The significance of induced demand in road design: a viewpoint comparison

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i. Preface

In this report, the results of my bachelor thesis research are presented, with which I aspire to wrap up my bachelor's degree in Civil Engineering at Delft University of Technology. The thesis addresses the significance of the so-called 'induced demand' phenomenon in road design. For readers with little time, the abstract to be found on the next page will provide the most important information contained within the thesis in a nutshell.

I would like to express my dearest gratitude to a few people. Firstly, many thanks to the six fellow students in our coaching group for your careful reviews and our inspirational meetings every week. This has helped me a lot, both in terms of feedback as well as mutual motivation to keep on track. Finally, I would like to thank my supervisors Maria Salomons and Natasa Roukouni, who have diligently helped me along the way, not only with their very detailed and constructive feedback but also by helping me to start shaping my initial and sometimes rather vague ideas into a concrete report.

Hans Erblich
Rijswijk, June 13th, 2021

ii. Abstract

In this thesis, the significance of the so-called ‘induced demand’ phenomenon is discussed. This phenomenon can occur when a stretch of road which is prone to congestion is widened. Although this widening should in theory solve congestion problems, it can often spawn additional effects, typically undesired and occasionally unforeseen. These effects could include shifts of travel in route and time (people formerly avoiding congested roads by departing at another time or taking a detour will now return to that road), but also new travels might be made which were not made before road widenings. All of these effects might eventually converge to raise traffic amounts to levels with which the widened road is just as prone to congestion as it was. This additional traffic demand which a widened or new road creates is commonly denoted as ‘induced demand’.
Although this induced demand phenomenon has commonly been acknowledged to exist, it seemed like there was little agreement on both its amount as well as its significance. Some readings seemed to suggest that for every percent of road capacity added, a percent of new traffic will occur, whereas other readings suggested that the effects were much smaller and might be limited to, e.g., merely a third of a percent extra traffic for a percent extra road capacity. A semi-systematic literature review has been carried out, enabling to compare writings of various origins, ranging from scientific papers via documents from governmental advisory bodies to newspaper articles for the general public. These writings help to determine the significance of induced demand. It has been found that there are major discrepancies, even amongst scientific literature, concerning the ways in which the induced demand is measured, both in terms of the actual quantities which are compared to each other, as well as the time span over which the aforementioned effects are measured. These discrepancies do not aid in creating an unambiguous message for policymakers, nor do they facilitate a straightforward approach in avoiding new congestion on widened roads. Combined with the remark to be found in many scientific writings that the induced demand topic is in need of more research, a relayed recommendation from this thesis is therefore that more research be performed into this topic. However, the main recommendation is that the newly done research be more standardised, both in terms of the measured quantities and the time span over which the effects are measured.

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1. Introduction

Roads are always constructed to fulfil the need for travel at that moment in time. In particular freeways, also called motorways or highways, are built for fast travel, with as few factors as possible that would have a negative effect on travel time. This could be achieved by omitting traffic signalling, level crossings, etc. If the actual capacity of a section of road is smaller than the demanded capacity due to traffic numbers (i.e., the number of vehicles using that road), congestion in the form of traffic jams can arise, which will then negatively impact travel time. This demanded capacity can obviously change over the course of the years, for example, due to new residential areas being built on the borders of a city. In the Netherlands, in the last couple of decades, the usual road extension or widening approach has primarily been focused on solving bottlenecks: if congestion would arise at a certain point, the road is usually widened or a detour is being constructed, and the point of trouble should, in theory, be free from congestion again (Taale, 2021).
However, a typically undesired phenomenon is alleged to result from these road widenings: traffic numbers can increase *as a result of* these road widenings, which might result in congestion returning again. Although this phenomenon, most commonly called 'induced demand' has often been acknowledged to exist and as such been described in writings of many origins, there is a large spread considering its significance. For example, Duranton & Turner (2009) demonstrated that in certain cases, every percentage of road capacity added will spawn an equal percentage of extra traffic. In contrast, van der Loop et al. (2014) found a ratio of car use to added lane kilometres of merely 0.4. Yet other, largely diverging, results can be found in other literature.

In this thesis, the various points of view considering the significance of the induced demand phenomenon will be analysed, which will try to help to answer the following research question: *What is the significance of the induced demand phenomenon with road widenings?* In order to obtain the answer to this research question, two analyses will be carried out. The first analysis will focus on the relevant stakeholders within the processes of road design and possible induced demand. The main part of this thesis will be the second analysis, which will analyse writings about the induced demand phenomenon in a manner that is as objective as possible. This will also ease comparisons between different forms of literature. More details on the chosen methodologies, as well as the reasons for choosing them, can be found within Chapter 3.

This thesis is composed in the following way: after the introduction in Chapter 1, the problem will be stated in Chapter 2, after which the methodology will be explained in Chapter 3. In Chapter 4, the stakeholder analysis will be carried out, after which the literature review will be carried out in Chapter 5. In Chapter 6, the discussion, the relevance of these findings will be discussed, which will also involve the results of the stakeholder analysis carried out in Chapter 4.
Finally, in Chapter 7, a conclusion will be stated based on the findings in Chapter 5 and the discussion.

2. Problem statement

If a stretch of road (for example a freeway) is receiving more traffic than it can handle, congestion in the form of traffic jams might arise. An intuitive reaction to this might be to expand the capacity of the road network, in order to accomplish congestion relief. This could be achieved by expanding the capacity of the congested freeway, e.g., by adding more lanes. It might also be achieved by constructing completely new sections of road, like the attempt to solve congestion on the A4 motorway by means of the addition of the A5 motorway to the Dutch freeway network (Nijland et al., 2010).
Next to the immediate effect of solving congestion on the formerly congested stretch of road, these infrastructural expansions are considered to have an impact in several ways. In the short term, the impacts can mostly be linked to the behaviour of travellers (Cervero, 2003). Some travellers will not change their behaviour at all (e.g., someone who already persisted in driving to work at a time at which traffic jams occurred and will continue to do so, albeit now with fewer traffic jams), some travellers will change their behaviour in terms of time shifts (e.g., someone who departed an hour too early for work to avoid traffic jams but now decides to depart an hour later as there are anyhow no traffic jams anymore) and some travellers will change their behaviour in terms of mode shifts (e.g., someone who previously took the train to work but now chooses to drive to work as their travel time by care has now become shorter).
In the long term, some additional effects can come into play. Firstly, areas that are well accessible by car have an added appeal for area developers. Therefore, if the reachability of an area increases, e.g., due to less congestion on the routes towards that area, more activities might start taking place in that area, leading to more traffic (Bleijenberg, 2017). Secondly, it has been shown that the total time that every human spends travelling per day is more or less constant at an average of 73 minutes. This phenomenon has been called the BREVER-law (*Behoud REistijd en VERplaatsingen*, or 'preservation of travel time and displacement') by the Dutch traffic expert Geurt Hupkes (Peters et al., 2001). Following this law, if a distance can be travelled within a shorter amount of time, people will tend to travel larger distances. This would imply that if the speed on a stretch of road increases due to less congestion occurring, it will result in more overall traffic movements.

Concludingly, adding more capacity to a road network could have many consequences which may, or may not, converge to raise traffic levels to larger amounts than formerly predicted and subsequently cause new congestion to occur. This effect has been named the "Fundamental Law of Road Congestion" by Duranton & Turner (2009).

Using economics, this effect can also be related to the theory of supply and demand. A basic visual representation can be found in Figure 2 (adapted from Noland, 2000). In this figure, the horizontal axis represents the quantity of travel, e.g., within a country. The vertical axis represents the total generalised price of travel (including factors like fuel cost, as well as the considered value of travel time). The line 'demand' represents the total demand for travel. It shows that if the price of travel drops, the quantity of travel will increase. The line 'supply before' (S1) represents the supply (in this case: of roads) before a road extension.
In this initial situation (before a road extension), the lines intersect at the red dot, which leads to a quantity of travel Q1 and a price of travel P1.
After a road extension has taken place, the price for the same quantity of travel has dropped. Therefore, the supply curve shifts down (S2). Now, the intersection point of the supply and demand curves is located at the blue dot. This will decrease the price of travel (P2), as well as increase the quantity of travel (Q2). The difference of Q2 minus Q1 represents the induced travel effect.

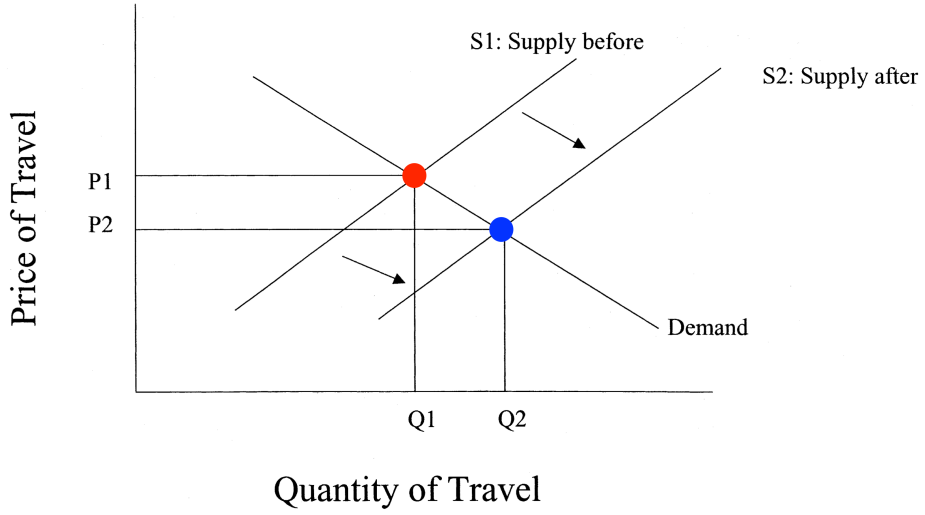

Figure 1: Graphical representation of induced demand effect, adapted from (Noland, 2000)

3. Methodology

In this chapter, the methodology will be described that will be used to analyse both the stakeholders in road design processes (3.1) and the literature considering the induced demand phenomenon (3.2).

3.1 Stakeholder analysis

In this thesis, a stakeholder analysis will be carried out. The goal of this analysis is to get an insight into the various stakeholders, which is as thorough and as systematic as possible. The results of this stakeholder analysis will subsequently be used in the discussion section of this thesis (Chapter 7) to allocate an importance to a certain viewpoint from a certain stakeholder. These viewpoints will be analysed in Chapter 6.

3.1.1 Stakeholder definition

A stakeholder is, according to the Cambridge Dictionary, "a person such as an employee, customer, or citizen who is involved with an organization, society, etc. and therefore has responsibilities towards it and an interest in its success" (Cambridge University Press, n.d.).
After having identified several stakeholders which are of relevance for this thesis, it is useful to be able to parametrise their properties, as this will also enable a more direct comparison, e.g., by means of a grid.

3.1.2 Parameters describing a stakeholder, analysis model used

A widely used model for stakeholder analysis is the model envisioned by A.L. Mendelow (1981), which has been adapted and refined several times since its publication. Most adaptations, e.g., by (Eriksen-Coats, n.d.) and (Mindtools, n.d.), use two parameters to analyse stakeholders, namely:

- Power: the ability at which the stakeholder can influence a result

- Interest: the amount of interest that a stakeholder has in a result. Mendelow (1981) refers to this parameter as 'dynamism'

As soon as these two properties of each stakeholder have been identified, the stakeholder can be placed in a power-interest matrix, of which an example is shown in Figure 3. This model has been considered to be the most relevant for the stakeholders in the topic (decision making processes in road design) that is being analysed.

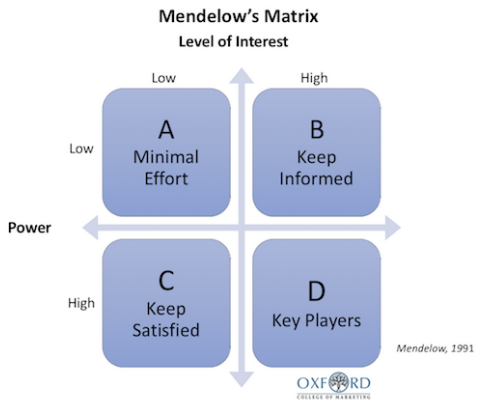

Figure 2: Two-dimensional stakeholder grid by Mendelow, adapted by (Eriksen-Coats, 2021)

3.2 Literature review

The heart of this thesis will consist of a literature review. There are several types of literature review that are commonly used. Their properties, pros and cons will be discussed in Paragraph 3.2.1, after which one type will be chosen, which will subsequently be cast into a shape that suits the to-be-done research the best.

3.2.1 Types of literature review

As a starting point, the guidelines on writing a literature review from Snyder have been considered (Snyder, 2019). Within this paper, a distinction is made between three types of reviews: systematic, semi-systematic and integrative reviews. The systematic review is most suited for comparing similarly natured literature in detail, whereas the semi-systematic review is more suited for a broader topic that might have been described in different ways. Lastly, the integrative review aims to create new concepts by merging several perspectives found.
The aim of the review carried out in this thesis is not to create any new concepts, it merely compares different points of view. Also, the literature considered will be of a myriad of resources and natures. Therefore, a semi-systematic review will be carried out.
In the guidelines by Snyder, there are references to several more in-depth examples on writing a semi-systematic review. These examples include the so-called thematic analysis, which would be the best suited for the type of literature review for this thesis, for reasons described below.

3.2.2 Thematic analysis: basis

A thematic analysis is a form of qualitative (i.e., usually non-numerical) analysis in which the main focus is on analysing and recognising 'themes', i.e., certain patterns, within the literature that will be compared (from now on referred to as 'data'). For the type of literature review done in this thesis, this has been considered the most appropriate way, as it can fit literature of various forms and origins and can review in a way that is as objectively as possible.

The standard framework for a thematic analysis consists of six steps, which will be listed below (Braun & Clarke, 2006).

1. **Familiarising with data**: thoroughly reading the data and getting familiar with its contents.
2. **Generating initial codes**, where 'codes' can be described as the most basic 'elements' of meaningful information that the data provides.
3. **Searching for themes** within the codes that have been established in Step 2. This step is performed by sorting the codes that have been found in the data, which makes it possible to group codes, hence extracting themes (i.e., a similar subject or topic found in the codes) from the data.
4. **Reviewing themes**: some themes will be found to be more relevant than others, or the data supporting them could either be too diverse or too scarce. Also, nuances can be applied, like themes that are of greater or lesser importance.
5. **Defining and naming themes:** i.e., which aspects of the data are being captured, and what do the themes contribute to the understanding of the data**.**
6. **Reporting**: placing the results in context and creating a coherent conclusion.

3.2.3 Literature review approach for this thesis

For this thesis, the literature review will be largely approached according to the thematic analysis framework as described above. A subtle difference is that some themes will already be established beforehand. This will be done to slightly narrow down the reviewing process, as the scope of the found codes and themes might otherwise get too large for the desired scope of this thesis. Also, some sorting will be applied to the found literature beforehand, in order to create already some overview within the list of found literature. To achieve this, the literature will be sorted in a table, which will list the title, author, year and the type of literature (e.g., a scientific paper, a newspaper, a report or something different).
In this thesis, step 2 from the thematic analysis (the 'coding' process) will imply that the most relevant data from the piece of literature will be summarised as briefly as possible. The relevance of the data is directly linked to the themes which are established beforehand.

The literature that will be reviewed will be found by using a systematic literature search. There are several approaches to this (Vrije Universiteit Amsterdam, 2021), like the building block approach (combining many search terms into one search query in order to get to the desired available literature as efficiently as possible) and the snowball method (once a relevant publication of any form has been found, use the cited literature contained in that publication to get to other relevant publications). For this thesis, the building block approach will be used as a starting point, supplemented by the snowball method.

3.3 Connection with discussion section

The aims for the discussion section in this thesis are:

1) Connecting the literature review to the stakeholder analysis. The connection of these two will be formed by the power and interest which the stakeholders have. This can be linked to the viewpoints for which the stakeholders stand, which have been determined in the literature review. In this way, it can be determined which viewpoints will most likely be the most influential. Depending on the eventual result, this might also be open for questioning.
2) Determining which areas could be in need of more research. This will follow from the conclusions of the literature review.

4. Stakeholder analysis

In this stakeholder analysis, the most relevant stakeholders in road widening processes as well as the possible extent induced demand phenomena will be described. The exact stakeholders will vary slightly from country to country, depending on the governance structure of the country. Therefore, in this stakeholder analysis, the stakeholders for The Netherlands are taken as an example.
Every stakeholder will also be assigned an amount of power (how influential the stakeholder is) as well as a level of interest. This is done according to the ideas of the author of this report. Finally, all stakeholders will be placed in a power-interest matrix, which aids in making the total landscape of stakeholders clearer.

(1) Rijkswaterstaat (Ministry of Infrastructure and Water Management): is responsible for maintaining roads as well as constructing new road sections. Also keeps statistics on the number of travels, as well as traffic jams and conflict points. Their power is high, as they will eventually execute possible capacity extensions, and their interest is high as well since maintaining and widening roads is one of their main activities.

(2) Politicians and their advisories: have to give approval for road widenings and will partially rely on advisory agencies (like the KiM, CLI, CPB). However, they could also be influenced by lobby groups from, e.g., the car or petrol industry (Follow the Money, 2020). Their power is therefore very high, however, their interest might not be too high (it will be considered 'medium') as they have a large range of other duties.

(3) Media: largely create the image that ends up with the general public (in the most extreme cases, this could be: road widenings can solve all traffic jams, or it could be: road widenings are totally fruitless). The aforementioned images might also stretch out to more influential parties. Therefore, their power could (albeit indirectly) be described as medium, and their interest low, as it is not a subject that is covered in great extent every day in media.

(4) Road users/travellers: will largely prefer the fastest route (apart from factors like: working on the train) and will therefore adapt their behaviour to the fastest route at that moment in time. Also, they might consider moving jobs or homes if travel times decrease. Their power (not considering individuals but all users) is moderately high. Their interest can best be described as both high and low: they will always be interested in taking the fastest or easiest route, but not make conscious decisions on this topic.

(5) Area developers: will adapt to changes in reachability of an area by possibly relocating or constructing offices, or by creating new homes. Their power is medium-low, and their interest is high.

(6) Environmental/"anti-car" activists; and exact opposites: advocates of cars: they could influence public opinion concerning road widenings as well as induced demand-related phenomena. Their power is medium-low, and their interest is medium-high.

(7) Public transport agencies: although its effect has been shown to be of limited influence.
they will try to offer the best service possible for their users, which might – in their view – tempt more people to abandon their cars, switch to public transport, and therefore aid to relieve congestion. However, research (Duranton & Turner, 2009) seems to show that even ample public transport supply is of limited influence on car use. Therefore, their power is low, and their interest is high.

(8) Local residents: for people living close to roads of which the capacity is being increased, the downsides of extra road capacity (more noise and air pollution) might outweigh its benefits (less travel time to and from their homes). Their interest can be classified as quite high, and their power as quite low.

(9) Municipalities: they will have a large interest in keeping the urban areas as accessible as possible. They could also exert influence on 'higher' forms of government to emphasise the need for new road widenings. However, they will have a wide range of other duties (just like with **(2)**). Their power is medium-high, and their interest is medium-high as well.

In Figure found below, the stakeholders are added to the Mendelow matrix which has been discussed in Paragraph 3.1.2. For this purpose, the numbers between brackets are used which have been given to every stakeholder above.

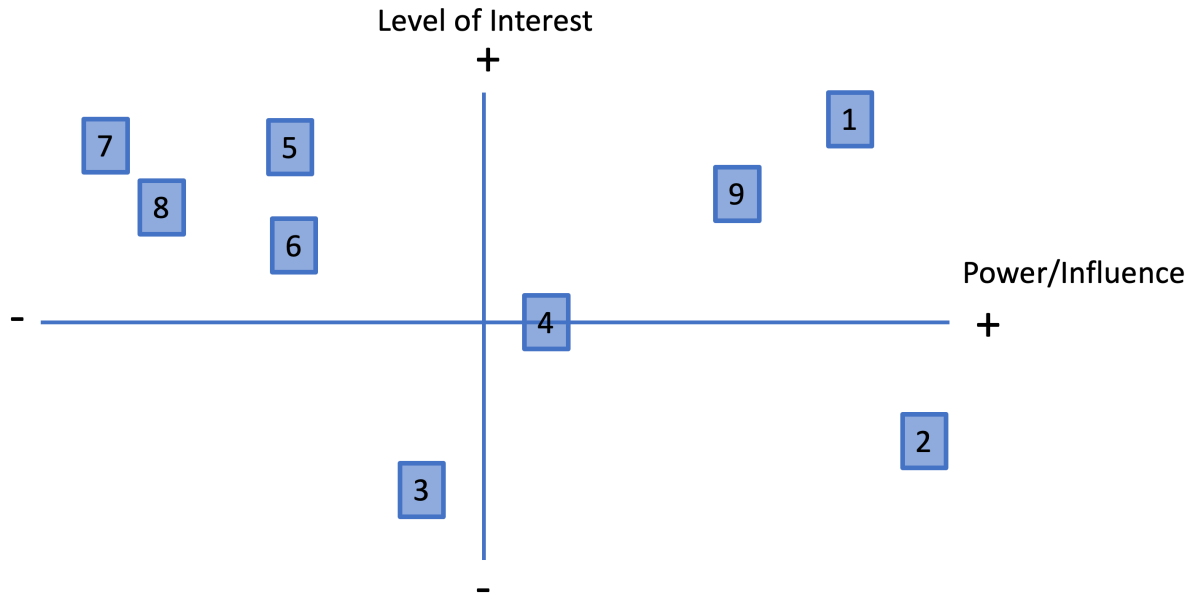

Figure 4: Stakeholder matrix, filled in with relevant stakeholders

5. Literature review

In this chapter, the literature review will be carried out in the manner described in Paragraph 3.2.3. First, as preparatory work, an overview will be made of the literature to be reviewed (5.1) and a few themes will be established (5.2), after which the actual analysis will be carried out and conclusions will be drawn (5.3).

5.1 Literature to be reviewed

5.1.1 Search methods

The literature which is to be reviewed was mostly found by some targeted search terms on Google, like 'induced demand'. Subsequently, the scientific papers which had information concerning this topic have been studied, and the most relevant ones have been added to the literature overview in Table 1 below and have been thoroughly analysed. For Dutch information on governmental policies as well as newspaper entries, terms like 'filebestrijding' (fight against traffic jams) and 'file beleid rijkswaterstaat' (traffic jam policy Rijkswaterstaat) were also used. Most literature refers to other literature. In some cases, this led to other discoveries which were then also used, especially if the writings used had many references to that new literature.

5.1.2 Types of literature

There are a few different types of literature discussed here, between which a distinction is made. Firstly, there is information meant for the general public, which will be called '*popular media*' here. This could include newspapers as well as articles on websites that clearly have the goal to inform the general public without pre-knowledge about traffic and road design. Also, there is scientific literature: papers, journal articles etc., which have been through a peer-review process and are meant for scientific or research purposes, these are referred to as '*scientific literature*'. Finally, there is literature that cannot be placed in either of the aforementioned categories, e.g., reports from Rijkswaterstaat, or from advisory boards of the government. These are meant for neither of the aforementioned purposes, at least not in the first place: their goal might be to inform other professional parties about current states of affairs. This literature forms the category '*other*'.

5.1.3 Overview of literature

In Table 1 found below, an overview will be given of the reviewed literature. To avoid any form of bias, the literature is sorted by year, Also, an abbreviation will be given in the form of a number between square brackets, to make referring easier within this chapter. A more extensive description of every source can be found in the 'References' section at the end.

Table 1: Literature to be reviewed. Abbreviations used in 'Type' (as discussed in Paragraph 5.1.2): SL = scientific literature (e.g., peer-reviewed), PM = popular media (e.g., newspapers), O = other

Ref.	Title	Author/*Source*	Type	Year
[1]	FILE. Wat doen we eraan?	Onrust	PM	1995
[2]	Empirical evidence on induced traffic: a review and synthesis	Goodwin	SL	1996
[3]	Relationships between highway capacity and induced vehicle travel	Noland	SL	1999
[4]	Induced travel: a review of recent literature and the implications for transportation and environmental policy	Noland et al.	O	2000

[5]	Road Expansion, Urban Growth and Induced Travel: A Path Analysis	Cervero	SL	2003
[6]	The Fundamental Law of Road Congestion: Evidence from US Cities	Duranton et al.	O	2009
[7]	De latente vraag in het wegverkeer	Van der Loop	O	2014
[8]	What's Up With That: Building Bigger Roads Actually Makes Traffic Worse	Mann	PM	2014
[9]	New findings in the Netherlands about induced demand and the benefits of new road infrastructure	Van der Loop et al.	SL	2015
[10]	Niet realistisch: de files oplossen met 1200 kilometer extra asfalt	Kuiken	PM	2016
[11]	Het Filemonster	Bleijenberg	PM	2017
[12]	Meer asfalt leidt altijd tot meer files. Toch geven we er elk jaar een miljard euro aan uit	Verkade	PM	2018
[13]	If you build it, they will drive: Measuring induced demand for vehicle travel in urban areas	Hymel	SL	2018
[14]	Inflatie van reistijd	Verhoef	PM	2018
[15]	NRC checkt: 'Meer rijstroken beste bestrijding fileleed'	Houtekamer	PM	2019
[16]	File-aanpak 2018-2021	*Rijkswaterstaat (no authors mentioned)*	O	2020

5.2 Themes to keep in mind

The main themes which will be examined are: induced demand, its definition and origins as well as its significance. Information contributing to this will be extracted from the literature found below. Sometimes other topics are also discussed in this literature, which might not be relevant for the pre-established topics. In that case, they are neither written down nor discussed in Paragraph 5.3, in order to limit the scope and size of the thesis.

5.3 Thematic analysis

In this paragraph, the thematic analysis, of which the approach has been discussed in Paragraph 3.2.2, will be performed. Of course, steps 1 and 6 can be omitted from this paragraph. The reference numbers used are the same as in Table 1.

5.3.1 Generating initial codes

In this paragraph, the most relevant information of each piece of literature (the 'data') will be mentioned. This has been done by reading the writings a few times, mostly two or three times, very thoroughly, and by subsequently trying to write down the most relevant information as concise as possible.

All information written in this paragraph is the information contained in this very piece of literature. Also, occasional conclusions drawn merely represent conclusions drawn by that very piece of literature. Hence, conclusions by the author of this thesis are not given in this section. These will be given from Paragraph 5.3.2 onwards. If a reviewed piece of literature cross-refers to another non-reviewed piece of literature, it is referred to in common APA-style.

[1] Onrust, *FILE. Wat doen we eraan?*

- To get rid of traffic jams, it seems the most logical to create more roads or widen them. The caveats coming with this are described here as environmental concerns, as well as possibly shifting the problem. Induced demand effects, or similar, are *not* mentioned.

[2] Goodwin, *Empirical evidence on induced traffic: a review and synthesis*

- Measured traffic counts rather than VKT (vehicle kilometres travelled, as used in, e.g., [4] and [6]).
- Loosely defines induced traffic as 'all extra traffic other than reassignment".
- Mentions "an elasticity of traffic volume with respect to travel time" of -0.5 in the short term and -1.0 in the long term, for a speed change which saves 10% of travel time.
- Concludes that "an average road improvement" will generate 10% of additional traffic in the short term and 20% in the long term and that individual cases might end up around double this amount. It is, however, not specified how much of this additional traffic is considered to be induced traffic.

[3] Noland, *Relationships between highway capacity and induced vehicle travel*

- Definition used here: "induced VMT" (vehicle mean traffic), being "any infrastructure change that results in either short run or long run increases in VMT".
- The input data used here is the mean of the total amount of vehicle miles travelled in the United States, as well as changes in lane miles, as provided by the Federal Highway Administration.
- Results show elasticities of vehicle mean travelled vs. changes in lane mile of 0.713 for interstate highways, 0.69 for arterial roads and 0.826 for collector roads. With a two-year lag, the values are between 0.2 and 0.5. The effect persists the longest with arterial roads.
- The elasticities seem to be larger (between 0.71 and 0.75) in urban areas, and smaller (between 0.33 and 0.78) in rural areas.

[4] Noland et al., *Induced travel: a review of recent literature and the implications for transportation and environmental policy*

- 'Induced travel' definition used: "the increase in VMT (vehicle miles travelled, red.) attributable to any transportation infrastructure project that increases capacity"
- According to [4], much of the disagreement about the existence of induced travel originates from traffic engineers' traditional assumption that total travel will be constant, despite changes in travel price (or: time cost), as well as the assumption that travel growth will merely be caused by exogenous factors.
- Existing research from the UK: SACTRA (1994), showing a larger growth in traffic than expected on corridors of which the capacity was increased. It is, however, not specified where the expectation was based upon. Also, traffic flows on parallel routes seemed to be higher than before. However, the focus was on traffic counts, so the increase in VMT cannot be fully discerned from, e.g., an increase in length of trips.
- Concludes that in countries/regions with lower fuel prices, more behavioural changes might result from changes in highway capacity, because travel time is a larger part of the general costs of travel. This suggests that induced travel effects might be larger in the aforementioned countries or regions.
- Statistic research from the US (similar to [13]) shows that "lane mile elasticities (with respect to VMT)" (of which the definition is not fully outlined) are between 0.3-0.7 on a county-scale and 0.7-1.0 on a metropolitan scale. Other research shows elasticity estimates of 0.3-0.6 in the short term and 0.7-1.0 in the long term. Most other research more or less follows these numbers.

[5] Cervero, *Road Expansion, Urban Growth and Induced Travel: A Path Analysis*

- Input data: data from 24 highway projects in California over 15 years
- "Most" studies study growth in VKT as a function of lane-mile additions. This article adds an intermediate step: road improvements make travel at higher speeds possible, and it is this that subsequently causes demand to grow.
- Discerns 'induced demand' (merely new traffic) from 'induced travel' (which might also include diversions in route or time) and uses the latter.
- Using this two-step model, an induced travel effect was found with an elasticity of 0.238. This lower elasticity than in many other models is attributed to the different way of modelling.

[6] Duranton et al., *The Fundamental Law of Road Congestion: Evidence from US Cities*

- In this paper, "the effect of lane kilometers of roads on vehicle kilometers travelled (VKT)" is examined, using data from the United States MSA's (Metropolitan Statistical Areas). The exact definition of "effect" is missing, however, the modelling used suggests that this is the eventual correlation between the two mentioned parameters.
- Existing literature using similar modelling to the one found in this paper generally shows a correlation coefficient ranging between 0.3 and 0.7 (Hansen, Gillen, Dobbins, Huang, and Puvathingal, 1993), (Hansen and Huang, 1997), [3]
- In this paper, the general result is a correlation coefficient between 0.82 and 0.86 for interstate highways outside of urbanized areas. Major roads in urbanized areas yield similar results. However, interstate highways inside of urbanized areas seem to suggest correlations around or even higher than 1.

[7] Van der Loop, *De latente vraag in het wegverkeer*

- Uses 'latente vraag' (latent demand) to be investigated in this report and defines it as 'the increase in car use over the entire day on the entire road network (in terms of vehicle kilometres travelled) arising as a result of road extensions'.
- The Dutch main road network was extended by 9%. Its usage increased by 16% between 2000 and 2012. Around 4% is estimated to be new traffic, of which half is estimated to be originating from other roads and half is estimated to be latent demand. It is especially occurring during peak hours: in the morning peak, the traffic increase is 10% and in the evening peak, it is 12%.
- Extant research has on average shown an elasticity of 0.3-0.5, which is in line with these findings of around 0.4
- In the traffic models used in the Netherlands, the Landelijk Model Systeem (National Modelling System) and the Nederlands Regionaal Model (Dutch Regional Model), latent demand is incorporated by modelling an infrastructure extension by means of changes in the choice for time, route and transport mode. When travel times decrease, more traffic is attributed to that route, and when travelling by car becomes the quickest, the car is chosen over the other traffic mode. However, possible effects on urban developments are not incorporated into the model.

[8] Mann, *What's Up With That: Building Bigger Roads Actually Makes Traffic Worse*

- Discovery over the last decades: "you can't build your way out of congestion" and claims that the ways of trying to solve traffic jams are "fruitless".
- Reference to [6], claimed that a correlation of 1 was found – in other words: for every percent of road capacity added, the amount of driving goes up by a percent.

- Causes: when creating the ability to travel, people will travel more, e.g., by moving out of a town, or making more car trips than previously. Also, a good road network attracts companies that need roads, bringing more traffic.
- Public transport merely adds more movements, it does not relieve congestion.
- Solutions could be: road pricing (tolls) for congestion, or higher parking tariffs

[9] Van der Loop et al., *New findings in the Netherlands about induced demand and the benefits of new road infrastructure*

- Different definitions of induced demand exist, it may be defined as all behavioural changes of travellers (Hills, 1966), or as a change in vehicle kilometres travelled on the total road network (McKinsey, 1986). It could also be narrowed down to all extra traffic on stretches of road which have been extended. In [9], the definition used is: "the increase in car use per day on the total network, in terms of the vehicle kilometres resulting from road expansion (new roads or adding lanes)". Other causes of extra car use, like economy or population growth, are discarded in [9], as well as route and time adaptations after road expansion.
- A large study considering the Amsterdam ring road concluded that one year after opening the last 'missing gap', the total amount of trips had increased by 8% (of which 5% is considered to be induced demand). A total of 25% of car users changed their route whereas 31% changed departure time, seeming to suggest a shift from off-peak hours to peak hours. (Bovy, 1992; HCG, 1991)
- Another study performed by the KiM in the Netherlands (also discussed in [7]) in the period of 2000-2012 found the amount of extra traffic in terms of extra vehicle kilometres to be around 4%, for a capacity increase of about 10% in those years. This study also found that car use increased by 10-12% in peak hours on road stretches with new lanes, partially from what [9] defines as induced demand, but also from time and route shifts. The proportion of these is not specified in [9].
- Most extant studies ([2], [4] and [5] are cited, as well as (Fulton et al.,2000)) seem to find an induced demand ratio (car use over infrastructure extensions) of 0.2-0.6, which seems to correspond to the KiM findings (0.4), which the article calls 'relatively low'. The article also mentions that this might partially be due to shifts in route choice, suggesting that a ratio of 0.2 might be more accurate.
- Increases in car use during peak hours (which, according to [9], does not qualify as induced demand) should not be confused with new car use due to new infrastructure (which, according to [9], does qualify as induced demand).

[10] Kuiken, *Niet realistisch: de files oplossen met 1200 kilometer extra asfalt*

- According to the advisory commission 'Loendersloot Groep', 1,200 kilometres of asphalt would be required for solving the extant road congestion problems completely, on average two lanes for the morning peak and one lane for the evening peak.
- According to this Loendersloot Groep, those extra kilometres would not be too prone to new traffic/congestion. The reason mentioned: the number of travellers currently taking the train but preferring the car would merely fill up the equivalent of half a lane. A more acute problem would be the requirement for proper distribution of all cars into cities and parking spaces.

[11] Bleijenberg, *Het Filemonster*

- The economic damage of traffic jams is estimated at €3b/y.
- In 1988 a plan was made by Rijkswaterstaat to reduce traffic jams to a third of the proportions. Instead, they have tripled in size up to 2010. There is too little understanding of the origins.
- The problem of not being able to solve traffic jams is especially apparent around freeways in urban environments, the reason being: a large route shift from roads inside of cities to roads outside of

cities. This might lead to a slightly higher average travel speed inside of cities, however, traffic jams reoccur on the new freeways.
- Also contributing is an increase in travelled distance when being able to travel faster. Finally, well reachable areas are attractive for new urban activities.
- Solutions: larger and more densely built cities, making shorter travelled distances viable, and increase transport speed inside those cities, using a smart combination of cars, public transport and bicycle.

[12] Verkade, *Meer asfalt leidt altijd tot meer files. Toch geven we er elk jaar een miljard euro aan uit*

- For 50 years, the need for road widenings seems to be fed by fear that within years, all roads will be clogged (NOS, 2016) (Dujardin, 2017), (Kegel, 2018). Public appreciation for these measurements is helped by using large terms like 'traffic infarct' (suggesting a parallel to health) 'delta plan' (suggesting a parallel to flood defences)
- For 30 years, there have been large discrepancies between calculated and eventual traffic numbers, which have always turned out much larger than expected (Bleijenberg, 2015)
- Induced demand is created by the appeal of areas that are better reachable after solving congestion problems, which will attract extra traffic (Bleijenberg, 2015).
- The general Dutch information supply concerning traffic jams, which also creates the "file top-50" does not take the width of traffic jams into account, merely the length, as this is most relevant for any individual road user. However, due to this way of measuring, it discards the *number* of people stuck in traffic.
- Reference to [6], also claiming a correlation of 1

[13] Hymel, *If you build it, they will drive: Measuring induced demand for vehicle travel in urban areas*

- In this article, the 'induced demand elasticity' is measured and defined as the causal link between and increase in vehicle miles travelled per capita and highway capacity extensions.
- Measuring induced demand elasticity is difficult due to statistical reasons, as well as likely unobservable factors. Also, some effects take many years to be observable (e.g., a commuter who might move or change job due to faster travel speeds).
- [13] discards and does not specify any *causes* of this induced demand: new travels or shifts of peak.
- The result of the investigation was an elasticity in the range of 0.892 to 1.063.

[14] Verhoef, *Inflatie van reistijd*

- In politics and media, the solving of traffic jams is a major issue. In the current policies, solving points of conflict (i.e., sections of road that are prone to congestion) has become the norm and the average person is used to this way of communicating. However, the caveats mentioned here do include a form of induced demand: "Expansion of road capacity offers relief for a short amount of time, but subsequently attracts new mobility, resulting in traffic jams again".

[15] Houtekamer, *NRC checkt: 'Meer rijstroken beste bestrijding fileleed'*

- Also mentions [6] as a source (incorrectly stating that traffic in Toronto was investigated), claiming a similar correlation of 1 as in [8]. In other words: it is claimed that for every percent of road capacity added, the amount of driving will up by a percent.
- Mentions an investigation of the KiM: a 9% increase in road capacity leading to 4% extra traffic of which half was completely new (more or less in line with [9]).
- Mentions the Rapportage Rijkswegennet from Rijkswaterstaat, which found that out of 7 widened roads, 4 resulted in shorter travel times, 2 remained equal and one got longer.

- Uses the BREVER law (of which a source is not mentioned, however, an explanation can be found with Peters et al. (2001)) to explain that when travel speeds are faster, people will tend to travel larger distances.

[16] Rijkswaterstaat (no author mentioned), *File-aanpak 2018-2021*

- In a report giving solutions to traffic jams in several ways (focussing on mitigation, prevention and avoidance), at a header 'Improving infrastructure at conflict points', the following sentence is found: "The adjustments to the infrastructure are one-off, the effects for traffic flow are lasting". No form of possible extra traffic attraction is mentioned.

5.3.2 Generating themes

Now that all important information has been derived (coded) from the data, several themes can be discerned which re-occur throughout all data, of which the different views will be discussed below.

Definition used
Although most literature reviewed covers more or less the same topic (growing traffic numbers resulting from infrastructural expansions), there seems to be little consensus on the exact way of measuring it. The most common way seems to be a relation between the total amount of vehicle kilometres travelled and kilometres of new infrastructural expansions, which [3], [4], [6], [7], [9] and [13] use.
Other definitions and ways of measuring found are a relation between traffic counts on a certain road after an expansion which has cut back travel time. The relative extra number of vehicles that passed the road is then linked to the amount of travel time the road expansion has made possible [2].
Finally, [5] uses an intermediate step to first determine the relationship between infrastructural expansions and higher travel speed, after which this higher travel speed is related to the amount of extra travel on the expanded road sections.

Timespan

As induced demand is a phenomenon of which the full effects will only become apparent after several years, accurately defining the time stretch over which measurements are taken is crucial for a right comparison. In the Amsterdam ring road study mentioned in [9], effects are observed one year after opening a road stretch. Another study mentioned in [9] observes effects over a 12-year time span, combining all extra traffic and all roadworks, making it impossible to discern between. In [13], the measured effects are split up between "short-term" effects and effects measured after 5 years. [6] uses a 20-year study period, using data from two consecutive spans of 10 years. [3] uses immediate effects as well as effects with a 2-year and a 5-year lag. [2] merely makes a distinction between 'short term' and 'long term' effects, without measuring the exact number of years. [5] measures effects over a period of 15 years.

Amount

The various researches which link the number of kilometres of new infrastructural expansions to the total amount of vehicle kilometres travelled, end up with elasticities of 0.4 [9], between 0.892 and 1.063 [13], 0.82-0.86 for highways outside of urban areas and major roads in urban areas, and around 1 for highways inside of urban areas [6], 0.713 for interstate highways, 0.69 for arterial roads and 0.826 for collector roads [3]. Other found elasticities are 0.238 at [5], although this is measured in a different manner.

Any areas more sensitive?

Most literature reviewed does not point to any areas being more prone to induced demand effects. However, [6] makes a distinction between highways vs. major roads inside urbanized areas vs. highways outside of urbanized areas. With this distinction, the highways in urban areas seem to stick out with elasticities close to or just above 1, whereas other roads seem to have an elasticity of 0.82-0.86. This observation is in line with [11], which also mentions a possible cause for this effect, being a large route shift from roads inside of cities to roads outside of cities.

Influence of public transport

A common thought is that public transport could help relieve traffic levels by means of travellers shifting mode. This might lead to less new demand on roads, in case public transit facilities would be improved whilst widening roads. [6] concludes that additional provision of public transport has no influence on the number of vehicle kilometres travelled, which is also mentioned by [8]. The exact opposite effect (people switching from public transport to road travel), however, has been proved to exist, albeit only 3% on a 27% trip increase [9]. According to [10], the number of public transport travellers who would take the car without traffic jams is about equal to 'half a lane' of traffic, however, no further details are given on the nature of that calculation.

Influence of fuel prices

This subject is covered to the most extent in [4], stating that the elasticity of fuel prices in relation to the number of vehicle kilometres travelled is between -0.45 and -0.9 for the United Kingdom. [4] also states that these elasticities will be larger in the United States (-0.56 in the short run and -1.18 in the long run and concludes that in regions with lower fuel prices, more behavioural changes can be expected from changes in travel speed (which would be one of the effects of road widenings), assuming a constant 'budget' for travelling, including a value for travel time. To quote [4]: "if fuel prices are low, then more of a behavioural response can be expected from changes in travel speeds". However, [4] comes to a totally different conclusion, stating that "our calculation is not sensitive to the assumptions made for vehicle operating costs. Even a tripling of fuel prices would make little difference here." In [3], a fuel price vs. vehicle kilometres travelled elasticity between -0.126 and -0.192 is found. [2] summarizes various results from previous studies by stating an elasticity of -0.1 to -0.5 and subsequently uses -0.15 for further calculations.

Origins

Although the *effects* of induced demand can be measured relatively easily in terms of route shifts, mode shifts or completely new travel, the origins of this induced demand are a subject that is not always discussed in detail. The main origin mentioned in [4], [6], [12], [8], [11], [3] and [5] is that extra road capacity will cause changes in accessibility within urban areas. These could subsequently result in changes in spatial allocation. In other words: with the facilitation of higher travel speeds, the likelihood of spatial reallocations is increasing, both in commercial (businesses) and private (residents) sectors. Another origin that is repeatedly mentioned (in [4], [8], [11] and [15]) has its roots in the alleged constancy of travel time which is best known in Dutch literature as the BREVER-law (Peters et al., 2001). This law states that the amount of time that a person spends travelling per day is more or less constant over the entire world. Following this law, more travels would be made when traveling speeds due to road capacity extension increase. Other causes mentioned include possibly larger shifts than foreseen from public transport to road traffic. This would be caused by fewer people travelling by public transport because of road capacity increases, which may

subsequently force public transport operators to reduce operational frequencies or increase fares, which will generate even more traffic [4].
Finally, it should be noted that in all of these findings, there seems to be little research done into the proportions of these origins of induced demand, in other words: how much these individual origins contribute to the total. An exception is in [6], which examines and calculates the proportions of several possible origins of induced demand. These include: the migration of both people and economic activity, individual behavioural changes, increases in the commercial transportation sector, and traffic diverting from other roads. One of the results from this that could be most relevant is that commercial transportation seems to be the most elastic to road capacity increase, with elasticities that are sometimes above 2, i.e.: for every percent of road capacity added, commercial transportation would increase with two percent.

5.3.3 Comparison table

In this paragraph, an overview of the found induced demand elasticities will be given in Table 2. It should be noted that the latter is not always defined as such. For this table, any link between road capacity and travel is given, e.g., in a sentence like “every percent of road capacity added generates xxx percent of extra travel”). If needed, a brief explanation of the number(s) is given as well.
If a piece of literature does not provide a number, elasticity, correlation or something of similar nature, it is omitted from this table. Also provided are the abbreviations of the type of literature, as discussed in Paragraph 5.1.2.

Table 2: Induced demand elasticities found. Abbreviations used in ‘Type’ (as discussed in Paragraph 5.1.2): SL = scientific literature (e.g., peer-reviewed), PM = popular media (e.g., newspapers), O = other

Ref.	Type	Elasticity	Comments
[2]	SL	0.5 (SR) 1 (LR)	SR = short run LR = long run
[3]	SL	0.69-0.83	
[4]	O	0.3-1.0	
[5]	SL	0.238	
[6]	O	0.82 - ±1	
[7]	O	0.4	
[8]	PM	1	Simplified reference to [6]
[9]	SL	0.4	Suggests 0.2 might be more accurate
[12]	PM	1	Simplified reference to [6]
[13]	SL	0.89-1.06	
[15]	PM	1	Simplified reference to [6]

6. Discussion

In this chapter, some results of the literature review which have been found in Paragraph 5.3.2 will be discussed and partially connected with the stakeholder analysis, performed in Chapter 4.

As already mentioned in Paragraph 5.3.2, the ways of measuring the amount of induced demand as well as the resulting induced travel are hugely diverse. This makes it considerably hard to compare viewpoints found in the diverse literature. It also minimises the possibilities for comparing the amounts of induced demand in different countries, as the measurement methods are of such diversity.
A few notable viewpoints will be discussed here. In the paper of van der Loop et al. (2014), mode and route shifts are discarded in the definition of induced demand (which most other literature does as well). Eventually, the paper gives an elasticity in the range of 0.3 to 0.5 as a result, meaning in this case that every percent of road capacity added will generate approximately 0.4 ± 0.1 percent of completely new traffic. The paper concludes that this is a 'relatively low' amount. However, as the elasticity of 0.4 is merely considering completely new traffic, it might be questioned whether one can really speak of a 'relatively' low amount.
Another remarkability found in the literature review is that most research focuses merely on new traffic and does not go into too much detail on route and time shifts caused by new infrastructure. However, with some research (Duranton & Turner, 2009) already suggesting elasticities of a total amount of vehicle kilometres travelled vs. added lane kilometres being close to 1, it might very well be that elasticities of *total* additional traffic (i.e., *including* route and time shifts) could end up well above 1. It might be interesting to also execute research into these total traffic numbers.

For the Dutch situation, with the stakeholder analysis showing Rijkswaterstaat to be a major stakeholder, both in terms of power and interest, it might be expected that the induced demand phenomenon will be well under its attention. However, it seems as if the effect is currently not getting too much attention, based on (Taale, 2021) as well as the document on Rijkswaterstaat's policy on solving traffic in the period 2018-2021 (Rijkswaterstaat, 2020). In the latter document, the fact that road widenings could attract extra traffic is not mentioned at all.
On the other side, various 'popular media' meant for informing the general public seem to report about the phenomenon in sometimes slightly erroneous ways. For example, while the often-cited research of Duranton & Turner (2009) suggests induced demand elasticities of around 0.85 for most types of roads, which can get close to or slightly above 1 for highways in urban areas, this result has often been found to be simplified to "a perfect one-to-one match" (Mann, 2014) or "for every percent of road widening that you perform, traffic eventually will increase with one percent" (Verkade, 2018). It could also be argued whether this "road widening" (used by Verkade, 2018) really is the same as the very quoted research which focused on capacity extension (Duranton & Turner, 2009). This distinction could be of extra importance because merely widening roads in one spot or solving bottlenecks could only lead to shifting the capacity shortage problems to other areas, such as the inner parts of cities where capacity or parking extensions are harder to realise (Kuiken, 2016). Another newspaper article mentions that the current traffic congestion problems on Dutch freeways can be solved by adding 1200 kilometres of lanes and subsequently states that these lanes will not clog again (Kuiken, 2016). However, neither exact calculations nor explanations of this statement are added. More nuanced information about the phenomenon meant for the general public has not been found.

7. Conclusion

In this thesis, the following research question has been posed: *What is the significance of the induced demand phenomenon with road widenings?* This question has turned out to be quite hard to answer for several reasons.
As already discussed in the previous chapter, it has turned out that there is hardly any standard in the way induced demand is measured: both the measured quantities and the time spans vary greatly amongst researches. The differences in measuring can be found to more extent in Paragraph 5.3.2 of this thesis. Also, there seems to be little consensus on which exogenous factors should be taken into account, which can be neglected, and which are most relevant.
Altogether, the majority of literature does seem to suggest that induced demand phenomena are real and occurring. Although the exact amounts of induced demand claimed are varying greatly, conclusive evidence pointing *against* the existence of induced demand has not been found, in either type of literature. Some literature suggests that relations between extra road capacity added and new traffic generated might be close to, or, in some situations, even above 1 (Duranton & Turner, 2009). However, almost all literature also suggests that this subject is in need of more research.
This thesis, therefore, relays the suggestion that more research be done into the induced demand phenomenon with road widenings. However, almost more importantly, a recommendation is added that the research method be more standardised, in terms of what is exactly measured, and after how much time the effects of road widenings are evaluated. With more standardised research performed in the future, it might also contribute to eliminating ambiguous messages that the general public reaches. At this moment, it appears there is a large gap between what is communicated by authorities and parties which the stakeholder analysis, performed in Chapter 4, has demonstrated to be of high importance on one side, and the exaggerations that most of the popular media researched have been found to make (e.g., generalising the results of research to strengthen their point) on the other side. In this way, more consensuses can arise between policymakers and the public, and the steps taken to overcome road congestions can be more successful. Also, possible developments regarding the significance of induced demand can be better tracked along the world, which is especially relevant given the rapid changes occurring in the world at this moment (e.g., the COVID-19 pandemic, which caused a surge in the number of people working from home), allowing for a better and swifter adaptation worldwide to momentary travel demands.

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