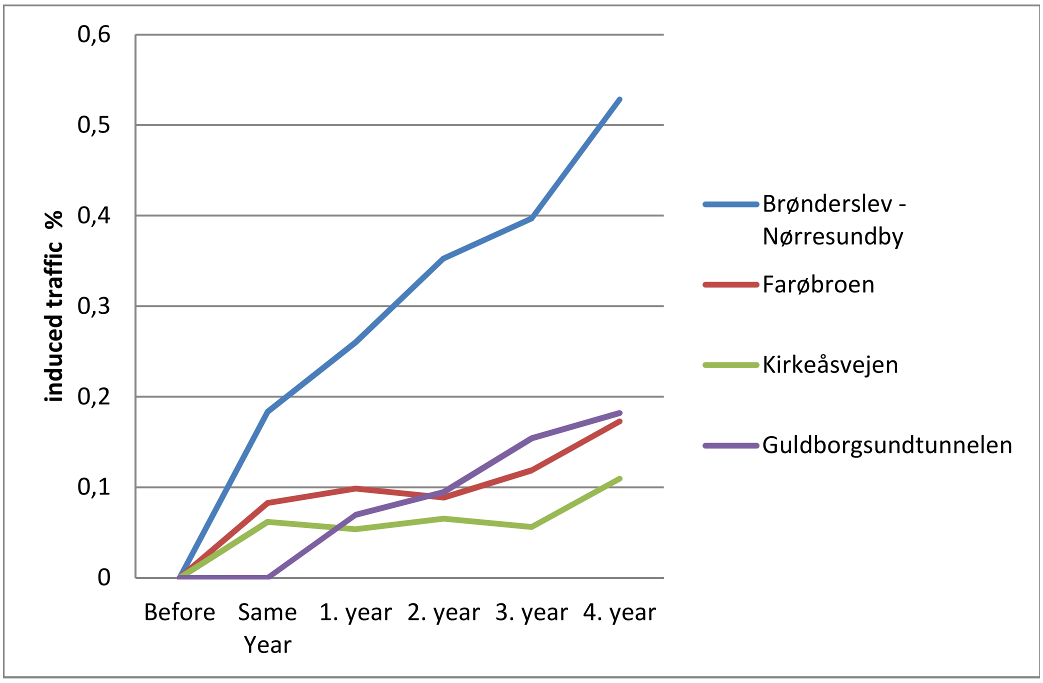



***Figure 19: Development in induced traffic (After general traffic growth has been subtracted) after the opening in year 0.***

Over the whole four year period all projects have experienced an increase in traffic after the general traffic growth has been subtracted. There are however some differences between the projects that are interesting to examine closer. For example, the Brønderslev-Nørresundby project is a motorway project in the north of Denmark. Kirkeåsvejen is a highway connecting the capital area and some of the larger recreational housing areas and a ferry connection to Jutland in north Zealand. Farøbridge is a motorway bridge in the south of Denmark and is located close to the Guldborgsund tunnel which is a highway tunnel. In the following each of the four case projects will be discussed in further detail.

### The Guldborgsund Tunnel and the Farø Bridge

Both the Guldborgsund tunnel and the Farø bridge are located south of the capital area and are connections to the isles Lolland and Falster. These are relative low-populated islands where Nykøbing-Falster is the largest city with approx. 16500 inhabitants. A lot if the inhabitants of the isles commute to the capital region and there is also a ferry connection (Rødby-Puttgarden) to northern Germany which provides a connection between the capital region of Copenhagen and central Europe. In addition to being located very closely together, the opening dates of the Guldborgsund tunnel and the Farø bridge are also very close, the Farø bridge opened in 1985 and the Guldborgsund tunnel opened in 1988, so it is likely that there has been some interaction between the two projects. E.g. the Guldborgsund tunnel was under construction when the Farø bridge opened. This meant that traffic from the newly opened Farø bridge could not continue in the Guldborgsund tunnel and traffic had for a few years to be redirected to a different crossing (Vejdirektoratet 1985).

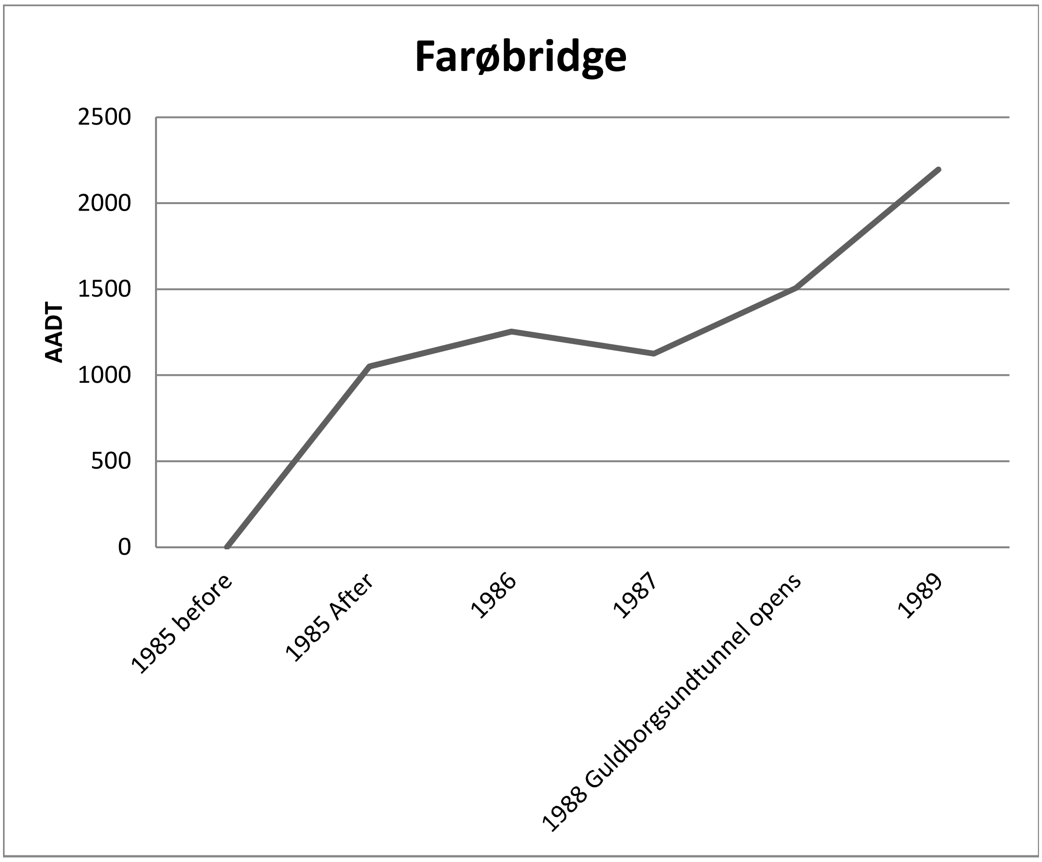



***Figure 20: The case of Farø bridge, showing when the Guldborgsund tunnel opened.***

This could explain the low level of induced traffic occurring after the opening of the Farø bridge until 1987 and the increase in traffic that occurs again when the Guldborgsund tunnel opens in 1988, as shown in ***Figure 20***. This would suggest that there has been some suppression of traffic in the construction period of Guldborgsund tunnel, when the traffic then could flow freely again after the construction had finished induced traffic occurred. The Guldborgsund tunnel has experienced a steady increase in induced traffic after opening of the project except for the first year. It seem unlikely that the project has not experienced induced traffic after the opening especially since the Farø bridge (which lies in connection of the Guldborgsundtunnel) experienced approx. 10% increase in induced traffic the same year.

### Brønderslev-Nørresundby motorway

The Brønderslev-Nørresundby motorway project is located in the north of Denmark between Aalborg, the largest city in the north region of Denmark, and Brønderslev, which is a medium sized town. However, the motorway would also be the primary road to Aalborg for two other settlements in the north of Denmark, namely the city of Hjørring and the town of Hirthals. So the motorway would mainly service the connection between these three cities and the regions capital Aalborg. Before the motorway was constructed the road used was a highway where the maximum allowed speed was for most of the distance 80 km/h, whereas the speed limit of the motorway is 130 km/h except a few passages where it is 110 km/h. Road speeds have thus increased and travel time decreased significantly between the cities. This means that the new motorway represents potential time savings and/or increased mobility for a lot of people in the northern region. This also seems to be reflected in the level of induced traffic that occurs after opening of this project. The Brønderslev-Nørresundby motorway has by far the highest level of induced traffic of any of the four projects as ***Figure 19*** shows.

### Kirkeåsvejen

Kirkeåsvejen is a highway in a recreational area which is relatively low-populated. The road was built in order to improve the connection between the capital area and the northern recreational housing areas of Zealand and to improve conditions for the incoming traffic from the ferry connection with Jutland via Sjællands odde (Vejdirektoratet 1986). As seen in ***Figure 19*** there only occurs a small amount of induced traffic over the four years after opening of the project. The reason for this could be the low population in the area. The inhabitants in the local area will typically commute into the capital area for work and leisure and the new road may not facilitate any further trips since the speed limits has not been raised and the road is only improved on a small stretch of the total road to the capital area. The owners of recreational houses will have limited benefits from the improvement as well. The road will not induce any further trips by owners of recreational houses since there only are a limited number of recreational houses in the area. Another reason for the limited induced traffic in this case could also be that the road users that drive though the area in order to use the ferry connection are not particularly affected by this “small” improvement compared to the relative “large” trip, so it does not represent any significant savings in general cost of undertaking the trip from Jutland to Zealand or conversely. Lastly it should be noted that there was a fairly high increase in national general traffic growth in the years of the opening, meaning that a large portion of the traffic registered will be attributed to general traffic growth and thus be subtracted from the actual growth registered.

Overall the development in induced traffic over the five year period shows an increase and this is in line with the theory of induced traffic. There does however seem to be a difference in the level of induced traffic depending on the road type and the amount of traffic on the road. This will be examined further in the following.

## 4.4 Road type and induced traffic

In order to examine the connection between road type and the level of induced traffic that occurs, the 45 projects are divided into four categories after road type. The four categories are:

- Motorway
- Highway
- Bypass
- Fixed link motorway bridges.

This is done in order to examine if a certain road type induces more traffic than others. Below in ***Figure 21*** the locations and types of project are shown on a map. Red are motorways, blue are highways, green are bypasses and black are fixed link motorway bridges. On the map below it is clear that the motorway projects are mostly located along in the major transport corridors in Denmark, whereas the highways and bypasses are mostly located in the rural areas. The locations of the two fixed link motorway bridges are also shown on the map and it can be see how they connect Sweden and Zealand with Jutland and the rest of Europe.


***Figure 21: Map showing location and type of project. Red = Motorways. Blue = Highways. Green = Bypasses. Black = Fixed link motorway bridges.***

Originally the goal was to obtain data for the four years after opening for all of the road projects. However, as mentioned earlier, this has proven difficult. As discussed above there the results are very uncertain when the sample of projects are this small, so this analysis will only concern the results from immediately after opening, where there are 45 projects accounted for. Below in ***Table 9*** the results for average induced traffic experienced by each type of road project is presented.

| | Motorway | Highway | Bypass | Fixed links |
|---|---|---|---|---|
| **Number of projects** | 20 | 8 | 15 | 2 |
| **Average induced traffic experienced immediately after opening** | 11% | 6% | 3% | 57% |

***Table 9: Average induced traffic on different types of road.***

As can be seen in ***Table 9***, induced traffic is as predicted by the theory most predominant where there the projects offer most time savings, namely Motorways and fixed-links. In the following the results for each of the four road types will be discussed in more detail.

## Fixed link motorway bridges

As expected, increases in induced traffic are most pronounced at fixed link motorway bridges, where there is an average increase in induced traffic of 57%. This is presumably because of the large increases in mobility and time savings that the new link provides. The two fixed link bridges included in this study are the Øresund Bridge and the Storebælt Bridge. The Øresund Bridge connects Zealand and Copenhagen to Sweden and Malmø and The Storebælt Bridge connects Zealand to the rest on Denmark, namely Jutland and Funen. Common for both bridges are that they connect Zealand, Funen and Sweden with Jutland and Central Europe and there were no fixed links before the bridge were built. This means they handle a lot of traffic and this is also some of the reason for the large increase in induced traffic that occurs on the bridges. Another reason for the large increase in induced traffic is also the large time savings achieved by using a bridge instead of taking a ferry.

## Bypasses

15 of the 45 projects investigated are bypasses. The bypasses are characterised by being short stretches of highways that redirect traffic around cities, with maximum speeds of 80-90 km/h. This means that the traffic benefits from bypasses are mostly achieved by avoiding traffic, traffic lights, roundabouts and the city speed limits of 30-60 km/h etc. in the bypassed cities. However bypasses are mostly around smaller cities and only cover short stretches of road. This means that the benefits are limited since the road bypassing the city in a semi-circle is longer than the direct road through the city. This can be one of the reasons for the moderate increase in average induced traffic at 3 %. Furthermore, most of the bypasses are located in rural areas with low population which also can be a reason for the modest level of induced traffic.

## Highways

8 of the 45 collected projects are highways and there is a 6% average increase in induced traffic the first year of opening. Highways are categorised by being longer stretches of road between cities, with a maximum speed limit of 90 km/h. As with bypasses most of the highways are located in more rural areas with low population and this can be some of the reason for the modest level of induced traffic compared to motorways and fixed link motorway bridges.

### Motorways

20 of the 45 projects investigated are motorways and as shown on the map in ***Figure 21*** above most of the motorways are located on the main transport corridors in Denmark. These main transport corridors connect the major cities in Denmark and Europe. This is also the reason for the large increase in induced traffic that occurs on the motorway projects. As ***Table 9*** shows the first year of opening there is a "jump" in traffic at 11% on average for the motorway projects. This is approximately twice as much as for highways and four times that of bypasses. One of the reasons for this, is the increased speeds a motorway offers compared to a highway or lower level roads. Motorways also connect the major cities where the density of dwellings and workplaces are highest. This means motorways will collect commuting traffic form rural areas and satellite cities around the major cities, as well as the long distance traffic that travels through the major cities. There are therefore a lot more people are affected by a new motorway and more people are tempted to travel more frequently or further because of the new opportunities a motorway brings.

Overall there is the tendency that, road projects which offer high time savings also experience more induced traffic. This is very much in line with the theory of induced traffic. The projects which experience high levels such as motorways and fixed-links are also located in the main transport corridors in Denmark, whereas the projects that experience low levels of induced traffic are mostly placed in more rural areas.

# 5 Conclusion

In the beginning of this report the main research question “To what extent does induced traffic appeared when building new roads or expanding roads in Denmark?” was posed. In order to specify and help answer this question, the following three research sub-questions were posed:

1. Do different road classifications generate different levels of induced traffic?
2. Does the level of induced traffic increase over time?

All of these research questions are attempted answered through the information, approaches and empirical information obtained in the Theory, Methodology and Analysis chapters. The following will summarise the findings of this report.

## 5.1 Findings

For this study reports from 45 projects were collected with appertaining traffic counts. The projects were distributed evenly over the country except Bornholm where there were none. Below is an overview of the data collected in this study.

- 684 screenlines where collected and checked.
- There is one project were all screenlines were accounted for in all the six registration intervals.
- 282 screenlines where accounted for in all,
- Of which 54 were collected from technical traffic reports which is a yearly publication by produced by the Road Directorate and the traffic database Mastra also managed by the Road Directorate,
- And 228 where collected from the Road Directorate’s before and after reports which are reports published after road projects have been constructed.
- The reports of 45 road projects where collected and before and after traffic counts had to be collected for; before, immediately, one, two, three and four years after opening of the projects. At each registration interval 114 screenlines could be collected if all data were available. However data availability was not good. Below is listed what actually was collected.
    - All 114 screenlines accounted for at before opening
    - All 114 screenlines accounted for at immediately after opening
    - 18 screenlines accounted for one year after opening
    - 17 screenlines accounted for two years after opening
    - 10 screenlines accounted for three years after opening
    - 9 screenlines accounted for four years after opening

As can be seen from the data collected the results must be interpreted with some caution due to the incompleteness of the data, especially in the years following the second registration interval where screenlines accounted for drops from all 114 to 18 screenlines.

The main research question was:

**To what extent does induced traffic appeared when building new roads or expanding roads in Denmark?**

As stated in the analysis, there was a large difference in the number of projects accounted for immediately after opening and one, two, three and four years after opening. So the results will be presented separately. Firstly, the results with all the projects accounted for immediately after opening will be presented. After that the long term results will be presented along with results of the more qualitative study of the long term development of induced traffic.

The foundation of this study is the reports of 45 projects which have been collected in order to examine if and how much induced traffic occurs when a new road has been built or a road capacity has been expanded. Traffic counts immediately after opening have been collected and induced traffic has been calculated for all of these 45 projects. The results are shown on ***Figure 22*** below.

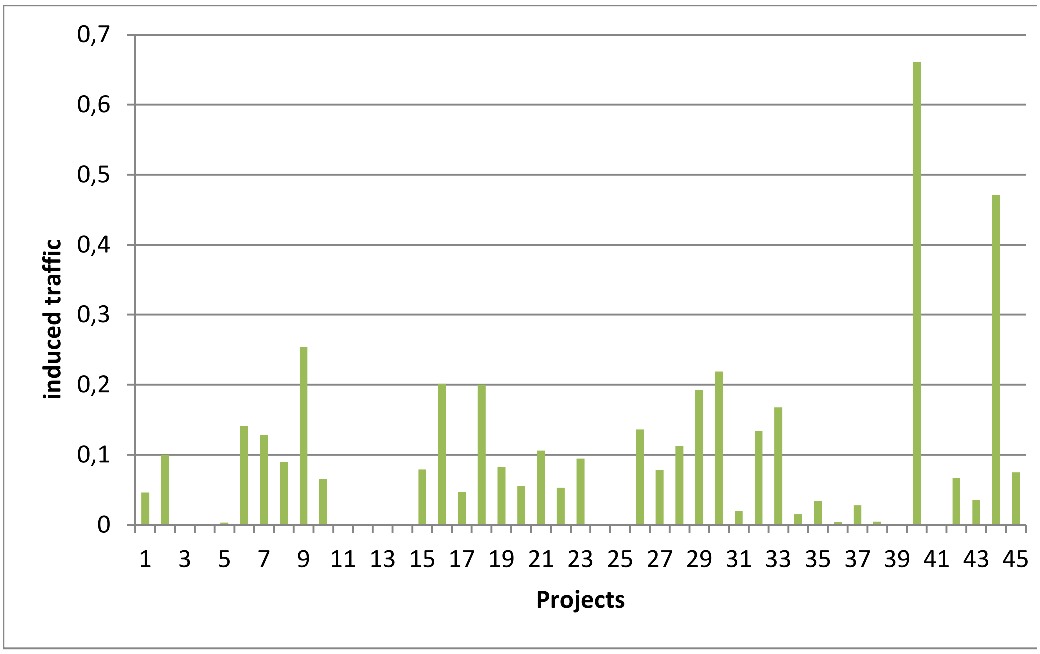



***Figure 22: showing the average amount of induced traffic experienced on each project in the study, immediately after opening.***

I have found that the average induced traffic experienced for all the projects included in this study is 9%. There are two projects that stand out and this is the fixed link motorway bridges, the rest of the projects experience around 0-20% of induced traffic. This means, that there is definitely evidence of induced traffic occurring when expanding road capacity. However, it is not all projects that has experienced induce traffic, 10 projects did not experience any induced traffic at all. This means that it is difficult to determine the magnitude of the induced traffic experienced by road projects in general. So in order to further examine the variation in induced traffic experienced by the 45 projects the results of the second research question is examined closer.

**Is there difference in induced traffic experienced by different types of road projects?**

To answer this, the 45 projects were divided into four categories according to road type and an analysis was performed in order to see if certain road types generate more induced traffic than others. The four road types are: Motorways, Highways, Bypasses and Fixed link motorway bridges. I have found the following levels of induced traffic for the four types of roads:

| | **Motorways** | **Highways** | **Bypasses** | **Fixed link motorway bridges** |
|---|---|---|---|---|
| **Number of projects** | 20 | 8 | 15 | 2 |
| **Induced traffic** | 11% | 6% | 3% | 57% |

***Table 10: average induced traffic on the four different road types.***

As ***Table 10*** shows, there are clear differences between how much induced traffic the different types of road projects experience. The highest level of induced traffic experienced is 57% on average for the fixed link motorway bridges. Even though the sample size in this category is only two projects this level was expected and in line with the theory of induced traffic. This is presumably because of the large savings in time and general costs the fixed link bridges offer and that they connect the main parts of the country and Europe.

There are also some variations between the other categories. The 20 motorway projects generate 11% induced traffic on average. It was also expected that the motorway projects would generate more induced traffic than highways and bypasses. This is because of the increased speeds and consequently time savings motorways offer. Induced traffic generated by the highway and bypass projects is a bit lower. Bypasses experience very little induced traffic, only 3% on average. In fact 8 of the 10 projects that did not generate any induced traffic are bypasses. This is most likely because they offer very little time savings and most of the bypasses in this study are located in rural areas with low levels of traffic and congestion. The highway projects experience 6% induced traffic on average, which is twice the level of bypasses. The highways are often also located in the rural areas, but in contrast to the bypass projects, they usually cover a longer stretch of road between two cities, whereas the bypasses projects only cover a short stretch of road around small towns. This may be the reason for the slightly higher level of induced traffic experienced on highways.

The results found in ***Table 10*** follow the theory of induced traffic rather well and shows that some of the variation in the 20-0% may be explained by the different types of road project. It is clear that the projects such as fixed-links and motorways which produce large time saving for car drivers generate more induced traffic than the projects which offer less time-savings such as highways and bypasses. In ***Figure 23*** below, the dispersion of the results is plotted using a boxplot. The black lines in the boxes are the median which indicate the middle value of the data set and the box indicates the first- and third- quartiles the middle 50% of the data registrations lie. This gives a visual representation of the dispersion of the data collected.

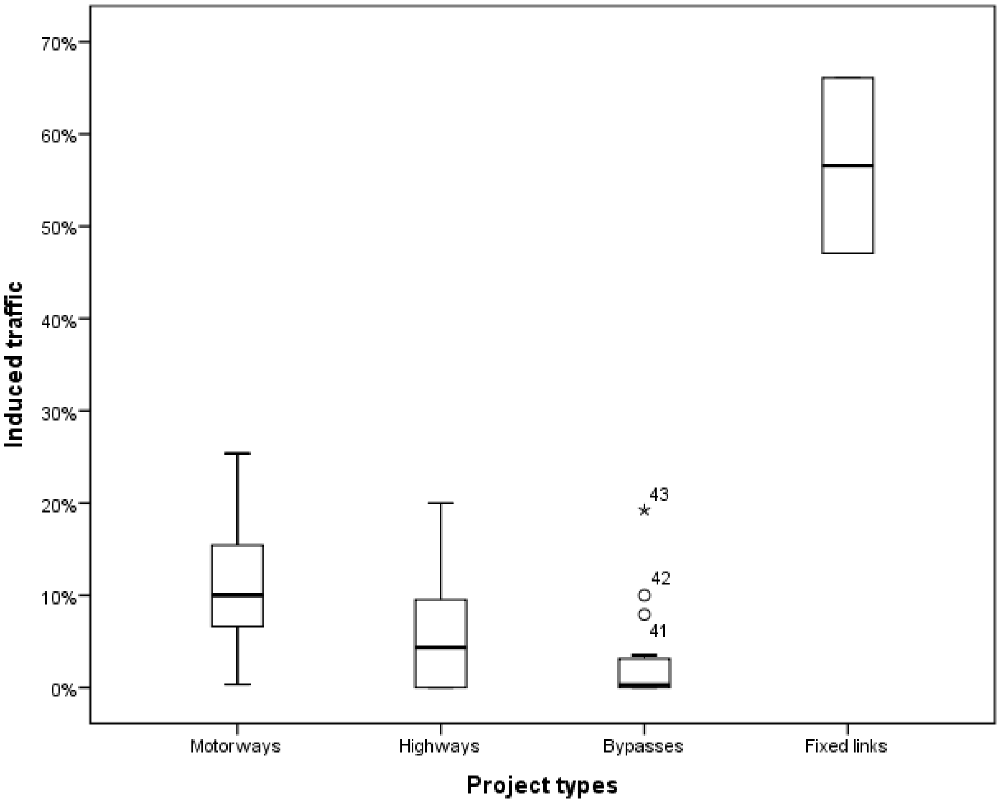



***Figure 23: Dispersion of the collected projects distributed on road type***

The motorway projects centred around 10% induced traffic with a little more dispersion upwards. In the case of the highway projects 75% of the data sample lie between 0% and 10% induced traffic with some dispersion up to 20 % induced traffic. For bypass projects the median are very close to 0% induced traffic. This is because there are a lot of projects which has experienced 0% induced traffic. Three projects (41,42,43) in the bypass data sample are marked as extreme values. In the last column the two cases of fixed-link bridges are shown. Since there are only two projects the box indicates the dispersion.

The initial induced traffic experienced by the road projects is however, not the entire effects of induced traffic as mentioned in the theory chapter. And one goal of this study was to investigate the long term effects of induced traffic.

## Does induced traffic increase with long term effects?

In order to study the long term development of induced traffic, traffic counts were taken in a period of four years after opening. However, I found that there were not much data available in the four year period after opening of the projects. So instead of doing a quantitative analysis as done for the immediately after traffic counts, I decided to do a more qualitative analysis on the projects where screenlines were accounted for in the whole registration period. This enabled a detailed analysis of the development of four projects, where fluctuations and deviations could be examined more closely and compared to the theory of induced traffic.

This qualitative analysis contained four projects: two projects with two screenlines accounted for over the whole four year period and two projects with one screenline accounted for over the four year period. The Guldborgsund tunnel and the Farø bridge projects both had two completed screenlines and the Brønderslev-Nørresundby and Kirkeåsvejen projects both had one completed screenline. It turned out that these four cases were very informative and illustrative in obtaining knowledge about the different types of projects and the interaction between projects located closely together. Brønderslev-Nørresundby is a motorway project, Kirkeåsvejen is a highway project and the Guldborgsund tunnel and the Farø bridge are respectively a highway tunnel and a motorway bridge located very closely together. The last two projects are not only located very closely together, but also have opening dates very closely together. This enabled the possibility to study any interaction between the two projects. The development of induced traffic over the four year period after opening, for the four projects is plotted on ***Figure 24*** below.

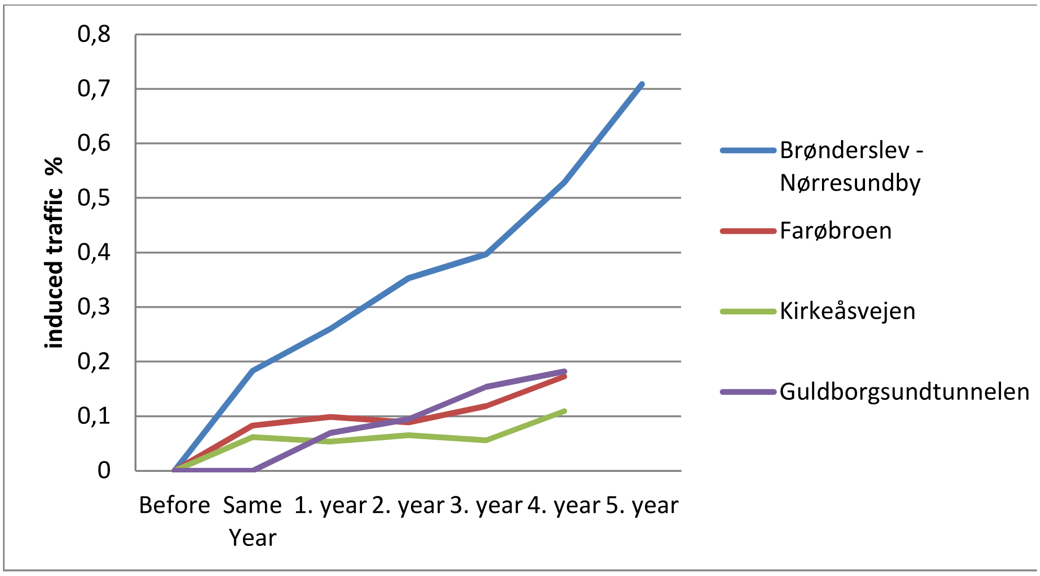



***Figure 24: Graph showing the development in induced traffic, of the four projects where screenlines are accounted for over the four year period after opening.***

***Figure 24*** shows, that all of the four projects experience an increase in induced traffic over the four year period. However there are clear differences in how much induced traffic the different projects has experienced.

The motorway project Brønderslev-Nørresundby experienced a significant increase in induced traffic over the four years. The Kirkeåsvejen highway experienced a little "jump" in traffic in the opening year, after that traffic seems to level off and with a slight increase over the four years. This was mainly because of the low levels of traffic on the road and the rural location of the road.

In the case of the Guldborgsund tunnel and the Farø bridge it was found that some interaction had occurred, which could be the reason that the Farø bridge curve is levelling off after the initial increase and then increases again when the Guldborg tunnel opens.

All in all it was found that the effect of induced traffic is not limited to the initial jump in traffic immediately after opening. As the theory predicts, the effects of increasing road capacity continues to generate induced traffic over a longer period of time and the projects of the current study follow this pattern. There does seem to be a difference in the level of traffic induced over time, depending on road type and traffic levels on the road. Lower-level roads such as bypasses and rural roads generate less induced traffic than high level roads such as motorways.

## 5.2 Comparison

The current study has examined whether 45 road projects have experienced induced traffic after opening. The results have shown that induced traffic does occur after opening; however, it is very context dependent on the type of road. In the following I will reflect on the results and try to compare the results with other international studies on induced traffic.

In studies on induced traffic it is common to express results of induced traffic in some form of elasticity, either with respect to travel time savings of capacity. This is beneficial in order to be able to compare the results of the different studies. Unfortunately, it has not been possible in this study to obtain travel time savings for each project or information on how much the capacity expansion for each project is percentage-wise. So the results of the current study are instead expressed in percentage-wise increase in traffic and compared to several studies compiled in a study by Goodwin (1996).

The studies compiled in the study by Goodwin are all methodologically similar to the current study, meaning that they employ before and after traffic counts taken at screenlines placed along the corridor in question. The timespan between the before and after traffic counts varies form a few months up to 20 years. Some of the studies compiled in Goodwin (1996) used an unimproved control corridor for comparison, instead of general traffic growth employed in this study. Other of the studies in Goodwin applied the same approach with general traffic growth as done in this study and lastly some studies had no correction for general traffic growth or "other factors" as Goodwin describes it. However, in the cases where there was no control for general traffic growth Goodwin assigned an arbitrary growth of 2% per year to compensate. The sources for the studies compiled in Goodwin (1996) are Beardwood & Elliot (1986), Castle & Lawrence (1987), Cleary & Thomas (1973), Pells (1989), Pizzigallo & Mayoh (1989), Purnell (1985), SACTRA (1994), Younes (1990). These studies contain 20 results from corridors analysed. It has not been possible for the author of the current study to obtain the studies mentioned above, so the comparison of the results of the current study, with the results of the studies mentioned above are made with Goodwins' (1996) rendering of the results of these studies.

Goodwin finds a 25% average increase in traffic, from the 20 results cited in Goodwins (1996). The 20 results range from 7% to 66%. However, this is from all the results where some of the traffic counts are taken 20 years after opening. If the results are divided in to categories after years after opening the results are:

- Less than a year 9.5%
- One year 22%
- 2-5 years 26%
- Greater than 5 years 33%.(Phil Goodwin 1996)

If these results are compared to the results of the current study we see that they are somewhat similar. Firstly, the overall results of the studies presented in Goodwin are compared with the overall results of current study. In Goodwin the range of the results varies from 7% to 66% induced traffic experienced. In the current study the results varies from 0% to 66% induced traffic experienced. . However, the road projects presented in Goodwin's material are all major infrastructure projects. In order to make the results Goodwin's material and the present study comparable, the smaller road projects of the present study (bypasses and highways) should therefore be omitted in the comparison, so that only major projects are compared. If the smaller road projects such as bypasses and highways are disregarded, then all the results (except for project one at 1%) in the current study range from 6% to 66%, which is very much in line with the studies presented in Goodwin (1996).

If we look at the category where there is less than a year between the before and after traffic counts, the results of the studies presented in Goodwin (1996) show an average of 9.5% induced traffic experienced. The correspondent interval in the current study is the immediately after registration which has experienced 11% induced traffic (excluding smaller projects[11]), in line of the results from Goodwin. The next categories in Goodwin are the one, 2-5 and greater than 5 years after opening, however, the number of road projects in the current study fall significantly after the immediately-after registration, so the results have to be interpreted with some caution. The long-term results from the current study seem to roughly follow the results from Goodwin (1996). From the qualitative discussion of the long-term effects of induced traffic and the graphs in ***Figure 24,*** it was shown that the road projects experienced an increase of induced traffic over the four year period, which roughly seems to correspond with the results in Goodwin.

If we look at the fixed-links bridges in the current study, the sample only consists of two bridges, namely, the Øresund and Storebælt Bridges. The two bridges generate a significant amount of induced traffic and it would be interesting to examine if this also is the case in other road projects involving major motorway bridges. Among the road projects presented by Goodwin there is also a motorway bridge where the results can be compared to the results of the fixed link bridges of the current study. The bridge in question is the Severn Bridge which is a motorway bridge. It should be noted that the bridge is not a fixed-link bridge, but is does represent significant time savings compared to not using the bridge. It is estimated that the trip not using the bridge represents a 50 to 110 km detour. The Severn Bridge connects South England with South Wales and more specifically the city of Bristol in England with Cardiff in Wales, which are large cities compared to a Danish context. The two fixed-link bridges in the current study experienced 47% (Øresund) and 66% (Storebælt) of induced traffic. The Severn Bridge experienced 44% induced traffic. Again the results from the current study are in line with the results presented by Goodwin.

All in all I think that the results of the current study follow the results found in the studies compiled by Goodwin (1996) very well. In the case of the long-term effects it is a bit more uncertain because of the lack of data in the Danish context. However, the tendencies found using screenlines in the current study seem to

[11] If the smaller projects are also included, the induced traffic within the first year is 9%.

follow the results presented in Goodwin (1996). Furthermore, both the results found in the current and the results presented in Goodwin (1996) are in line with the theory presented in the theory chapter. There thus appears to be considerable similarities across the two different national contexts (all of the studies in Goodwin (1996) are located in the UK and all the study in the current study are located in Denmark). The road networks are similar in the UK and Denmark and I think that the comparison between road projects of the different countries is possible.

Lastly it should be kept in mind that the methods and approaches used in the current study in order to obtain empirical evidence of induced traffic are not able to capture the full effect of induced traffic. This is mainly due to; the restricted area covered by corridor analysis; the generally induced part of general traffic growth traffic and the shortcoming of corridor analysis to capture small trips and trip-chains within the screenline. This means that the results of the current study are conservative and the full effect of induced traffic will most likely be greater than presented in this chapter.

# 6 Discussion & reflections

As mentioned in the concluding chapter the results of this study are severely affected by the lack of available data. This discussion chapter will mostly concern the implication of this lack of data, both in relation to this study and in relation to evaluation of planning in general. Furthermore reflections on how induced traffic is used in transport planning will be presented along with a discussion on different approaches to traffic planning.

## 6.1 Experiences with induced traffic so far

The following section will discuss experiences with induced traffic in Denmark so far and compare them with experiences in the UK.

The results presented in the concluding chapter shows that there does occur induced traffic immediately after opening of a road project when increasing road capacity, at least for fixed links, motorways and highways. And as the qualitative analysis of the four case projects show, induced traffic seems to increase over a longer period. However, because the mechanisms of induced traffic are highly complex in nature, further discussion of the results and their implications is warranted and will be presented in the following.

The results of this study and other studies on induced traffic clearly show that induced traffic is a real phenomenon and should be taken into consideration when planning for the future. However this has often not been the case up until now. Only lately have attempts to included induced traffic into traffic models been made in Denmark and only some of the effects of induced traffic have been included. In an international context one of the major efforts to document induced traffic has been the Standing Advisory Committee on Trunk Road Assessment SACTRA (1994) appointed by the UK Department of Transport (DoT). The committee's report has been very influential in the research on induced traffic and led to major changes in the UK road appraisal program (Noland & Lem 2002). In 1998 the UK Department of Environment, Transport and the Regions (DETR) established a new direction for UK transportation policies with the publication of the white paper "A new deal for transport: better for everyone (Department of Environment Transport and the Regions 1998)" (Noland & Lem 2002). This paper was a direct break with the "predict-and-provide" approach to transport planning, which had governed in the UK up until this point. According to Goodwin, this paper lead to

> *"…a recognition of the importance of a co-ordinated approach to public transport, walking and cycling, together with policies aimed at reducing less necessary travel where possible; ensuring that the costs of congestion and environmental pollution are, as far as practical, met by those who cause them (in which the revenue from new pricing systems would be kept under local control and used for transport improvements); an emphasis on better maintenance and management of the road system rather than increasing its capacity; consideration of the effects on transport of other policies in land-*

*use, health, education etc.; development of institutional structures or contractual arrangements able to bring these changes about; and conditions in which people's everyday behaviour and attitudes may be in harmony with policy, finance and environmental constraints."* (Goodwin 1999) p.656

These changes in policies did not appear overnight out of nothing they were influenced by several studies stretching over many years, where one of these studies was the SACTRA report (Goodwin 1999). It should be mentioned, that several researchers have noticed that there have been "steps backwards" in regards to abandoning the predict-and-provide paradigm (Richardson 2001; Noland & Lem 2002).

In a Danish context there have only been performed limited studies on induced traffic and only recently attempts to incorporate some effects of induced traffic into transport modelling have been made (Twitchett 2012; Nielsen & Fosgerau 2005). A few models are now able to include limited effects of induced traffic. The Ørestadens Trafik Model (OTM) which was developed in 2002 to assess demand for the new Metro in Copenhagen and the National Traffic Model (Landstrafikmodellen) (LTM) which is in its final stages of development. The OTM only covers the Capital region and only includes limited effects of induced traffic. The LTM has been long awaited and covers the whole of Denmark. The LTM is also supposed to be able to include more effects of induced traffic. In regards to traffic policy in Denmark, there still seems to be a predict-and-provide approach to congestion- and other traffic related problems and there have been no sign of abandoning the this strategy. This may have to do with the limited studies on induced traffic and ex-post evaluation of road infrastructure in a Danish context.

Although the results of the current study have to be interpreted with some caution they do imply that induced traffic occurs when increasing road capacity in a Danish context. Induced traffic is an influential factor in transport planning and the Transport ministry should acknowledge the effect of induced traffic, especially if sustainable development is to be achieved in the transport sector. Currently a report from the Danish Infrastructure Commission published in 2008, entitled The Danish Transport Infrastructure 2030, acts as the standing guidelines for the future development of Danish infrastructure and appraisals of road infrastructure projects (Infrastrukturkommissionen 2008). The commission was a government-appointed commission which had the main objectives:

- To analyse and assess the key challenges and development potential for the infrastructure and national traffic investments until 2030.
- To identify and assess the strategic options and priorities and to put forward suggestions to strengthen the basis for the national investment decisions in the transport area. (Infrastrukturkommissionen 2008)

However, as noted in Næss et al. (2012), the report does not acknowledge that congestion has a traffic-suppressing effect, and the report assumes that traffic growth will occur at a fixed rate regardless of congestion or not. This has some serious consequences in appraisal of road projects. If the traffic-supressing effect of congestion is not recognised, then then future congestion levels will be greatly exaggerated when forecasts of traffic levels on the existing road network are made. This means that the no-build alternative in an appraisal of different road projects will seem much worse that actually would be the case and thus increase the incentive for the other alternatives. A further discussion of this pessimism bias can be found in (Næss 2011). Furthermore, it should be noted that ignoring congestions suppressing effect also means ignoring that induced traffic occur when congestion is relieved.

The reason for ignoring induced traffic can be many, but there seem to be an inherent institutional belief within government agencies that the effect of induced traffic is marginal and that inclusion of induced traffic in appraisals, forecasts and models will have no significant effect in the decision making process (Næss et al. 2012; Twitchett 2012). Other researchers have suggested that there also can be a strong aspect of power when dealing with models and forecasts, and that it is conceivable that planners have been encouraged to manipulate numbers and models (Kain 1990; Wachs 1989; Flyvbjerg et al. 2006). The rationales for ignoring induced traffic will not be discussed further in this study, the above was simply to illustrate that there can be many reasons why induced traffic is not included in traffic planning.

No matter the reason for ignoring induced traffic, it is the author's opinion that induced traffic should be included in future transport-planning and appraisals in order to secure a sustainable development of transport infrastructure in the future. The development of LTM is a step in the right direction. However, this approach might not be the best approach, as will be discussed in the following section. Furthermore, the transport policies put forth by the Danish Government and Transport Ministry should reflect that induced traffic is in fact a real and influential factor in traffic development. Fighting congestion with capacity expansion is not a solution. There may not be many Danish studies available, but there are plenty of international studies on induced traffic which can be utilised until further studies on induced traffic are carried out in a Danish context (SACTRA 1994; Hills 1996; Phil Goodwin 1996; Phil Goodwin 1999; Litman 2012; Stathopoulos & Noland 2003; Næss et al. 2012; Duranton & Turner 2011; Næss et al. 2001; Noland & Lem 2002; Noland 2001).

## 6.2 Ex-post evaluation

Through the process of collecting data for this study is has become evident that not much systematic ex-post evaluation of road infrastructure has been done in Denmark - or at least such evaluations have not been systematically documented and archived. A recent Ph.D. study which has examined inaccuracy in transport project evaluation by the use of ex-post data for road and rail projects in Denmark has come to a similar conclusion about the ex-post evaluation of road projects.

> "*In order to obtain the necessary decision support documents I initially started out by contacting the responsible directorates for road and rail planning in Denmark... ...However, it quickly became apparent that systematic storage of such information was nowhere to be found. Both the road and the rail directorate claimed that no such archive existed in their organizations, and after contacting the ministry of transport I was given the same message here.*" (Nicolaisen 2012) p. 88

In the search for data in relation to the current study, I have reached a similar conclusion on the data availability of post-evaluation of road projects. Enquiries by the author, for archives of post-evaluated road projects at both the Road Directorate and the municipalities gave no result. However, as part of the current study ca. 50 before and after post-evaluation reports have found, ranging from the 80ties to present time. All the before-and-after reports are alike in appearance and contain the same type of information. This would suggest that they are made after the same template and post-evaluation of road projects has been made. But whether some form of semi-systematic post-evaluation has been made without systematic archiving or the before-and-after reports are made randomly, but with the same template, is unknown. In any case, it is clear that no systematic archiving has been performed and the before and after reports are not used in systematic ex-post appraisal program.

The lack of ex-post evaluation came as bit of a surprise to the author of the current study since road infrastructure investments often cost many millions DKK. One would think that the Danish government would be interested in knowing if the billions DKK spent on road infrastructure each year actually fulfil their intended purpose or not.

Since Denmark is a member of the EU, the country is required by law to carry out ex-ante evaluations such as environmental impact assessment (EIA) on large infrastructure projects. However no systematic ex-post evaluation is in place in the Danish planning system. It is all very well with a lot of forecasts and predictions about the outcome of road infrastructure projects, but if the outcome of these road projects does not turn out as the forecasts predict, then what are the use of these predictions?

In other countries they have already acted on these observations above and implemented ex-post evaluations of road projects. In the United Kingdom the Highways Agency has implemented the Post Opening Project Evaluation (POPE). The POPE program is divided into two programs addressing Major Schemes and Local Network Management Schemes (LNMS), respectively. POPE of major schemes is evaluating projects of over £ 10 million and LNMS evaluates projects less that £ 10 million. The POPE of major schemes is undertaken at one year after and five year after opening of the schemes. The POPE of LNMS is undertaken one year after opening of the scheme. The Pope program allows the Highways Agency to compare costs, benefits and other impacts predicted in the preliminary stages of the scheme, with the outcome (after opening of the scheme) (Highways Agency 2012).

According to the Highways Agency:

> *"These comparisons allow lessons to be learnt about the effectiveness of the existing appraisal processes and hence lead to better decision making in the future."* (Highways Agency 2012)

It is my belief that a program such as POPE would be hugely beneficial to Danish transport planning, not only to policy-makers and professionals transport planners, but also researchers in transport planning.

For policy-makers a program such as POPE could create clarity about which initiatives should be implemented to counter certain problems in transport such as congestion, accidents and pollution. Furthermore it would enable them to better evaluate if the million DKK investments are successful or unsuccessful and help them to make better investments in the future.

For professional transport planners a POPE program could help them to better realise the national transport goals set forth by politicians. Evaluations of previous road projects could help them better determine which solutions are suited for certain problems.

For researchers in the transport field a POPE program could be a very valuable source for data on traffic and transport. This data could be beneficial in future research on transportation and environmental impacts of road projects. The data could also help accuracy of traffic models and future predictions of traffic, accidents, emissions and so on.

Furthermore, a POPE program could help to increase transparency and participation in the transport planning process for the general public. If the public had access to systematically evaluated projects, this would enable them to compare the impacts of completed and evaluated projects to similar new proposed projects.

In relation to the current study and its results, there is no question that better data availability in the form of ex-post evaluation of road projects could have been hugely beneficial. The results on the long-term effects of induced traffic suffered because of lack of data. If data for the four year period after opening had been available, the long-term results would have been much improved. Systematic ex-post evaluation and archiving of road infrastructure projects could provide valuable knowledge and data which not only can be used in the study of induced traffic, but also in the research of project appraisal in general. We need better knowledge of the effects that follow major infrastructure projects.

## 6.3 Reflections on methods and approaches to induced traffic

There is no doubt that better data on induced traffic could obtain better results than this study has produced. But even if all the data searched for in this study had been obtained there would still be several effects of induced traffic that the methodology chosen in this study could not uncover/detect. As discussed earlier there are other methodological approaches to capture the effects of induced traffic, however, none of them can fully capture all the behavioural responses which produce of induced traffic. The sheer complexity of thousands of individuals' responses to changes in their accessibility and the interaction between these responses is incomprehensible and anything short of knowing exactly where everyone is at all times will fail to capture the effect of induced traffic completely. Furthermore, even if one could hope to capture the full effect of induced traffic facilitated by a road project, the mechanisms behind induced traffic are so heavily context-dependent that no precise prediction can be made about new future road projects (Næss & Strand 2012).

This raises the question if striving towards more and more precise prediction is desirable? Of course some degree of prediction is desirable and uncovering mechanisms and causal relationships in traffic systems will always be a goal for transport researchers, but traffic models become more and more advanced and much planning and decision making are based on predictions and forecasts made by these models.

The use of models can of course have some benefits, but there are also some disadvantages of complex models. The newest traffic model in Denmark is the LTM which is able to include some of the effects of induced traffic, however complex models are very expensive and running the model is very cumbersome and time consuming. Maybe some of the resources used on these elaborate models could have been utilised better in in other areas of the planning process. The complexity and intricacy of models can also sometimes seem as a black box for non-experts and hinder the transparency of the planning process. This means that the whole planning process can be very confusing and opaque to NGOs and non-professionals. Furthermore, results from complex and intricate models are often perceived as more factual than more qualitative results (Porter 1995; Ascher 1981). Presenting results in exact numbers from a highly sophisticated traffic model seem very factual and convincing. It may also seem intimidating, and questioning the results of a several-million-DKK traffic model which has taken two months to run the calculations, can be terrifying for non-experts.

Instead of perusing these perfect predictions in the policy and decision making process, maybe other more qualitative methods could be applied. Approaches such as theory-informed estimates as in (Næss & Strand 2012) and backcasting are examples of more qualitative methods for planning and forecasting. Backcasting is a method first introduced by John B. Robinson in 1982 in order to analyse how to obtain desirable futures. The backcasting method is a long term planning tool intended for analyse of scenarios 20-100 years in the future and according to Robinson:

> *"The major distinguishing characteristic of backcasting analysis is a concern, not with what futures are likely to happen, but with how desirable futures can be attained. It is thus explicitly normative, involving working backwards from a particular desirable end point to the present in order to determine the physical suitability of that future and what policy measures would be required to reach that point."* (Robinson 1990) p. 822

The backcasting approach is thus not concerned with elaborate predictions of the future or trying to accommodate these. I believe that such a method would be much more suitable for the accuracy of the predictions we are able to make about behavioural responses as for example induced traffic, where we maybe are able to conclude on the direction and roughly on the magnitude, but not on the precise end result. In ***Figure 25*** below the concept of backcasting is illustrated.

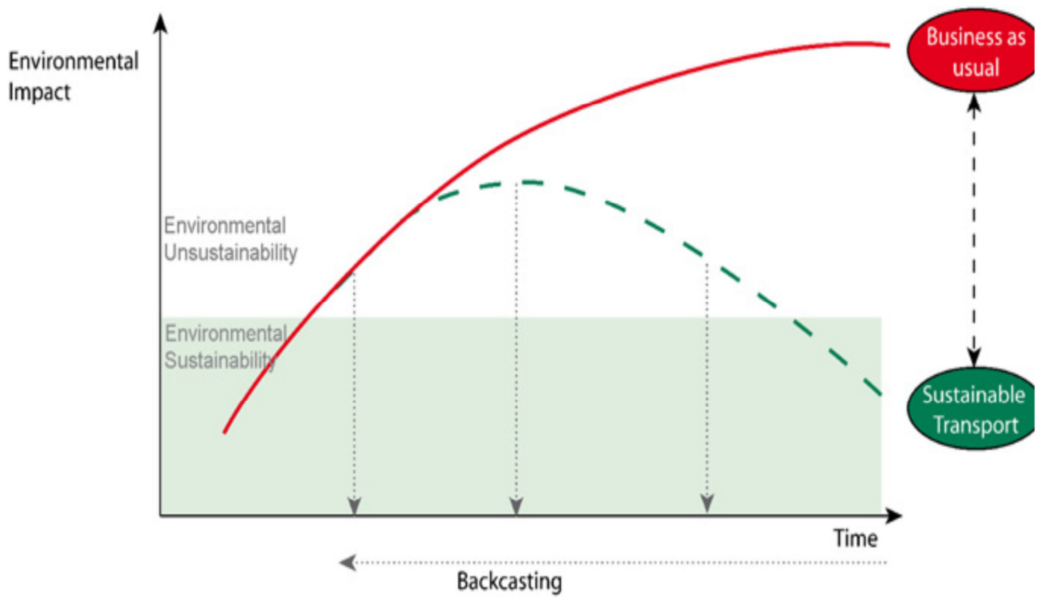



***Figure 25: The backcasting framework.*** (Hickman & Banister 2007)

In contrast to the complex "black box" traffic models mentioned earlier, this approach will make the planning process more transparent by having a clear normative goal and encouraging public participation. In should be noted that the backcasting method has a relative long time span in order to allow significantly different scenarios to develop. This means that backcasting is not suitable for planning new road infrastructure five or ten years out in the future. For more detailed planning a shorter-term method if preferable and can used in combination with the backcasting approach. The backcasting method is, however, well suited for overall policy changes or paradigm shifts, as for example abandoning the "predict-and-provide" paradigm in favour of a more sustainable approach to transport planning as has been attempted in the UK.

The backcasting method can also be combined with other planning tools, so combining backcasting with a more qualitative theory-informed method of assessing the outcome of proposed initiatives, might be preferable. As mentioned above, backcasting is a long-term planning tool, but in order to reach the desired end-scenarios different initiatives would have to be analysed with the purpose of determining the initiatives' effect on the path to the end-scenario. In Næss & Strand (2012) they argue that predictions at this level of planning should be carried out by a qualitative theory-informed method. This is done in the light of which predictions actually are possible at this level of planning. Furthermore, they argue that:

> *"Instead of using sophisticated models to calculate 'precisely wrong', transport planners should aim to be 'approximately right', using theory-informed adaptations of state-of-the-art knowledge about induced traffic to the planning context at hand."* (Næss & Strand 2012) p. 292

There are of course other and different methods that could be utilised in forecasting and future planning, the methods mentioned here were just an example of how to break free of the predict-and-provide paradigm which reigns in transport planning in Denmark and instead plan for more sustainable future. However, if methods such as backcasting and reference class forecasting are to be used, or even if sensible planning is to be carried out, some form of ex-post evaluation of projects has to be implemented in order to provide us with information on the impact of the projects proposed.

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