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The Economic Costs of Unfinished Highways in the Czech Republic

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Declaration of Authorship

The author hereby declares that he compiled this thesis independently; using only the listed resources and literature, and the thesis has not been used to obtain a different or the same degree.

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Prague, July 29, 2019

Signature

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Abstract

This thesis attempts to introduce between economists overlooked topic of highway effects to a wider audience in the hope of promoting discussion about the efficiency of infrastructure investment. It is also believed to be the first academic writing to question, verify, update and extend the official Czech guidelines used for highway cost and benefit analyses through a wide literature review, making it useful to road transport experts. The main focus is on the unit prices and quantities estimation of various costs and benefits, whereas the software calculation is not analyzed in such detail. Literature review, centered around the European recommendations and related academic research, a brief description of the cost and benefit evaluation of road infrastructure in the Czech Republic, and proposed changes in time costs, accidents, air pollution, climate change, landscape, biodiversity and time indexation are presented.

JEL Classification R410, R420, Q510
Keywords cost-benefit analysis, transport externalities, road infrastructure, highways

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Abstrakt

Tato práce se snaží širšímu publiku představit ekonomy přehlížené téma efektů dálnic a posílit diskuzi o efektivitě investic do infrastruktury. Velmi pravděpodobně je první akademickou publikací, která ověřuje, aktualizuje a rozšiřuje oficiální českou metodiku používanou pro analýzu přínosů a nákladů dálniční infrastruktury, za pomoci širší literatury a může být užitečnou i pro experty. Hlavní důraz je kladen na jednotkové ceny a odhady množství nákladů a přínosů, zatímco samotné softwarové kalkulace nebyly detailně zkoumány. Rozbor literatury, tvořený především evropskými doporučeními a relevantním akademickým výzkumem, stručný popis výpočtu nákladů a přínosů z dopravní infrastruktury v České republice a navrhované změny v cestovním času, nehodovosti, znečištění ovzduší, změny klimatu, krajiny, biodiverzity a časové indexace tvoří hlavní obsah práce.

Klasifikace R410, R420, Q510
Klíčová slova Analýza nákladů a přínosů, externality dopravy, silniční infrastruktura, dálnice

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Nomenclature

CBA	Cost-benefit analysis
CEA	cost-effectiveness analysis
CO	Carbon oxide
CO2	Carbon dioxide
CZK	Czech Koruna
dB(A)	Decibel A-weighting
E5	A fuel mixture with 5% volume of ethanol
EIA	Environmental impact assessment
EXNAD	Externí náklady z automobilové dopravy (External costs from automobile transport)
GDP	Gross Domestic Product
GHG	Greenhouse Gases
GWP	Global Warming Potential
HC	Hydrocarbons
IPCC	Intergovernmental Panel on Climate Change
km	Kilometre, Kilometer (US)
MCDA	Multi-criteria decision analysis
NEG	New Economic Geography
NMVOC	Non-methane volatile organic compounds
NOx	Nitrous oxides
O3	Ozone
PM10	Particulate matter smaller than 10 micrometres
PM2.5	Particulate matter smaller than 2.5 micrometres
ppb	Parts per billion
ppm	Parts per million
PPP	Purchasing Power Parity
SO2	Sulfur dioxide
t	tonne
TEN-T	Trans-European Transport Network
VOC	Vehicle Operating Costs
WTA	Willingness-to-accept
WTP	Willingness-to-pay
ŘSD	Ředitelství silnic a dálnic

1. Introduction

The topic of highways is considerably polarized, both politically and publicly, partly due to the long tradition of slow construction progress in the Czech Republic. Nonetheless, public investment into transport infrastructure is limited and, naturally, attempts to find the combination with the highest benefits and the lowest costs. Road transport competes with rail transport, individual transport contends with public mass transport, and investment in long-range projects contests financing at the local, town level. Unbiased and accurate evaluation of highway effects, without the same being true for other infrastructure, could dangerously skew the decision making and adversely affect the life quality and environment of thousands of people and animals for decades. For example, the negative externalities of road and air transport per passenger-kilometer are four times those of rail, mainly due to accidents and emissions. (Essen et al., 2011) This difference may seem too high to justify any investment into road infrastructure at all, however, around three quarters of both passenger and cargo total transport performance was provided by roads in the Czech Republic in 2016. (ŘSD ČR, 2018a) Highways, substantially safer than ordinary roads and coupled with improvements in emissions, may indeed be an alternative to difficult and time-consuming railways construction and behaviour change.

The author initially aimed to quantify the costs and benefits for all unfinished highways in the Czech Republic, as shown in the thesis proposal. However, this proved to be an especially difficult task even for a single highway and as the issues within the official methodology were becoming obvious, the focus of the thesis shifted there. For example, a simulation of the traffic demand is virtually impossible without a complex commercial model, which is quite expensive even for ŘSD. Simillar situation applies to the travel time in congestion, vehicle operating costs, emission flows and noise propagation. Moreover, the public population distribution data lack the required detail and the commercial ones would likely be required. If the thesis was to estimate all of this without a simulation, even a small inaccuracy could be multiplied by from 20,000 vehicles per day on a regional highway up to 99,000 vehicles per day on the busiest one (ŘSD ČR, 2016) over multiple years. Unfortunately, many factors could be subject to such an error.

The thesis examines the cost-benefit evaluation methodology of the new highways in the Czech Republic from the economics perspective. The current cost-benefit analysis applied by the Directorate of Roads and Highways (ŘSD) is very detailed and complex, however, the monetary values and methods could be subject to error or outdatedness. Currently, this thesis is believed to be the first academic writing to question the methodology used in highway construction in the Czech

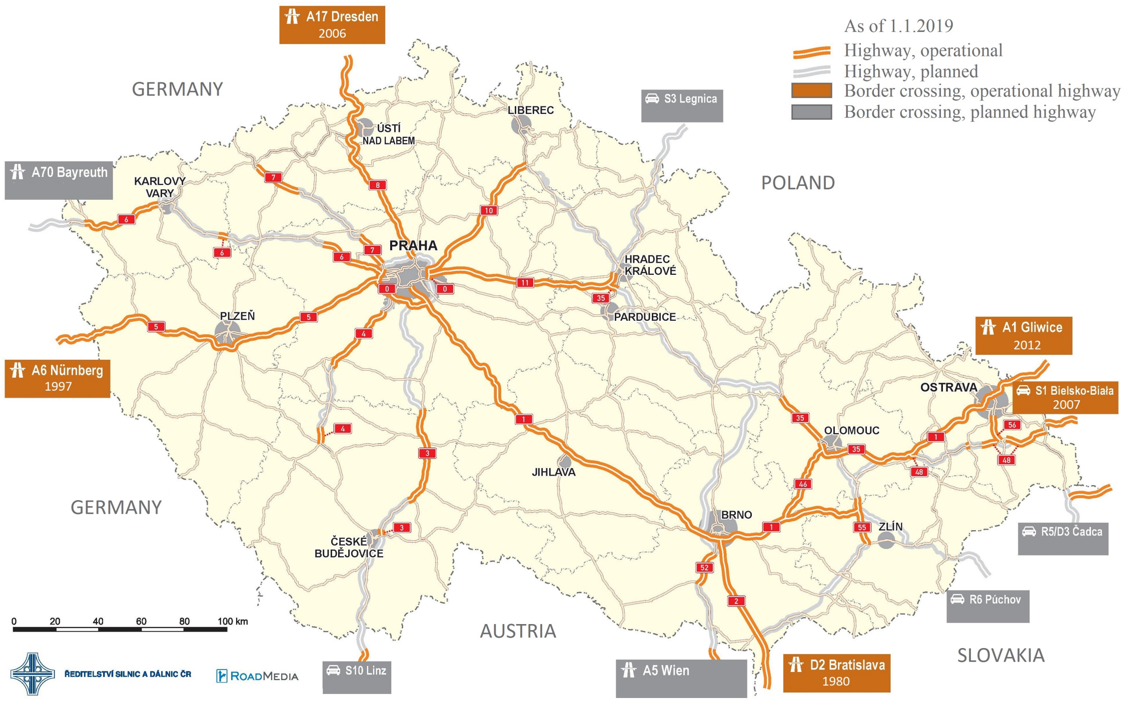
Republic. Therefore, specialised, single topic studies in addition to foreign road infrastructure evaluation methodologies were read and compared with the Czech one. The hypothesis is that several unit values are underestimated and cause the resulting evaluations to present inaccurate results. The thesis investigates and provides a large number of suggestions for time savings, accidents, noise, air pollution and climate change in order to reduce the inaccuracy of highways evaluation.

The structure of the thesis is following. After the introduction, in the Literature and Theory chapter, the possible approaches and related difficulties to each benefit or cost category of highways are presented. In the next chapter, Current Methodology, the present Czech guidelines are explained, which includes evaluation approaches and proposed values. The fourth chapter, Proposed Changes in Methodology, unites the two previous chapters by suggesting and arguing for the changes in the evaluation guidelines. After that, the chapter called Limitations, Other Approaches and Further Research contains additional issues this thesis could not deal with. Finally, a short conclusion is provided.

2. Literature and Theory

Highways

Figure 1: Highway Connections to Neighbouring Countries



Source: ŘSD ČR (2019b), translated by author

The highway density, kilometres of highways per 1000 square kilometers of country area, in the Czech Republic is still well below developed, and even vast European countries, like Spain and France. According to the author's calculation based on ŘSD ČR (2019a), the highway density of the Czech Republic in September 2018 was 15.77 km per 1000 square kilometers and would reach 25.2, if all planned highways were built. For comparison, highway densities calculated by the author based on the Eurostat 2017 database are provided: Germany 36.4, Switzerland 35.3, Portugal 33.3, Denmark 30.4, Hungary and Austria both 20.8, France 18, and the UK 15.6.

As of 2018, the Czech Republic had 1,244 km of highways in operation with 743 km remaining to complete the highway grid. (ŘSD ČR, 2019b) The first highway in the Czech Republic was opened in 1971 and, currently, out of 19 planned highways, 6 highways are completed, 4 highways are more than halfway completed, 8 highways are less than halfway completed and construction of one has not yet begun. Most of the highways in the Czech Republic fall under European TEN-

T (Trans-European Transport Network) core or comprehensive corridors (ŘSD ČR, 2018b) and, according to law, the highways and first-class roads are the property of the Czech Republic, while the second-class and third-class roads are owned by the regions. (Zákon o pozemních komunikacích, 1997, §9)

The highway commission pace has not been regarded as satisfactory by citizens and politicians for many years. This seems to be not only caused by the problems in project preparations as mentioned by Nejvyšší kontrolní úřad (2018), but also due to underfinancing. Firstly, according to Nejvyšší kontrolní úřad, the yearly commission speed needs to increase from 16 to 25 km per year to achieve the 2050 target of the finished highway network, which was postponed from 2010. On the other hand, they found that the costs of building highways in 2013-2017 decreased on average by 55%, that is to levels of other European countries. Secondly, in 2018, toll and highway fees for personal vehicles together amounted for 52% of earned income (without refunds and transfers) of SFDI, the national fund for transport infrastructure, however, only 16% of the total expenditures were directed into highways (SFDI, 2019), which in 2010 already served 22.8% of total road transport. (Čihák et al., 2013) Lastly, around 75% of total transport performance was provided by road transport in 2016. (ŘSD ČR, 2018a)

Economic Effects

Important economic effects of highway infrastructure will now be discussed. In the RAND summary, Shatz et al. (2011) mention cheaper and increased market reach for producers, a wider choice of suppliers, decreased inventory costs thanks to just-in-time production, greater employment opportunities of workers, empowerment to live further from work, and short term benefits from construction.

There are several valuable insights about the highways from the USA. First, the interstate highways are believed to had positively affected the productivity and economic output. (Fernald, 1999, cited in Shatz et al., 2011) In their meta-analysis, Shatz et al. find highways to generally increase productivity and economic output with the magnitude influenced by highway type, condition and quantity of current network, and other characteristics of the nearby area. For example, Nadiri and Mamuneas (cited in Shatz et al., 2011) show, that highway investment constituted 32% of yearly productivity growth from 1952 to 1963, but only 7% from 1980 to 1989. This, Shatz et al. note, could be due to the gradual completion of the interstate system from 1956 to 1992. Second, highways accelerated suburbanization and resulted in the weakening of the central cities. (Baum-Snow, 2007, cited in Shatz et al., 2011) So-called urban sprawl is often cited as one of the main arguments against highway extension, especially additional lanes. Third, industries, which use highways extensively, benefited the most. (Keeler and Ying, 1988, cited in Shatz et al., 2011) Fourth, highway infrastructure tends to affect the neighbouring regions by a spillover effect. As Shatz et al. (2011) report, these spillover effects could be both positive and negative and highway planning should be aware of infrastructure tendency to move economic activity from one area to another without any net benefit. Due to this, Shatz et al. suggest differentiating between gross and net economic effects of infrastructure projects, where the studied area needs to be great enough (entire state or nation) to capture the whole spillover. Examples of economic indicators that are likely to be affected by spillover effect are regional GDP, employment, wages or real estate values.

Evaluation of Transport Investments

Despite the existence of other methods, transport investment is usually evaluated by cost-benefit analysis (CBA). In the European Union, after several harmonization efforts, CBA could also be considered the default method. In addition, multi-criteria decision analysis (MCDA), cost-effectiveness analysis (CEA) and their combinations are also allowed in the Czech guidelines by SUDOP (2018). CEA usually aims to select the least costly option to attain one specified goal, MCDA attempts to satisfy as many most important variables as possible, while CBA chooses the option with the highest monetized net benefits. As the last step, time discounting of costs and benefits is applied in CBA (sometimes in other methods) to reflect the time preference of humans. The best possible approach could be to create a separate report with all the variables before monetization (to enable MCDA examination), and then attach a CBA with a very detailed sensitivity and scenario analysis. This increase of transparency could decrease misuse and misunderstanding, the main problems of CBA noted by Misuraca (2014). Note that prices tend to be taken without taxes, which are seen as just a transfer of utility from the taxpayers to the government.

Issues of CBA will now be briefly discussed. Firstly, CBA cannot explain the distribution of benefits and costs in the spillover effect. Whether or not will the benefits (such as increased market and increased labour force) be shifted from the newly connected area, which may suffer from increased unemployment and worker emigration, to the already developed area will not be understood from CBA. The New Economic Geography (NEG) approach, accounting for agglomeration and dispersion effects, may be used to overcome this limitation as suggested by Roberts et al. (2009). Secondly, assigning a monetary value to human life seems to be frequently criticized. Thirdly, the use of discount rate, especially a higher one, for externalities such as climate change is questioned by some authors, as noted by Cater (1994). He explains that the irreversibility of climate and limited choices in the future are not to be fixed by changes in the discount rate, but by the introduction of additional costs in later years. Moreover, for the problem of seemingly negligible figures in late years a good example is given:

If the present value of a benefit occurring 100 years from now appears small, it is simply because a relatively small investment is all that is required to produce goods and services of equal value to that benefit 100 years from now. (Cater, 1994, p.70)

Costs of Travel

Costs of travel, one of the most important factors in CBA, are usually divided into time costs and vehicle operating costs. First, after highway construction, time savings could be evaluated for three passenger categories: current users of road transport, users switching from a different mode of transport, and new users, who were not traveling on this route before (induced traffic). (European Commission, 2014) According to the same document, half of the time-saving benefit of current users is to be used for modal change and induced traffic. Due to complexity, time savings need to be estimated by the traffic model taking into account congestion, driver behaviour and traffic growth in the future, including induced traffic, which stands for an additional increase in traffic resulting from increased use of better infrastructure. There is a debate about the significance of the effect as various studies find contradictory results. For example, Sloman, Hopkinson, and Taylor (2017) find evidence for the induced traffic to be between 5 and 10 percent above the standard traffic growth in period of 3 to 8 years. However, they also speculate that infrastructure is more likely to be upgraded in regions with high growth rates. Additionally, they indicate a mixed effect of improved infrastructure on collisions after correcting for downward trends in traffic accidents over time. This suggests that the increased traffic may consume the benefit of a relatively safer road. Second, vehicle operating costs estimate the direct costs to the owner depending on the infrastructure, such as fuel consumption, maintenance and repairs. Evaluation of both time savings and vehicle operating costs requires complex software simulations and often relies on insufficiently supported assumptions. However, setting the unit costs tends to be simple as most of the items have a market price.

Costs of travelling were estimated in a Czech willingness-to-pay survey by Máca et al. (2012). Despite using different categories than the guidelines (trip frequency, income category and purpose of travel), they estimated hourly costs to be CZK 179 for car passengers and CZK 71 for bus passengers. Moreover, they also evaluated the costs of time variability of travel, i.e. unexpected delays, and hourly costs of being in congestion.

Several traffic measurings provided average occupancy rates for cars and buses, an important value for the costs of travel estimation. The car occupancy rate of 1.3 was observed in Prague from 2010 to 2016 by the Department of transportation engineering of the technical administration of roads of the city of Prague (2017) and in Zlín (population 74,947 in 2016) by Kočí (2017). Bus occupancy rates in Swedish regions in 2013 were between 5.1 and 20.7 according to Xylia and Silveira (2017). Adra, Michaux, and Andre (2004) reported the following values: 26.26 in Italy (2000), 13.75 in Milano (2000) and 17 in the European Union (1999). Department for Transport (2012) divided passenger-miles by vehicle-miles and estimated the average bus occupancy in London and outside of London to be 19.3 and 9.1, respectively

Road Accidents

The highways are widely considered to have a relatively lower accident rate than major, especially urban roads. In the Czech Republic, the death on the highways compared to the major roads was about 5.26 times less likely and the heavy injury was about 4.44 less likely for the same driven distance in 2017. (Ministry of Transport and BESIP, 2017) Moreover, pedestrians accounted for 20% of total casualties and cyclists for 6.7% in 2018 and that more than 60% of accidents happened in town. (Centrum služeb pro silniční dopravu, 2018)

Table 1: Relative Accident Rates of Selected Road Types

	Highway		I. Class			II.class
	6 line	4 line	4 line	2 line	2 line town bypass	2 line
Death	0.4	0.35	0.65	1.65 (1.15)	1.35	1.67 (0.5)
Injury	29.3	25.2	46.0 (116.9)	109.8 (138.9)	88	151.3 (163.2)
Property damage	220	181	192 (500)	302 (393)	217	291 (333)

Units: Number of persons and Number of accidents per 100,000,000 vehicle-kilometres, respectively. Numbers in brackets stand for urban area.
Source: Úsek výstavby ŘSD ČR (2017)

Accident costs are calculated differently in European countries despite harmonization efforts, such as the project HEATCO (see Bickel et al., 2006). Two main sources of differences could be identified based on Kasnatscheew et al. (2016). First, they suggest that the number of accidents reported to the police is smaller than the actual number of accidents (under-reporting), therefore, accident figures tend to be multiplied by country-specific correction coefficients. Death underreporting is usually considered low, although as Adminaite et al. (2018) note, extreme cases exist: 15% in the Netherlands in 2016, between 15% and 25% in Greece in the period 1985-2015 and 5% in Poland in 2009. Yannis et al. (2014) suggest that underreporting was significantly affected by misreporting of injuries (when the injury is considered slight by police, but as serious by hospitals) in their data from the Czech town Kroměříž. However, underreporting should not be exaggerated, because Kasnatscheew et al. (2016) state that small material damage and low severity of injury are the main reasons for underreporting in transport. Estimates based on data synthesis from police, healthcare providers and insurance companies could replace the generalised coefficients from the HEATCO. Second, they note, countries calculate different per accident or per person costs based on various cost subcategories. Categories recommended by Kasnatscheew et al. could be seen in Table 2 and Table 3. However, they mention, that cost subcategories, such as grief, pain and lost quality of life, depend on willingness-to-pay (and willingness-to-accept) surveys that need to be conducted. An overview of these surveys is provided later in this chapter.

Calculated human costs in the Czech Republic, Germany and Italy are substantially smaller than in other countries, where human costs amount for up to 94% of total costs per fatality, as can be seen in Kasnatscheew et al. (2016). Czech accident costs are calculated by the Transport Research Centre (Centrum dopravního výzkumu) and do not include all categories recommended by Kasnatscheew. The access to the original source Aktualizovaná metodika výpočtu ztrát z dopravní nehodovosti na pozemních komunikacích by Vyskočilová et al. was denied, but the included categories could be seen in Valach (2014). They include nonmaterial harm (defined by Czech law) as a form of human costs, that can be obtained from the insurance companies through the court system. They valued nonmaterial harm in case of death at CZK 586,000 and in case of serious injury at CZK 435,000 in 2014. Even though the production loss amounts for most of the total costs in death and serious accidents (Valach, 2014), it does not include non-market production losses. Thus a significant increase in total accident costs could be expected if willingness-to-pay surveys are introduced into calculation.

Table 2: Categories of per Accident Costs

Administrative			
Police	Fire department	Insurance	Legal costs
Property damage			
Vehicles	Infrastructure (incl.buildings)	Cargo	Personal property
Other			
Congestion costs	Vehicle unavailability		

Source: Author, based on Kasnatscheew et al. (2016)

Table 3: Categories of per Casualty Costs

Medical					
First aid and transportation	Emergency department	Hospital treatment		Non-hospital treatment	Aids and appliances
		Overnight	Not overnight		

Production loss		
Market production loss	Non-market production loss	Employee recruitment, training, vocational rehabilitation

Human costs	
Pain and grief	Quality of life

Other		
Visiting costs of relatives	House adaptation and moving costs	Funeral

Source: Author, based on Kasnatscheew et al. (2016)

Value of statistical life (VSL) is a method of obtaining a monetary value of human life often used in road accidents and air pollution evaluation usually based on revealed preference study or stated preference survey. Revealed preference studies usually observe market behavior, for example, in labour or housing market. In stated preference surveys, such as willingness-to-pay (WTP) or willingness-to-accept (WTA), the participants are asked questions, from which VSL could be deduced. Kutáček and Šeďa (in Kutáček, 2009) mention puzzling questions, the validity of obtaining value of life by summing small financial amounts, and immorality of life monetization as frequently criticized points of the stated preference method. The context could also influence VSL. Nellthorp et al. (2000) note that the environmental risk is evaluated higher than the traffic accident risk, and Jones-Lee (as cited in Nellthorp et al., 2000) proposes a conversion factor of two between them - VSL of 20 million from a road accident survey may be expected to be 40 million in an environment survey.

Kutáček and Šeďa estimated VSL to be around CZK 20 million in the Czech Republic in their 2003 WTP survey. (Kutáček, 2009) They measured the proportion of people, who would accept a higher fuel price for a fewer car accident fatalities. In three rounds with different price changes, they showed that VSL estimates were very sensitive to input values, stressing out a proper survey form. Alberini, Ščasný, et al. (2006) estimated mean VSL to be CZK 40.16 million and median VSL to be CZK 18.52 million. They surveyed willingness-to-pay for the reduction in death probability from cardiovascular and respiratory illnesses in Czech towns Praha, Brno and Ostrava. They found that VSL increases with income (elasticity around one) and decreases with age. A later study by

Alberini and Ščasný (2011) estimated adult VSL at CZK 18 million and child VSL at CZK 25 million in the Czech Republic. They find higher VSL in case of cancer risk and lower VSL in case of road accidents (CZK 12 million for adult and CZK 19 million for child). They speculate that traffic accidents are valued less as they may be perceived as influenceable risks.

In comparison, labour market studies, using wage premium as risk compensation, tend to provide higher VSL estimates. Melichar, Ščasný, and Urban (2010) estimate VSL for death accidents in work in the range between CZK 60 million and CZK 266 million (in 2009 prices), where lower bound stems from subjective risk model, and upper bound from objective risk model. They note that this implies risk underestimation by employees. A meta-analysis by Doucouliagos, Stanley, and Giles (2011) estimated VSL to be $2.74 million in 2000 dollars. Transposing by GDP per capita growth (PPP adjusted) to 2017 and applying the average exchange rate for 2017, yields CZK 67.02 million. GDP per capita growth adjustment was suggested in HEATCO by Bickel et al. (2006) and could be supported by previously mentioned VSL income elasticity of one. (Alberini and Ščasný, 2011) An overview of VSL estimates could be seen in Table 4 below.

A proportion of VSL for serious (13%) and slight injury (1%) cost evaluation is supported by Nellthorp et al. (2000) in the UNITE project. The values are said to originate from the 1998 European Conference of Ministries of Transport (exact reference was not provided by Nellthorp et al). Additionally, 9% of VSL for temporary serious injury and 32% of VSL for permanent serious injury based on Persson et al. (cited in Nellthorp et al., 2000) could be proposed.

Table 4: VSL Estimates

		2017 price level estimate (CZK million) by GDP per capita growth
Alberini, Ščasný, et al. (2006)	Mean	48.8
	Median	22.5
Kutáček and Šeďa (2003) as in Kutáček (2009)		28.1
Alberini and Ščasný (2011)	General	19.9
	Car accident	14.4
Doucouliagos, Stanley, and Giles (2011)		67.0
Wage estimate by Melichar, Ščasný, and Urban (2010)	Lower	67.5
	Upper	299.4

Source: Author, using GDP per capita growth for the Czech Republic from World Bank (2019).

Noise

The traffic noise is commonly measured in decibels, dB, with various corrections and modifications, such as decibels A-weighting, dB(A). Despite the hearing subjectivity, a 10 dB increase in sound level generally doubles the loudness. (Noise Quest, 2018) Road noise is mostly influenced by traffic intensity and composition, the slope of the road, road surface, vehicle speed, distance, height, characteristics of the landscape including both vegetation and buildings and weather. Despite less intensive traffic at night, higher speeds tend to be achieved, effectively increasing the noise. (Liberko and Ládyš, 2011) Noise can affect health, well-being and productivity. Noise exposure, according to the European Environment Agency (2014), leads to annoyance, sleep disturbance, higher blood pressure and cardiovascular diseases. First two affect mental health, the latter two tend to lead to premature deaths. As the main health risk is sleep disturbance, noise is usually measured separately for day and night. Based on 4 meta-analyses, EEA suggests that risks start increasing from 50-55 dB, and World Health Organization Europe (2018) highly recommends preventing night noise levels above 45 dB. (Uhlířová and Ministry of Transport, 2016) The number of people affected by a certain noise level for larger projects may be modelled by a specialised road noise acoustic modelling software.

Noise reductions could be achieved by noise barriers, silent road surfaces, traffic reductions and also by changes in vehicle tires, engine and aerodynamics. Noise barriers tend to be the most effective, although not universal, sound countermeasures. They can reduce the noise in close vicinity from 5 to 18 dB (Černoch, 2014), prevent accidents with non-flying animals, and block the air pollution from spreading, which could, depending on the weather, increase or decrease the pollution behind the wall. (Baldauf et al., 2008) However, containing sound is no easy task, as any gaps in the wall, such as crossroads, drastically reduce efficiency. The drawbacks include additional construction and maintenance costs, aesthetic and separation effects. Masonry, earthworks berms, vegetation and walls from concrete, wood, plastic, fiberglass, aluminium or composites are often combined to provide both noise absorption and noise reflection. (Uhlířová and Ministry of Transport, 2016) Silent road surfaces, according to Černoch, could lower the noise up to 6 dB, and reduce the noise in the most perceived sound frequencies, while also increasing the lifetime of the road. Moreover, as illustrated by Bernhard and Wayson in Černoch (2014), noise could be decreased by the use of quieter tyres, engine and better aerodynamics. Note that electric cars, despite having relatively silent engine, suffer from simillar aerodynamics and tyre noise as vehicles powered by an internal combustion engine at higher speeds. Additionally, reducing traffic by half is likely to decrease noise by 3 dB (Křivánek, Mejzlík as cited in Černoch, 2014)

Noise costs could be estimated by willingness-to-pay, housing prices or medical expenses. According to a Czech study by Sieber and Melichar (2014), willingness-to-pay for decreasing the noise level from 70 to 60 dB was CZK 1,308 per person per year, and CZK 132 per one dB decrease per year per person and double of that for noise levels above 70 dB (CZK 264). They note that these figures tend to be smaller than in other countries. For international comparison and sensitivity analysis, the Swedish estimates by Bångman (2016) could be used. Housing prices, as claimed by EEA (2010), tend to decrease by 0.5% for each decibel over 50-55 L_{DEN}, day-evening-night noise level with a penalty for evening and night noise, however, as suggested by Peeters and Blokland (2018), prices may not represent subjective disturbance or health consequences, which are not recognized publicly. Lastly, a different approach was used in Máca et al. (2012). In their increased risks simulation non-lethal heart attack was valuated at CZK 167,500, lethal heart attack included value of life years lost, and costed the sleep disturbance at 2% of GDP per capita for each employee facing sleeping disorders, based on Godet-Cayré et al. (2006).

Air Pollution and Greenhouse Gases

This section is split into three parts. First, an overview of pollutants and their effects is presented. Then traffic composition, released quantity of each pollutant, and traffic forecast for the Czech Republic are described. Lastly, the unit costs of each pollutant are discussed.

Pollutants Overview

Two main categories of harmful chemical compounds released in vehicle operation are usually considered. Firstly, air pollutants could be toxic even in small amounts, adversely affect health over a long exposure, negatively alter nature, chemically react and form other harmful compounds or smog. Secondly, greenhouse gases (GHG) tend to be harmless to humans, but on the other hand, affect the global climate by preventing the energy, that had already reached Earth and turned into heat, from leaving to space. Long-lived GHG such as carbon dioxide, methane and nitrous oxide are very stable in the atmosphere and can influence the climate for decades or longer. (IPCC, 2007) Climate change has consequences with associated costs, albeit rather difficult to evaluate. Essen et al. (2011), for example, mention rise in a sea level, shifts in agriculture, health consequences (including vector transmitted diseases), ecosystem alterations and more frequent excessive meteorological conditions. Some compounds, such as sulfur dioxide, can reflect some of the incoming sun energy contributing to global cooling instead. Additionally, water vapour and clouds play a significant role in climate change. When temperature increases, additional evaporation occurs, creating a feedback loop. IPCC (2007) suggests that increased water vapour could double the warming effect caused by carbon dioxide. Clouds contribute to both cooling and warming and are considered the largest source of uncertainty. (IPCC, 2007) Lastly, vehicle operation also produces not commonly mentioned non-exhaust emissions. In particular, Grigoratos and Martini (2014) suggest that dispersion of settled dust (resuspension), brake, tyre and road wear, may represent up to half of the total (exhaust and non-exhaust) particulate matter emissions.

The effects of several air pollutants and greenhouse gases are discussed in the following paragraph. Carbon dioxide (CO_2), a long-lived greenhouse gas, sources mainly from fossil fuels combustion and land use, as carbon is bound in both plants and soil. IPCC (2007) suggests that around half of CO_2 is removed in under 30 years, 30% stays for centuries and 20% persists for millennia. Ozone (O_3) in the lowest part of the atmosphere, troposphere, has a global warming effect and is a short-lived GHG often formed by other pollutants. Particulate matter (PM), that adversely affects human health and climate is divided into two categories: larger particles with a diameter between 2.5 and 10 micrometres, PM_{10}, and more harmful smaller ones with a diameter of 2.5 micrometres or less, $PM_{2.5}$. According to the World Health Organization (2015), the smaller ones are breathed in and out through the lungs while the larger ones are believed to be stopped before entering deeper in the lungs. They propose that exposure to PM leads to the following problems: shorter life expectancy, stroke, heart disease, asthma, lung cancer, reduced lung function and low birth weight, but also possibly to learning disabilities, Alzheimer's disease, depression, autism, obesity, birth defects and diabetes. (World Health Organization, 2015) Due to lung development, the WHO states, children are especially vulnerable. Moreover, they report that some particle types contribute to climate warming, some to climate cooling. Non-methane volatile organic compounds ($NMVOC$) is a very large group of various compounds that pollute the air and lead to additional formation of ozone. Note that methane is excluded as it is only harmful as a greenhouse gas. Nitrous oxides (NO_X) is a group of nitrogen and oxygen compounds, the most important being nitric oxide and nitrogen dioxide. They participate in global warming with mixed, location-dependent effects (IPCC, 2007), cause acid rains and, together with VOC, form smog. A toxic gas sulfur dioxide (SO_2) is associated with breathing problems, sulfates and acid rains, as well as formation of the particulate matter $PM_{2.5}$. (World Health Organization, 2015) Additionally, SO_2 possesses a global cooling effect due to sunlight scattering. (IPCC, 2007) Carbon monoxide (CO) is a poisonous gas in high concentrations, and long-term, low concentrations exposures may be possibly responsible for increased hospitalizations of people with heart disease, reductions in newborn weight and neurological damage over. (Townsend and Maynard, 2002) Several hydrocarbons (HC) likely lead to mutations of the genome with closely associated increases in cancer and birth defect risks. (K. Kim et al., 2013)

Traffic Composition and Outlook

Increasing traffic and reduction of pollution per vehicle seem to be the main opposing forces that affect air pollution in time. Firstly, the Czech traffic growth coefficient by Ministry of Transport (2018), predicts the traffic in 2055 to increase in all regions compared to 2016 levels by 10% to 40% in cars, around 50% in light cargo vehicles, and around 30% in heavy vehicles. Secondly, pollution per vehicle is regulated by EURO emission norms, maximum sulfur content of the fuel and CO_2 fleet averages.

EURO emission norms aim to reduce grams of CO, HC, NMHC, NOx and PM produced per kilometre. However, severe downward manipulations of the emissions were found in the so-called 2015 Dieselgate, with diesel cars exceeding the emission limits in real-world conditions many times. (European Environment Agency, 2016) Likewise, the CO_2 emissions became up to 42% higher, according to Fontaras, Zacharof, and Ciuffo (2017) and Tietge et al. (2017). This led to stricter regulation and control. Therefore, only cars registered from 2021, when the real driving emissions tests are fully implemented, might be believed to truly reflect the EURO norms. (European Automobile Manufacturers Association, 2017) Finally, ATEM (2016) predicts that almost all vehicles on the Czech roads will satisfy the currently strictest EURO 6 emission standard by 2040 and reports that highways tend to be used by newer cars than other roads.

The CO_2 emissions have not been regulated until recently. European Commission (2019c) set a 2015 fleet emissions target of newly registered cars to be 130 grams of CO_2 per kilometre and 95 from 2021 onwards. This value should be lowered by additional 15% and 37.5% for cars; 15% and 31% for vans; 15% and 30% for trucks and buses in 2025 and 2030, respectively. (European Commission, 2019a,2019) However, cars with emissions under 50 g/km, including electric vehicles, count as more than one car in these fleet emissions calculations (European Commission, 2019c) and may skew the real emissions downwards.

Lastly, sulfur dioxide (SO_2) emissions from the vehicles depend on the sulfur content of the fuel, which has remained 10 part per million since 2009 in Europe. (TransportPolicy.net, 2019) However, no recent study to verify guidelines proposed SO_2 emissions of a car, light cargo vehicle and heavy cargo vehicle was found.

Costs

Price estimates per tonne of carbon monoxide (CO), which were not summarized by Essen et al. (2011) and not included in the Czech methodology, are scarce and aged: USD 520, USD 1050 (Matthews and Lave, 2000, 1992 USD) and 12 Australian Dollars (2001) (Stanley as cited in Pratt, 2002). Unfortunately, the original work by Stanley to find reasons for such a small value was not found. Adapting all three values to 2018 by GDP per capita growth (PPP adjusted) and average exchange rate for 2018 provides CZK 17,781, CZK 35,903, CZK 285.

The climate change externality, as a result of GHG emissions, could be calculated in two ways. Firstly, avoidance costs are the most effective expenditures to reduce GHG emissions in order to avoid a certain concentration threshold (usually associated with a specific temperature rise). Secondly, damage costs reflect the impact of climate change, for example, costs of preventive measures and inevitable losses. In European calculations, the avoidance approach is preferred by Essen et al. (2011), mostly because some aspects of climate change with great consequences have unknown probability, and the EU has already declared goals that follow the avoidance principle. In the existing literature, they find the suggested price per tonne of CO_2 equivalent to differ greatly due to high dependence on oil price and discount rate. For this reason, it is more complicated to chose one value to use in the thesis, although to some degree, sensitive analysis can correct for that. Van Essen et al. follow Kuik, Brander, and Tol (2009), who calculated low, middle and high values of EUR 69, 129 and 241, respectively, for the year 2025, increasing to EUR 128, 225 and 396 in 2050. These values are relatively high as they consider the most ambitious target of temperature increase around 2.1°C over pre-industrial temperatures (450 ppm CO_2-equivalent) (IPCC, 2007) and, based on own calculations, seem to rise yearly between 2.5% (low value) and 2% (high value). Note that the highest market price of the European CO_2 allowance was 29.1 EUR in July 2019. (Markets Insider, 2019)

Highway construction and maintenance produces greenhouse gases. Emissions resulting from material extraction and transport as well as operation of construction machinery could be easily evaluated through a spreadsheet calculator developed by Highways England (2015). For example, a Korean study by Seo and S. Kim (2013) calculated that, on average, 7,451, 29,598, and 120,179 tonnes of CO_2 were emitted per km of four-lane concrete highway, tunnel and bridge, respectively. Moreover, Hanson and Noland (2015) suggest that a significant portion of the emissions is tied to the material production, which is out of the highway planning institution control, and explain how different approaches to road reconstruction yield different GHG emissions.

The effect of air pollution on biodiversity could also be evaluated. NEEDS (2006) estimated such costs per tonne of pollutant to be EUR 100 for sulfur oxides (SO_x), EUR 540 for nitrogen oxides (NO_x) and EUR 1,410 for ammonia (NH_3) in the Czech Republic (2004 price level). Adjusting values by the Czech CPI to 2019 would yield EUR 136.25, EUR 735.74 and EUR 1,921.10, respectively.

Other Effects

A separate evaluation of implicit externalities related to road transport is recommended by Essen et al. (2011) in the CE Delft study with the following main categories: energy production and distribution (well-to-tank), vehicle and infrastructure production, maintenance, and removal. They would also include potential risks associated with energy production, for example, nuclear accidents or oil spills, if more recent estimates could be found. In their study, however, they do not calculate vehicle and infrastructure implicit external costs due to supposedly high uncertainty, lack of data and great scope expansion of the study. This omission could be challenged by significant emissions in road construction and the vehicle battery production process. Although it may be dubious to associate vehicle production with a certain highway, this is not the case for the road construction. Additional externalities mentioned by Essen et al. (2011) to be accounted for are nature and landscape restoration costs, time losses of non-motorized traffic due to congestion, and soil or water pollution.

The negative impacts of infrastructure on landscape and biodiversity tend to be evaluated by either human-oriented willingness-to-pay or nature-oriented experts' opinion studies. (Schreyer et al., 2004) When land is built upon, it becomes called sealed. After the area is unsealed (for unsealing costs), the so-called restoration costs, one time expenditures of biotope conversion, may then be required. The CE Delft study by Essen et al. (2011) uses unsealing costs of EUR 27.2 per m^2 (not found in the referenced source) and biodiversity restoration costs of EUR 1.52 per m^2(NEEDS, 2006). Adjusting the original German unsealing costs by PPP adjusted GDP per capita (as recommended by Van Essen et al.) gives the 2018 Czech unsealing costs of EUR 28.6 per m^2. Experts' opinions restoration costs are estimated in detail for each country and biotope in NEEDS and the suggested figure for the Czech Republic is EUR 0.63 per m^2 in 2004. Adjusting to 2018 by CPI would result in value of EUR 0.84 per m^2. Note that half the actual area of road embankments and associated land is considered in restoration costs calculation in NEEDS. Nevertheless, as both unsealing and restoration costs stem from the late nineties research, more recent estimates may be preferred.

Water pollution costs, barrier effect, visual effects and energy dependency may also be estimated. (Schreyer et al., 2004) However, these may be difficult to evaluate and tend to have broad ranges. For example, the proposed range for energy dependency by the 2008 IMPACT handbook mentioned by Schreyer et al. is from EUR 0.002 to EUR 0.11 per litre of mineral oil.

3. Current Methodology

This section will explain the Czech methodology by SUDOP (2018) used for transport infrastructure evaluation with the focus on highways. There is no separate guidebook for highways in the Czech Republic, however, the highways are usually explained with additional detail. The aim is to show all possible approaches and monetary values used in calculations to enable the discussion in the next chapter. Additional information, not provided in the guidelines, gathered through personal consultations with a ŘSD expert, Ing. Borovička, is also presented.

There are several phases of highway evaluations once the technical proposal is finished. The most important probably being choice of a method, calculation, sensitivity analysis and ex-post evaluation. Two main methods for evaluation of infrastructure projects are proposed by SUDOP: cost-benefit analysis (CBA) and multi-criteria decision analysis (MCDA), while the other evaluation methods need to be approved by Central Commission of the Ministry of Transport. (SUDOP, 2018) The use of MCDA is recommended by SUDOP, when more difficult to monetize goals and values are present, but MCDA does not, unlike CBA, provide clear information when the value for the society is generated (net present value). Highways are usually evaluated by CBA, therefore, this thesis focuses on CBA. In addition, difficult to navigate environmental impact assessment (EIA) study may be conducted, but not being part of economic evaluation, it is beyond the scope of this text. Examples of EIA could be found online. (CENIA, 2019) Finally, ex-post evaluation of analysis accuracy in 3 to 10 years after the project completion may be ordered by the Ministry of Transport. (SUDOP, 2018)

The traffic model, despite being largely neglected by the Czech guidelines, is at the core of highway cost-benefit analyses and could also be used to predict infrastructure expansion needs. The model allows to calculate the use of roads, highways and rail when upgrading or expanding infrastructure and includes the changes in time. According to personal consultations with Borovička, ŘSD buys outputs from a commercial model, operating at a higher detail and more frequently updated than the national traffic model owned by the Ministry of Transport. According to Borovička, induced traffic is not considered separately in the commercial traffic model.

Cost-benefit analysis (CBA) consists of financial analysis and economic analysis, which are linked via conversion factors. First, the financial analysis is relatively straightforward and mainly consists of investment costs, maintenance costs and revenues for the investor. The source of financing is also to be included as the Czech government and the European Union frequently share the costs, moreover, private capital can also contribute. Maintenance costs are calculated with the HDM-4 software based on the use of the road as shown by Borovička. Construction, material, real estate and planning costs are provided by Czech norms. The 4% discount rate is to be used in financial analysis. (SUDOP, 2018) Second, the conversion factors, provided by SUDOP (2018), are coefficients transforming financial or market prices to economic values. Before the conversion, they specify, the price has to be lowered by VAT and by profit margin of 6% for construction costs, 5% for information technologies and 2% for maintenance and they advise to calculate a weighted average of factors instead of multiplying every item by according factor. Third, the economic analysis, on the other hand, attempts to capture the effects on the whole society. SUDOP (2018) state that the time horizon for CBA analysis is 30 years for road, rail and waterway transport projects and splits into investment phase and operating phase. They state that the investment phase begins with the construction and is required to include all previous expenses (e.g. planning, real estate) and that all assets with longer durability than 30 years (tunnels, bridges, earthworks, drainage, road base) should have a residual value. The most important output of economic analysis is the net present value (NPV), which operates with discounted costs and benefits over the project lifetime and should be greater than zero to justify the project realization. So-called 5% social discount rate is to be used in the economic analysis according to SUDOP.

Table 5: Conversion Factors

Skilled labour		0.615
Unskilled labour		0.584
Loose construction material (incl. concrete)		0.979
Other construction material		0.981
Information technology		0.98
Energy and fuel		0.837
Land		0.162
Others		0.998
Simplified	Investment	0.807
	Repair and maintenance	0.791
	Reinvestment	0.829

Source: SUDOP (2018)

Costs of Travel

The costs of travel tend to be the most important cost factor in most CBAs and one of the main reasons better infrastructure is built. The general approach is to estimate the travel time (for each vehicle category) based on the traffic forecast from the traffic model for the compared projects and multiply the differences by according time cost factors. This is calculated entirely by the HDM-4 model used by ŘSD in case of highways, however, in case of traffic lights, rail crossings and crossroads, micro simulations would be preferred. (SUDOP, 2018) The traffic model and algorithms used in the HDM-4 model will not be covered in detail in this thesis, instead, the cost values and certain input values will be presented.

The following values and assumptions are suggested by SUDOP (2018) (based on the European HEATCO project) unless a dedicated traffic study is conducted. First, the one-to-one ratio of commuting and other travel is assumed. Second, 90% of passenger travel is assumed to be non-work. Third, 10% of passenger travel and 100% of cargo travel is assumed to be work. Fourth, car occupancy of 1.7 persons per vehicle, bus occupancy of 25 persons per vehicle and estimated payloads for four cargo vehicle categories are proposed. Sixth, in case of expected mode transfer, half the time difference benefit of the switching passengers or cargo should be applied (rule of one half). Seventh, perceived time coefficients are suggested: for walking to or from a vehicle (1.5), waiting (1.5), time in vehicle (1.0), time for transfer (1.0), and for a number of transfers (7.0). Eight, time costs for transport, which SUDOP obtained from the recommended 2002 level by European yearly inflation with growth elasticity, are summarized in Table 6.

Vehicle operating costs (VOC), cost borne by the vehicle owner, is another evaluated cost category. Vehicle maintenance frequency depending on technical attributes such as type of vehicle, speed, road surface, gradient and weather conditions could be modelled and then multiplied with the unit costs. Six cost categories (fuel, oil, tires, maintenance and overhead costs, and wages of people in the vehicle) and six vehicle categories (three types of cargo vehicles with different load weights, cargo trailers, buses, and cars with vans), each having different VOC, are considered by SUDOP. Additional inputs for 2017, namely, vehicle prices, yearly mileage, hours of operations, lifespan are overhead costs provided by SUDOP (2018) are summarized in Table 7.

Unit costs for the VOC calculation are claimed to be based on market research. (SUDOP, 2018) Retrieval of the yearly average fuel cost without VAT and consumption tax from the Czech Statistical Office, the average wage of a manual worker and the average wage in the category Transport and Warehousing from the Information System of Average Pay (ISPV) is recommended by SUDOP. For highways, the VOC calculation is integrated into the HDM-4 model owned by ŘSD, however, simplified costs (shown in Table 7) should, according to SUDOP, be used when mode change, e.g. road to rail, is to be expected.

Double counting of costs that are associated with both costs of travel and vehicle operating costs needs to be avoided. (SUDOP, 2018) For that reason, SUDOP offers a different cargo costs: CZK 0.31 per tonne hour of low value commodities, CZK 6.13 per tonne hour of ordinary cargo and CZK 18.39 per tonne hour of high value commodities. Unless a detailed study is conducted, they assume 73% of cargo to be of low-value, 14% of normal value and 13% of high-value.

Table 6: Time Costs

			EUR (2002)	CZK (2017)
Work		Bus	11.45	481.7
		Car	14.27	600.34
Non-work	Short commute	Bus	4.13	168.01
		Car	5.75	233.92
	Long commute	Bus	5.31	216.02
		Car	7.38	300.23
	Other - short	Bus	3.46	140.76
		Car	4.82	196.08
	Other - long	Bus	4.45	181.03
		Car	6.18	251.41
Cargo		Road	2.06	86.66

Note: Cargo units are EUR per tonne hour and CZK per tonne hour, respectively.
Source: SUDOP (2018) based on Bickel et al. (2006)

Table 7: Vehicle Operating Costs

Vehicle	Vehicle price	Tyre price	Wheels	Mileage in km	Yearly hours of operation	Lifespan in years	Yearly overhead costs
Car, van	410,900	1,280	4	13,300	300	13	17,800
Cargo (up to 3.5t)	700,000	2,370	4	35,040	1,650	10	50,900
Cargo (3.5-10t)	1,308,700	5,710	6	68,540	2,000	15	97,900
Cargo (above 10t)	2,533,800	9,550	10	64,080	2,000	12	148,700
Semi-trailer	2,906,000	11,320	12	111,040	2,880	10	200,700
Bus	3,925,800	8,340	6	70,000	1,750	11	189,010

Item	Cost	Unit
E5 gasoline	10.80	CZK/liter
Diesel fuel	11.68	CZK/liter
Engine lubricant	144.78	CZK/liter
Maintenance labour	158	CZK/hour
Driver wage	185	CZK/hour

Simplified approach (mode switch)		
Vehicle	Cost	Unit
Car	5.58	CZK/km
Light cargo	9.02	CZK/km
Heavy cargo	21.65	CZK/km
Bus	18.95	CZK/km

Note: 2017 economic prices in CZK; t stands for tonnes (metric tons); bus category includes articulated buses.
Source: SUDOP (2018)

Accidents

Accidents, a negative externality of transport, are evaluated in SUDOP (2018). First, differences in accidents in three categories (death, injury, property damage) between compared projects are established. Secondly, these differences are multiplied by according monetary values. This is done automatically by HDM-4 software, nevertheless, it does not, according to SUDOP, allow for light and heavy injury differentiation.

Quantity of accidents could be based on average accident rates for the Czech Republic, by using the corrected relative accident rates for various road classes, unless a road-specific study is conducted. (SUDOP, 2018) Sources of accident under-reporting, according to SUDOP, are the 30 day monitoring period and the absence of an obligation to call the police when there are no injuries or fatalities, the damage is less than CZK 100,000, and there is no third party property damage. Their correction coefficients, different from the HEATCO by Bickel et al. (2006), could be seen in Table 8.

Monetary values for each accident type apply to all modes of transport in SUDOP (2018). Proposed estimates by Transport Research Centre (who refused to share the underlying study) are summarized in Table 8 and simplified values provided by SUDOP, for use in small or mode transfer projects, are shown in Table 9. Note that SUDOP generalised the injuries compared to the original European source by Bickel et al. (2006).

Table 8: Accidents Correction Coefficients and Monetary Values

	Adjusting coefficient		Monetary value
	Average (SUDOP)	Car (Bickel et al.)	CZK (SUDOP)
Death	1.02	1.02	20,790,000
Serious injury		1.25	5,033,600
Average injury	2.81	2.00	942,053
Slight injury		1.63	649,800
Property damage	6.00	3.50	344,900

Note: Price conversion to 2017 CZK level by SUDOP. The generalised Average injury is intended for road transport and the HDM-4 model.
Source: SUDOP (2018), Bickel et al. (2006)

Table 9: Accidents Simplified Costs

Passenger transport costs (CZK per 1,000 passenger km)	
Car	1,039
Bus	396
Road passenger average	1,080
Rail passenger	19

Cargo transport costs (CZK per 1,000 tonne km)	
Light cargo vehicle	1,808
Heavy cargo vehicle	328
Road cargo average	547
Rail cargo	6

Note: Price conversion to 2017 CZK level by SUDOP. Based on Essen et al. (2011)
Source: SUDOP (2018)

Noise

Two approaches to noise costs calculation are suggested in the Czech guidelines by SUDOP (2018). In greater projects with obligatory noise studies, the number of people affected by each noise level is multiplied by the unit costs from Table 10. Whereas, for projects without such a study, and projects with an expected modal shift, traffic volume is to be multiplied by simplified unit costs also shown in Table 10.

Table 10: Noise Costs

	CZK per affected person per year				
Noise in dB(A)	55-59	60-64	65-69	70-74	75-79
Road	2,252	3,828	5,436	8,363	11,032
Rail	643	2,252	3,828	6,755	9,424

Simplified Noise Costs			
Passenger transport costs (CZK per 1,000 passenger km)		Cargo transport costs (CZK per 1,000 tonne km)	
Car	55	Light truck	203
Bus	51	Heavy truck	58
Rail	39	Rail	32

Note: Price conversion to 2017 by SUDOP based on Essen et al. (2011). In literature known 5 dB 'rail bonus' shifts rail noise costs one class lower. (Essen et al., 2011)
Source: SUDOP (2018)

Air Pollution and Greenhouse Gases

The impact of emissions on health, structures, materials, agriculture, ecosystems and biodiversity has to be included in every CBA according to SUDOP (2018), however, in practice, the calculations include only two following categories. Firstly, air-polluting gases considered are particulate matter (PM), non-methane volatile organic compounds ($NMVOC$), nitrous oxides (NO_X) and sulfur dioxide (SO_2). Secondly, measured greenhouse gases (GHG) are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). According to SUDOP, the greenhouse gases are multiplied by the following factors to obtain the 100-year global warming potential CO_2 equivalents (as in IPCC, 2007): 1 for CO_2, 25 for CH_4 and 298 for N_2O. The road project emissions of GHG and air pollutants are evaluated automatically by the EXNAD programme within the HDM-4 software with the unit costs presented in Table 11, where a simplified emissions factors from vehicle-kilometres used in the absence of software modelling can also be found.

Table 11: Costs of Air Pollutants and Greenhouse Gases

	Unit costs (CZK/tonne)					
Pollutant	CO_2	NO_X	SO_2	$NM\ VOC$	$PM_{2.5}$	PM_{10}
Rural					1,375,556	551,095
Suburban	2,877	504,724	451,145	52,685	2,187,533	875,725
Urban					6,894,628	2,760,095

	Simplified emissions (grams per vehicle-km)					
Pollutant	CO_2	NO_X	SO_2	$NM\ VOC$	$PM_{2.5}$	PM_{10}
Car	188	0.512	0.0055	not provided	0.029	0.051
Bus	556	5.02	0.054	not provided	0.103	0.99
Light cargo vehicle	221	0.694	0.0025	not provided	0.045	0.059
Heavy cargo vehicle	721	7.626	0.0274	not provided	0.202	0.111

Note: Price conversion to 2017 by SUDOP. Place of GNG origin is irrelevant as the climate is affected globally. NM VOC are produced by fuel burning vehicles, but no simplified emission factors were provided in the guidelines.
Source: SUDOP (2018), Essen et al. (2011)

Other Effects

Other valid benefits may be included, however, the inclusion of other costs in SUDOP (2018) is not mandatory and not mentioned at all. Other benefits stated by SUDOP are the development of the region, increase in accessibility of goods and personal transport, utilization of unused land, effects on the landscape, and fragmentation (or increased accessibility) of habitat.

Sensitivity Analysis and Growth Trends

CBA has to include sensitivity and risk analysis with the following actions recommended by SUDOP (2018). The first step is identifying the critical variables, i.e. factors whose 1% change alters the net present value by more than 1%. Secondly, the percentage changes in variables, such that the net present value turns zero, are found and the likelihood of such a change is discussed. Thirdly, evaluation of net present value for optimistic and pessimistic extremes for each critical variable, so-called scenario analysis, is further recommended by SUDOP (2018). Finally, a discussion between experts from various fields concerning possible risks, probabilities and risk management should follow.

Growth trends are handled in an Excel spreadsheet allowing for different growth coefficients and elasticities after the evaluation by the HDM-4 model. The growth values are yearly increases (for example inflation), whereas the elasticities represent a proportion of these growth values to be applied to dependent variables. The growth values in period 2018-2050 for inflation (1.5%), costs of construction (0%), real GDP growth (1.9%) and real wage growth (1.3%), as well as, elasticities tied to real GDP growth for work and cargo transport travel time (0.5), non-work travel time (0.4) and all other externalities (0.7) were provided by SUDOP (2018).

4. Proposed Changes in Methodology

Traffic

Automated traffic intensity measuring for all highways and main roads conducted more frequently than every five years would have two main benefits. First, bottlenecks could be spotted sooner making planning more responsive. Second, induced traffic could be observed. The monitoring of traffic after the highway completion was not undertaken in the Czech Republic (according to Borovička, one ex-post study on highway D8 is being conducted), making the distinction between the short term traffic diversion and the longer-term traffic induction seemingly impossible. The difficulty of traffic increase prediction due to induced demand, without experience and detailed look at the city planning, may be the reason for its omission in both the traffic model and the methodology. However, the problem is that induced demand causes the growth coefficients of affected roads to be seriously underestimated - that is the traffic on affected roads grows much faster than the national or regional levels. This could be seen in the work on road constructions in England by Sloman, Hopkinson, and Taylor (2017).

The traffic growth coefficients provided by the Ministry of Transport and used in the traffic model may be overestimating the total traffic in the future. Appendix A based on data from the Czech Statistic Office and the Ministry of Transport calculated the yearly average growth of road traffic in period 2006-2017 to be 0.28% for cargo weight, -1.01% for cargo mileage, -1.26% for the number of passengers and 1.42% for passenger mileage. Train and public transport mileage increased accordingly with 3.12% for train passenger mileage and 2.04% for city public transport mileage. (Český statistický úřad, 2019a) Although the author is aware that the provided evidence is not sufficient to propose future growth trends in traffic, it may be strong enough to challenge the prediction that road traffic in 2055 will increase in all regions with around 50% growth in light cargo vehicles, around 30% growth in heavy vehicles and 10-40% growth in cars. (Ministry of Transport, 2018)

Costs of Travel

The costs of time seem to be overestimated, whereas the cost ratio of work and non-work travel is likely incorrect. Two approaches, average pay and a willingness-to-pay study, were used to compare the cost of business travel proposed by the methodology (CZK 600.34 per hour), which is based on HEATCO by Bickel et al. (2006). Firstly, the average net hourly wage for working 8 hours and 261 days (including paid holidays) a year would be CZK 145.85 in 2019. (Český statistický úřad, 2019b; Peníze.cz, 2019) Secondly, increasing the 2011 time costs estimated by Máca et al. (2012) by GDP per capita growth provides CZK 197.36 and CZK 78.28 (elasticity 0.7) and CZK 205.63 and CZK 81.56 (elasticity 1.0) for car and bus, respectively. In contrast, the original guidelines would use only 0.5 elasticity for work and 0.4 for non-work. The non-work time, usually considered to cost between 25% and 40% of the work time (European Commission, 2014), based on Máca et al. seems to be worth from 70% to 79% of the work time, depending on the income and trip frequency.

Lower average car and bus occupancies could be recommended for use it the sensitivity analysis. First, the lower bound would be 1.3 persons per car, as supported in the literature section. The upper bound would remain the European average of 1.7 (Fiorello et al., 2016) currently used by the Czech guidelines. Second, the suggested lower bound occupancy rate for buses could be either 17 or 20 passengers, based on the preferred source mentioned in the literature section, and the upper bound 25 as suggested by the Czech guidelines, although without any supporting reference. Clearly, a Czech bus occupancy study would be beneficial for further research.

The addition of small time savings assessment, time variability costs and congestion costs could further improve the analysis. The share of small time savings (less than 3 minutes) on the total time savings, mentioned in the HEATCO by Bickel et al. (2006), could be provided in the sensitivity analysis. Next, unexpected delays and congestion costs, both of which were evaluated in Máca et al. (2012), would enable a closer reflection of the travel time complexity.

Vehicle operating costs calculation could be considered correct and no changes are recommended.

Accidents

Underreporting correction coefficients should be particularized and based on the Czech data. Currently, the coefficients are the averages of various modes of transport (car, motorbike, bicycle and pedestrian) and said to be based on the HEATCO by Bickel et al. (2006). However, the coefficient for generalised injury (2.81) is not provided by Bickel and others. Nevertheless, taking averages of vastly different categories should be avoided. Moreover, due to traffic composition differences, especially between urban and non-urban areas, the use of several sets of coefficients, suggested by Bickel et al., could be recommended. To establish the Czech coefficients, available data from the Czech Police could be extended by data from medical service providers, if they could be made available.

Extension of accident categories could be proposed. First, a differentiation between serious and slight injury needs to be added into the HDM-4 model. According to SUDOP (2018), the HDM-4 model does not allow for light and heavy injury differentiation, despite Bickel et al. (2006) in HEATCO advising to do so. Moreover, the Czech Police provides light and heavy injury differentiation (Ředitelství služby dopravní policie, 2019). Second, the difference between permanent and temporary serious injury should be recognized, monitored, added to the model, and monetary values of both calculated.

Monetary values of accidents need to differ between the modes of transport and the addition of VSL could be recommended. Firstly, there is only one value per each accident type regardless of the transport mode. This is problematic for the average material damage per accident valued at CZK 344,900. For road transport, however, per accident average costs of CZK 62,501 (2018) and CZK 60,838 (2017) could be obtained from the report by Ředitelství služby dopravní policie (2019). This difference, together with a very high underreporting coefficient (6.00), is likely to overestimate the material damage accident costs. Note that monetary values may require frequent revisions. Secondly, VSL should be added to the original calculations by the Transport Research Centre shown by Valach (2014). CZK 14.4 million VSL estimate for car accidents (Alberini and Ščasný, 2011) for lower bound and CZK 48.8 million (Alberini, Ščasný, et al., 2006) for upper bound could be used. The comparably higher labour market VSL estimate by Melichar, Ščasný, and Urban (2010) may be used in the sensitivity analysis. The addition of VSL for fatality and injuries could be compared with the original values in Table 12. VSL was adjusted by yearly Czech GDP per capita growth, as suggested by Bickel et al. (2006) in the HEATCO. However, Bickel et al. warn that increasing the figure could exaggerate VSL over time unless additional studies are conducted regularly.

Minor improvements could also be suggested. Firstly, a different indexation for each accident category should be enabled and calculation moved from an Excel spreadsheet (CBA Tabulky) directly into the HDM-4 model. Secondly, a more frequent review of the relative accident rate coefficients might be advised. Lastly, additional costs of accidents could be measured, such as delay time, extra emissions and vehicle operating costs due to reduced traffic flow after an accident.

Table 12: Accidents Monetary Values with VSL

		Monetary value (CZK)			Sensitivity analysis (CZK)	
		SUDOP (2018)	Lower bound	Upper bound	Lower bound	Upper bound
Death		20,790,000	35,190,000	69,590,000	88,290,000	320,190,000
Serious injury	Permanent	5,033,600	9,641,600	20,649,600	26,633,600	100,841,600
	Temporary	5,033,600	6,329,600	9,425,600	11,108,600	31,979,600
Injury		942,053	-	-	-	-
Slight injury		649,800	793,800	1,137,800	1,324,800	3,643,800

Note: 2017 price level. Applies to all modes of transport. VSL for the generalised Injury, used in the HDM-4 model, was not included for being overly simplistic.
Source: Author's calculations based on SUDOP (2018), Nellthorp et al. (2000)

Noise

Noise costs used in the methodology based on the CE DELFT are significantly higher than shown in a Czech willingness-to-pay study. However, the results of the study may just reflect public unawareness of the health effects, and correction is not recommended unless more research shows similar results. Nevertheless, using the estimates as a lower bound in a sensitivity analysis could provide a test of robustness for cost-benefit analyses, which include noise countermeasures.

Air Pollution and Greenhouse Gases

The costs of air pollution do not reflect the number of exposed people very well. The calculation seems to be based on the mass of pollutants and population density only. Additionally, an inconsistency in density classes was found as both the Czech and the European methodologies describe the population density as fixed classes, however, an appendix of the European one by RICARDO-AEA (2014) claims these values to be the median populations from Eurostat, and suggests different intervals. Moreover, the emissions inhaled by drivers seem to be ignored and the increased costs for parts of the population (children, pregnant women and senior population) are only reflected in unit costs, but not in the number of affected people. Perhaps the traffic model, with already a solid detail of population distribution, may be used for more detailed emission modelling.

The local air polluting effects of non-methane volatile organic compounds (NMVOC), carbon monoxide (CO), hydrocarbons (HC) and non-exhaust particulate matter (PM) emissions should be evaluated in the Czech methodology as well as in the original European RICARDO study.

The costs of the NMVOC emissions, associated with smog, ozone and health problems (World Health Organization, 2015), need to reflect the number of people exposed. However, no such study evaluating the costs per tonne of NMVOC from transport other than RICARDO was found. Moreover, no estimates of grams per vehicle-km of NM VOC produced by fuel-burning vehicles are provided for the simplified approach by the guidelines. On the other hand, CO and HC are regulated under the EURO emission standards, therefore, the emission quantity could be estimated based on dynamic traffic composition. Lastly, whether non-exhaust PM emissions are calculated in the Czech methodology is unclear. In the original source by Essen et al. (2011), the PM10 non-exhaust emissions are recognized, while the PM2.5 non-exhaust emissions are not. As the smaller particles can amount up to half of the non-exhaust emissions (as could be seen in Table 13) and a tonne of PM2.5 is more than twice as expensive as a tonne of PM 10 (Essen et al., 2011), an underestimation of total costs is evident even in van Essen et al.. Furthermore, the significance of not publicly known, unregulated non-exhaust emissions is likely to increase with newer and electric cars producing low or none exhaust emissions.

The simplified emission factors in the methodology may need to be updated. This would be even more important if they were the inputs to the road transport emissions calculation programme EXNAD. These values seem to reflect the 1997 EURO 2 emissions standards as could be seen in Automobile Association (2017), and more than 85% of Czech vehicles had a stricter emission standard in 2015. (ATEM, 2016) Generally, the values of NOx and PM of the most recent 2015 EURO 6 are almost ten times smaller. As mentioned in the literature review, an observed correlation between newer cars and high capacity roads may be reflected in the future methodologies. Next, per vehicle kilometre carbon dioxide (CO_2) emissions may be overestimated in the near future. A 40% real-world emissions underestimation margin, suggested by Fontaras, Zacharof, and Ciuffo (2017) and Tietge et al. (2017), added to a 2015 CO_2 fleet limit resulted in 182 grams per kilometre, slightly lower than 188 grams per kilometre proposed for a car by the methodology. However, this figure will almost surely dramatically drop for the cars registered after 2021, where both stricter testing and lower fleet emission levels will apply. Finally, the official European fleet emissions may become seriously skewed by the very low emission vehicles as mentioned in the literature section.

Recommendations from an attempt to increase the accuracy of the emissions from vehicles of different EURO norms, different fuel type and different road conditions could be proposed. First, vehicles that use alternative fuels should be evaluated separately to avoid lowering the average emissions. Second, the differentiation between petrol and diesel in cars is necessary. Third, emissions of highway driving and congested traffic vary to the extent that they need to be separated in calculations. Fourth, the difference between real-world emissions and laboratory tests needs to be considered until 2021, when the emissions of newer diesel cars are likely to lower the figures significantly. Fifth, the division of vehicles based on the year of commission and testing procedure may be used to control emission manipulations. Lastly, a weighted average of emissions based on the observed dynamic traffic composition and associated EURO norms may be calculated in 2020 for both highways and other roads, when the next traffic composition study by ATEM could be expected. This calculation is likely to be more representative than the currently used typical vehicle per each category.

The greenhouse gases time indexationand unit costs could be corrected and the emissions from infrastructure construction may be added. First, the real GDP growth indexation of climate change costs with the elasticity of 0.7 should be replaced with increasing avoidance costs due to the absence of an elasticity supporting reference, a mismatch between strictly increasing avoidance costs and possible fluctuations in real GDP, and an additional uncertainty embedded in the real GDP growth forecast. Secondly, the price of CO_2-equivalent tonne could follow the 2025 price range of EUR 69 and EUR 241 proposed by Kuik, Brander, and Tol (2009) increasing yearly between 2% and 2.5% to EUR 128 and EUR 396 in 2050 in the absence of inflation. Despite reintroducing the forecast uncertainty, increasing the range with inflation is necessary. It should be noted that this range reflects only the less ambitious target of 2.1°C temperature increase and not the stricter, certainly more expensive 1.5°C target of the Paris agreement signed by the European Union. Moreover, new research, technology, as well as climate action progress need to be monitored to update the guidelines frequently. Third, the highway construction emissions spreadsheet calculator by Highways England (2015) could be adopted by the Czech methodology.

Ecosystem and biodiversity degradation costs, despite being related to air pollution, will be mentioned separately in Other Effects.

Table 13: Estimated Pollutants per Kilometre

	Exhaust only				Brake, tyre and road			
	NO_x		PM_{10}		PM_{10}		$PM_{2.5}$	
	Congested urban traffic	Highway	Congested urban traffic	Highway	Urban traffic	Highway	Urban traffic	Highway
Car	0.63	0.34	0.049	0.019	0.028	0.015	0.015	0.009
Light truck	9.19	3.15	0.095	0.027	0.040	0.019	0.020	0.011
Heavy truck	19.31	5.36	0.252	0.065	0.136	0.078	0.074	0.046
Bus	10.32	2.61	0.240	0.062	0.113	0.060	0.057	0.034

Note: In grams per vehicle-kilometre. Congested urban traffic could be considered the upper bound and highway the lower bound. For PM, the data source does not differentiate between congested and uncongested urban traffic. As PM 2.5 is, by definition, included in PM 10, double-counting needs to be avoided.
Source: Author, based on ATEM (2016), Ligterink (2017), Wakeling et al. (2017)

Other Changes

Unsealing and restoration costs could be added to the methodology to estimate the negative impacts of infrastructure on landscape and biodiversity. For the Czech Republic, the 2018 unsealing costs of EUR 28.6 per m^2 based on the CE Delft study by Essen et al. (2011) and the 2019 restoration costs between EUR 0.84 per m^2 based on NEEDS (2006) are calculated by the author. However, more recent research would be preferred to replace these values.

Economic effects should be recognized and presented in the methodology despite their difficult evaluation. First, the productivity growth as shown in the RAND summary by Shatz et al. (2011) generally exists and tends to diminish with network density. Second, suburbanization and associated negative effects need to be discussed and managed with the help of local authorities. Note that the unsealing costs do not reflect the negative costs of urban sprawl as they were not designed to. Third, possible lobbying of industries with increased benefits from highways may be replaced by a public-private partnership offer. Fourth, the spillover effect needs to be expected and might even be estimated by extensive data gathering as mentioned previously.

Constant construction prices assumption is likely incorrect. Historical data from the Czech Statistics Office (attached in Appendix B) do not suggest that the price index of construction works stopped growing in 2015 as written by SUDOP (2018) in the methodology. Moreover, in 2018, when SUDOP released the methodology, the growth in the price index of construction prices in 2015 and 2016 must have been already published. The construction prices seem to be tied to the economic cycle in the short-term and to inflation in the long-term, therefore, approximation with inflation is more likely than constant prices of construction costs.

Growth elasticities for the time indexation should be changed. GDP growth per capita instead of real GDP growth is to be used and elasticity of 0.7 (1.0 for upper bound) instead of 0.4 nonwork and 0.5 for work and cargo transport should be used. This approach is recommended by Bickel et al. (2006) in the HEATCO and supported by two studies, where elasticities between 0.7 and 1.0 were found, mentioned by the European Commission (2014). Moreover, despite having the same results, the application of growth trends and elasticities before discounting in the CBA seems to be more appropriate both formally and logically.

The sensitivity analysis of the accident costs seems not detailed enough. According to Borovička, only changes in the total accident costs are considered, whereas a change in certain kind of accidents (e.g. fatality), while holding others (e.g. injury, property damage) fixed, is not covered in the sensitivity analysis. This may or may not pose a risk based on the proportions of each accident category on the total costs.

5. Limitations and Further Research

Limitations

Induced and transferred traffic is not considered in the highway planning procedure as it tends to be difficult predict and empiric studies or ex-post valuations for the Czech Republic are not detailed enough or do not exist whatsoever. Such omission is likely to increase the travel time both in the short and long term, overestimating the time-savings benefit, and is probably the greatest shortcoming in the whole methodology.

Further research

The following issues could be studied in the future. First, the commercial traffic model used by ŘSD could be closely investigated and compared with the traffic model of Prague administered by Prague Institute of planning and development (IPR Praha) and Technical Road Administration - Department of Transport Engineering (TSK-ÚDI). Air pollutants flow and concentrations could be verified by a model developed by ATEM (2011) and Mathematical-Physical Faculty of Charles University. Second, benefits from all planned bypasses and all unfinished highways could be compared. Currently, the public opinion seems to be biased in favour of building highways, but a highway connection to the town without bypass could worsen the problems as highways need to complement the urban infrastructure. Third, possible trade and toll increases from national and international transport, in the case of international highway connections, could be evaluated. Fourth, visual and barrier effects associated with roads and railways might be investigated and then included in the methodology. A willingness-to-pay study on perceived discomfort from the visual presence of transport infrastructure (controlling for noise and emissions) and a study on largely unnoticed barrier effect on pedestrians could be the first step. Fifth, future research could prove or falsify the hypothesis that the transfer of traffic to highways decreases accident rates for motorbikes, making motorbikes significant enough to be included in the guidelines.

6. Conclusion

The thesis reviewed and proposed extensions in the main topics covered in the Czech methodology, namely, costs of travel, accidents, noise, air pollution and climate change, while also attempting to look into the underlying mechanisms of the calculation and offered this information to a wider audience outside the specialised institutions.

The immense complexity of transport effects was revealed, while also showing a need for simpler, specialised and localised studies in each of the effects, before more detailed recommendations could be given. This applies the most to the road noise evaluation and value of travel time, which, until now, were the best European estimates transferred through purchasing power parity. Nevertheless, described studies will likely be conducted, and this thesis would provide a suitable starting point for their rapid application.

Road, rail and even air transport evaluation would benefit immensely from such research, but the required work lies in their practical comparison. In the Czech Republic, financing of infrastructure projects could even worsen in the future, for example, due to the depletion of the European funds, making the decisions between road, rail, long-distance or city level, including public transport, even more important. More studies and a better understanding of the transport infrastructure is needed in order to decide correctly, how much unfinished should the Czech highways system remain, or whether the benefits of its completion justify the costs.

References

Adminaite, D. et al. (2018). *An Overview of Road Death Data Collection in the EU: PIN Flash Report 35*. URL: https://etsc.eu/wp-content/uploads/PIN-FLASH-35-final.pdf.

Adra, N., J. L. Michaux, and M. Andre (2004). *Analysis of the load factor and the empty running rate for road transport. Artemis - assessment and reliability of transport emission models and inventory systems*. <hal-00546125>. URL: https://hal.archives-ouvertes.fr/hal-00546125/document.

Alberini, A. and M. Ščasný (2011). "Context and the VSL: Evidence from a Stated Preference Study in Italy and the Czech Republic". In: *Environmental and Resource Economics* 49, pp. 511–538. DOI: https://doi.org/10.1007/s10640-010-9444-8.

Alberini, A., M. Ščasný, et al. (2006). *The Value of a Statistical Life in the Czech Republic: Evidence from a Contingent Valuation Study*. URL: http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.312.4705.

ATEM (2011). *Model emisí a imisí škodlivin ČR na základě výsledků sčítání 2010*. URL: https://www.rsd.cz/wps/wcm/connect/f1914d22-c5e1-4692-8c88-7d7f6594210f/Emise+a+imise+CR+2010.pdf?MOD=AJPERES.

— (2016). *Zjištění aktuální dynamické skladby vozového parku v roce 2015 a prognóza skladby vozového parku do roku 2040*. URL: https://www.rsd.cz/wps/wcm/connect/5c62aa6e-a639-40e0-98be-e64680534c3b/2015+Dynamicka+skladba+VP.pdf?MOD=AJPERES.

Automobile Association (2017). *Limits to improve air quality and health*. URL: https://www.theaa.com/driving-advice/fuels-environment/euro-emissions-standards.

Baldauf, R. et al. (Oct. 2008). "Impacts of noise barriers on near-road air quality". In: *Atmospheric Environment* 42.32, pp. 7502–7507. DOI: 10.1016/j.atmosenv.2008.05.051.

Bångman, G. (2016). *Analysmetod och samhällsekonomiska kalkylvärden för transportsektorn: ASEK 6.1*. Kapitel 20 English summary of ASEK Guidelines. URL: https://www.trafikverket.se/contentassets/4b1c1005597d47bda386d81dd3444b24/asek-6.1/asek_6_1_hela_rapporten_180412.pdf.

Bickel et al. (2006). *HEATCO Deliverable 5: Proposal for Harmonised Guidelines*. URL: https://trimis.ec.europa.eu/sites/default/files/project/documents/20130122_113653_88902_HEATCO_D5_summary.pdf.

Cater, J. C. Jr. (1994). "Environmental externalities and the social rate of discount". In: *The Electricity Journal* Volume 6.10, pp. 66–72. DOI: https://doi.org/10.1016/1040-6190(93)90097-5.

CENIA (2019). *Informační systém EIA*. URL: https://portal.cenia.cz/eiasea/view/eia100_cr.

Centrum služeb pro silniční dopravu (2018). *Dopravní nehody 2018*. URL: https://www.cspsd.cz/storage/files/nehody_2018.pdf.

Černoch, Adam (2014). *Vyhodnocování dopravního hluku a jeho modelování*. URL: https://www.vutbr.cz/www_base/zav_prace_soubor_verejne.php?file_id=80121.

Český statistický úřad (2019a). *Přeprava věcí a osob, přepravní výkony: Zjišťování Ministrstva dopravy*. URL: https://vdb.czso.cz/vdbvo2/faces/cs/index.jsf?page=vystup-objekt&pvo=DOP05-D&skupId=1613&z=T&f=TABULKA&katalog=31028&pvo=DOP05-D&c=v3~8__RP2017.

— (2019b). *Průměrné mzdy - 4. čtvrtletí 2018*. URL: https://www.czso.cz/csu/czso/cri/prumerne-mzdy-4-ctvrtleti-2018.

— (2019c). *Tab. 4.1 Indexy cen stavebních děl v členění podle klasifikace CZ-CC na 4 místa (kód: 011043-19)*. URL: https://www.czso.cz/csu/czso/ipc_cr#csp.

— (2019d). *Tab. Hlavní makroekonomické ukazatele (kód: 350004-19)*. URL: https://www.czso.cz/csu/czso/hmu_cr.

Čihák, M. et al. (2013). *Páteřní síť silnic a dálnic v ČR*. URL: https://www.rsd.cz/wps/wcm/connect/2c493ac4-a7c1-4baf-912b-e9ecb6b8e9e4/RSD-paterni-sit-silnic-a-dalnic-v-cr.pdf?MOD=AJPERES.

Department for Transport (2012). *Annual Bus Statistics: Great Britain 2011/12*. URL: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/11854/annual-bus-statistics-2011-12.pdf.

Department of transportation engineering of the technical administration of roads of the city of Prague (2017). *Prague Transportation Yearbook 2016*. URL: http://www.tsk-praha.cz/static/udi-rocenka-2016-en.pdf.

Doucouliagos, C., T. D. Stanley, and M. Giles (2011). "Are estimates of the value of a statistical life exaggerated?" In: *Journal of Health Economics* 31, pp. 197–206. URL: https://www.sciencedirect.com/science/article/pii/S0167629611001342.

EEA (2010). *Technical report No 11/2010: Good practice guide on noise exposure and potential health effects.* URL: https://www.eea.europa.eu/publications/good-practice-guide-on-noise#tab-news-and-articles.

Essen, Huib van et al. (2011). *External Costs of Transport in Europe: Update study for 2008.* URL: https://www.cedelft.eu/publicatie/external_costs_of_transport_in_europe/1258.

European Automobile Manufacturers Association (2017). *Auto industry welcomes more stringent emissions tests coming into effect on 1 September.* URL: https://www.acea.be/press-releases/article/auto-industry-welcomes-more-stringent-emissions-tests-coming-into-effect-on.

European Commission (2014). *Guide to Cost-Benefit Analysis of Investment Projects: Economic appraisal tool for Cohesion Policy 2014-2020.* URL: https://ec.europa.eu/regional_policy/sources/docgener/studies/pdf/cba_guide.pdf.

— (2019a). *Post-2020 CO2 emission performance standards for cars and vans.* URL: https://ec.europa.eu/clima/policies/transport/vehicles/proposal_en#tab-0-0.

— (2019b). *Reducing CO2 emissions from heavy-duty vehicles.* URL: https://ec.europa.eu/clima/policies/transport/vehicles/heavy_en.

— (2019c). *Reducing CO2 emissions from passenger cars.* URL: https://ec.europa.eu/clima/policies/transport/vehicles/cars_en.

European Environment Agency (2014). *Noise in Europe 2014.* URL: https://www.eea.europa.eu/publications/noise-in-europe-2014.

— (2016). *Comparison of NOx emission standards for different Euro classes.* URL: https://www.eea.europa.eu/media/infographics/comparison-of-nox-emission-standards/view.

Fiorello, Davide et al. (2016). "Mobility Data across the EU 28 Member States: Results from an Extensive CAWI Survey". In: *Transportation Research Procedia* 14, pp. 1104–1113. DOI: 10.1016/j.trpro.2016.05.181.

Fontaras, G., N. Zacharof, and B. Ciuffo (2017). *Fuel consumption and CO2 emissions from passenger cars in Europe – Laboratory versus real-world emissions.* URL: https://www.researchgate.net/publication/313885157_Fuel_consumption_and_CO2_emissions_from_passenger_cars_in_Europe_-_Laboratory_versus_real-world_emissions.

Godet-Cayré, Virginie et al. (Feb. 2006). "Insomnia and Absenteeism at Work. Who Pays the Cost?" In: *Sleep* 29.2, pp. 179–184. DOI: 10.1093/sleep/29.2.179.

Grigoratos, T. and G. Martini (2014). *Non-exhaust traffic related emissions: Brake and tyre wear PM.* URL: http://publications.jrc.ec.europa.eu/repository/bitstream/JRC89231/jrc89231-online%20final%20version%202.pdf.

Hanson, C. S. and R. B. Noland (Oct. 2015). "Greenhouse gas emissions from road construction: An assessment of alternative staging approaches". In: *Transportation Research Part D: Transport and Environment* 40, pp. 97–103. DOI: 10.1016/j.trd.2015.08.002.

Highways England (2015). *Carbon emissions calculation tool.* URL: https://www.gov.uk/government/publications/carbon-tool.

IPCC (2007). *Climate Change 2007: The physical science basis.* Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)] URL: https://www.ipcc.ch/site/assets/uploads/2018/05/ar4_wg1_full_report-1.pdf.

Kasnatscheew, A. et al. (2016). *Deliverable 5.1: Review of European Accident Cost Calculation Methods – With Regard to Vulnerable Road Users.* URL: https://www.indev-project.eu/InDeV/EN/Documents/pdf/review-cost-calculation.pdf?__blob=publicationFile&v=1.

Kim, K. et al. (Oct. 2013). "A review of airborne polycyclic aromatic hydrocarbons (PAHs) and their human health effects". In: *Environment International* 60, pp. 71–80. DOI: 10.1016/j.envint.2013.07.019.

Kočí, M. (2017). *Budoucnost automobilové dopravy ve Zlíně.* URL: https://www.zlin.eu/clanky/dokumenty/6874/174m3kma-3-koci-future-of-iad.pdf).

Kuik, Onno, Luke Brander, and Richard S. J. Tol (Apr. 2009). "Marginal abatement costs of greenhouse gas emissions: A meta-analysis". In: *Energy Policy* 37.4, pp. 1395–1403. DOI: 10.1016/j.enpol.2008.11.040.

Kutáček, S. (2009). "Aplikace teorie externalit na vybraný segment odvětví dopravy". Disertation Thesis. Masarykova univerzita, Ekonomicko-správní fakulta. URL: https://is.muni.cz/th/dvnpp/DIZERTACE_Kutacek_velka-obhajoba.pdf.

Liberko, M. and L. Ládyš (2011). *Výpočet hluku z automobilové dopravy: Manuál 2011*. Page 34. Ředitelství silnic a dálnic České republiky. URL: https://www.rsd.cz/wps/wcm/connect/a079dd27-3636-459e-b654-c46f1ff2a76d/Metodika_2011.pdf?MOD=AJPERES.

Ligterink, N. (2017). *Real-world Vehicle Emissions: Discussion Paper No. 2017-06*. URL: https://www.itf-oecd.org/sites/default/files/docs/real-word-vehicle-emisions.pdf.

Máca, Vojtěch et al. (2012). *Kvantifikace externích nákladů dopravy v podmínkách České republiky*. URL: https://www.czp.cuni.cz/czp/images/stories/Vystupy/TranExt/ZZ_TranExt_final.pdf.

Markets Insider (2019). *CO2 European Emission Allowances*. URL: https://markets.businessinsider.com/commodities/co2-european-emission-allowances.

Matthews, H. S. and L. B. Lave (2000). "Applications of environmental valuation for determining externality costs". In: *Enviromental Science and Technology* 34.8, pp. 1390–1395. URL: https://pdfs.semanticscholar.org/510f/9af9fef0d611ac3b9d5e3d7f21564f386a97.pdf.

Melichar, J., M. Ščasný, and J. Urban (2010). "Hodnocení smrtelných rizik na trhu práce: Studie hedonické mzdy v ČR". In: *Politická ekonomie* 58.5, pp. 657–674. URL: https://www.researchgate.net/publication/227473868_The_Valuation_of_Risks_in_the_Labor_Market_Hedonic_Wage_Study_in_CR/stats.

Ministry of Transport (2018). *Technické podmínky TP 225, oprava č.1: Prognóza intenzita automobilové dopravy*. URL: http://www.pjpk.cz/data/USR_001_2_8_TP/TP_225_2018_oprava_1.pdf.

Ministry of Transport and BESIP (2017). *Národní strategie bezpečnosti silničního provozu: Informace o plnění v roce 2017*. URL: https://www.ibesip.cz/getattachment/Pro-odborniky/Narodni-strategie-BESIP/Plneni-strategie/Hlavni-zprava.pdf.

Misuraca, Pamela (2014). *The Effectiveness of a Costs and Benefits Analysis in Making Federal Government Decisions: A Literature Review*. URL: https://www.mitre.org/publications/technical-papers/the-effectiveness-of-a-costs-and-benefits-analysis-in-making-federal.

NEEDS (2006). *Assessment of Biodiversity Losses*. URL: http://www.needs-project.org/RS1b/RS1b_D4.2.pdf.

Nejvyšší kontrolní úřad (2018). *Výstavba dálnic*. URL: https://www.nku.cz/assets/kontrola/analyzy/vystavba-dalnic.pdf.

Nellthorp, J. et al. (2000). *Valuation Conventions for UNITE*. UNITE (Unification of accounts and marginal costs for Transport Efficiency) Working Funded by 5th Framework RTD Programme. ITS, University of Leeds, Leeds, April 2001. URL: http://www.its.leeds.ac.uk/projects/unite/downloads/D5_Annex3.pdf.

Noise Quest (2018). *Basics of sound*. URL: https://www.noisequest.psu.edu/noisebasics-basics.html.

Peeters, Bert and Gijsjan van Blokland (2018). *Decision and cost/benefit methods for noise abatement measures in Europe*. URL: http://epanet.pbe.eea.europa.eu/fol249409/noise/decision-and-cost-benefit-methods-noise-abatement-measures-europe.

Peníze.cz (2019). *Výpočet čisté mzdy 2019*. URL: https://www.penize.cz/kalkulacky/vypocet-ciste-mzdy#mzda.

Pratt, Caroline (2002). *Estimation and valuation of environmental and social externalities for the transport sector*. URL: https://www.atrf.info/papers/2002/2002_Pratt.pdf.

Ředitelství služby dopravní policie (2019). *Informace o nehodovosti na pozemních komunikacích v České republice v roce 2018*. URL: https://www.policie.cz/clanek/statistika-nehodovosti-900835.aspx?q=Y2hudW09Mg%3d%3d.

RICARDO-AEA (2014). *Update of the Handbook on External Costs of Transport: Final Report*. RICARDO-AEA. URL: https://ec.europa.eu/transport/sites/transport/files/handbook_on_external_costs_of_transport_2014_0.pdf.

Roberts, M. et al. (2009). *Regional Economic Impacts of Highway Projects, Very Preliminary Draft*. URL: https://pdfs.semanticscholar.org/dbb9/1a8994017d56b1fbba1dc5946729a53c67ca.pdf.

ŘSD ČR (2016). *Celostátní sčítání dopravy 2016*. URL: http://scitani2016.rsd.cz/pages/map/default.aspx.

— (2018a). *Silnice a dálnice v České republice 2017*. URL: https://www.rsd.cz/wps/wcm/connect/dbc399d7-56eb-4c7a-b7ef-aef2283647a0/%C5%98SD+ro%C4%8Denka+2017_CZE_web.pdf?MOD=AJPERES&CACHEID=dbc399d7-56eb-4c7a-b7ef-aef2283647a0.

— (2018b). *Silnice a dálnice v České republice, 2017*. URL: https://www.rsd.cz/wps/wcm/connect/dbc399d7-56eb-4c7a-b7ef-aef2283647a0/%C5%98SD+ro%C4%8Denka+2017_CZE_web.pdf?MOD=AJPERES&CACHEID=dbc399d7-56eb-4c7a-b7ef-aef2283647a0.

— (2019a). *Délky a další data komunikací*. URL: www.rsd.cz/wps/portal/web/Silnice-a-dalnice/delky-a-dalsi-data-komunikaci.

— (2019b). *Mapy: Výstavba v síti TEN-T 2019*. URL: https://www.rsd.cz/wps/portal/web/Silnice-a-dalnice/mapy.

Schreyer, Christoph et al. (2004). *External Costs of Transport: Update Study*. URL: http://habitat.aq.upm.es/boletin/n28/ncost.en.pdf.

Seo, Y. and S. Kim (Oct. 2013). "Estimation of materials-induced CO2 emission from road construction in Korea". In: *Renewable and Sustainable Energy Reviews* 26, pp. 625–631. DOI: 10.1016/j.rser.2013.06.003.

SFDI (2019). *Výroční zpráva o činnosti a účetní závěrka Státního fondu dopravní infrastruktury za rok 2018*. URL: https://www.sfdi.cz/soubory/obrazky-clanky/dokumenty-2019/2019_vz_2018.pdf.

Shatz, H. J. et al. (2011). *Highway Infrastructure and the Economy: Implications for Federal Policy*. URL: https://www.rand.org/content/dam/rand/pubs/monographs/2011/RAND_MG1049.pdf.

Sieber, P. and J. Melichar (2014). "Ekonomické hodnocení hluku ze silniční dopravy: Studie podmíněného hodnocení". In: *Politická ekonomie* 2014.6, pp. 824–849. URL: https://econpapers.repec.org/article/prgjnlpol/v_3a2014_3ay_3a2014_3ai_3a6_3aid_3a984_3ap_3a824-849.htm.

Sloman, L., L. Hopkinson, and I. Taylor (2017). *The Impact of Road Projects in England*. Report for CPRE. URL: https://www.cpre.org.uk/resources/transport/roads/item/4542-the-impact-of-road-projects-in-england.

SUDOP (2018). *Rezortní metodika pro hodnocení ekonomické efektivnosti projektů dopravních staveb*. Státní fond dopravní infrastruktury. URL: https://www.sfdi.cz/soubory/obrazky-clanky/metodiky/2017_02_rezortni_metodika-komplet.pdf.

Tietge, U. et al. (2017). *From laboratory to road: A 2017 update*. URL: https://www.theicct.org/publications/laboratory-road-2017-update.

Townsend, C. L. and R. L. Maynard (Oct. 2002). "Effects on health of prolonged exposure to low concentrations of carbon monoxide". In: *Occupational and Environmental Medicine* 59.10, pp. 708–711. DOI: 10.1136/oem.59.10.708.

TransportPolicy.net (2019). *EU Fuels: Diesel and gasoline*. URL: https://www.transportpolicy.net/standard/eu-fuels-diesel-and-gasoline/.

Uhlířová, M. and Ministry of Transport (2016). *Technické podmínky – TP 104 Protihlukové clony pozemních komunikací*. Ministerstvo dopravy. URL: http://www.pjpk.cz/data/USR_001_2_8_TP/TP_104_2016.pdf.

Úsek výstavby ŘSD ČR (2017). *Příloha C3: Uživatelský návod k českému systému hodnocení silnic programem HDM-4*. URL: https://www.rsd.cz/wps/wcm/connect/3da37891-2cfa-49c8-b634-ff88c77e93d5/Priloha+C3+-+Uzivatelsky+navod+CSHS+171115.pdf?MOD=AJPERES.

Valach, O. (2014). *Ekonomické dopady nehod, financování opatření NSBSP*. Presentation for conference Brno Safety. URL: https://www.cdv.cz/file/brnosafety-2014-prezentace-ondrej-valach-ekonomicke-dopady-nehod-financovani-opatreni-nsbsp/.

Wakeling, D. et al. (2017). *UK Informative Inventory Report (1990 to 2015)*. p. 155-156. URL: https://uk-air.defra.gov.uk/assets/documents/reports/cat07/1703161205_GB_IIR_2017_Final_v1.0.pdf.

World Bank (2019). *GDP per capita growth*. URL: https://data.worldbank.org/indicator/NY.GDP.PCAP.KD.ZG.

World Health Organization (2015). *Climate Change and Health: Training Modules*. URL: http://www.searo.who.int/entity/water_sanitation/documents/climatechangeandhealthtrainingmodulesweb.pdf.

World Health Organization Europe (2018). *Environmental Noise Guidelines for the European Region*. ISBN 978 92 890 5356 3. URL: http://www.euro.who.int/__data/assets/pdf_file/0008/383921/noise-guidelines-eng.pdf?ua=1.

Xylia, Maria and Semida Silveira (Jan. 2017). "On the road to fossil-free public transport: The case of Swedish bus fleets". In: *Energy Policy* 100, pp. 397–412. DOI: 10.1016/j.enpol.2016.02.024.

Yannis, G. et al. (2014). "Modeling road accident injury under-reporting in Europe". In: *European Transport Research Review* 6.4, pp. 425–438. DOI: https://doi.org/10.1007/s12544-014-0142-4.

Zákon o pozemních komunikacích (1997). *Zákon č. 13/1997 Sb.:* URL: https://www.zakonyprolidi.cz/cs/1997-13.

Appendix A: Transport Growth Trends

Table 14: Modes of Transport Performance in the Czech Republic (2006-2017)

		2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Average yearly change (%)
Cargo	Total tonnes	100.0	101.9	97.4	82.6	81.4	80.8	78.5	80.6	88.6	98.9	97.1	102.9	0.24
	Rail cargo tonnes	100.0	102.3	97.5	78.7	85.0	89.3	85.1	86.1	93.9	99.8	100.6	99.0	-0.08
	Road cargo tonnes	100.0	102.0	97.1	83.3	80.1	78.6	76.3	79.1	86.9	98.7	97.1	103.3	0.28
	Water cargotonnes	100.0	110.3	93.8	81.1	80.8	93.3	87.0	79.6	87.6	91.2	87.5	77.2	-1.90
	Air cargo tonnes	100.0	100.0	90.9	68.2	63.6	54.5	40.9	40.9	40.9	27.3	27.3	27.3	-6.06
	Pipe transport tonnes	100.0	93.2	109.2	90.5	103.0	95.7	104.8	94.4	110.6	101.5	67.6	123.7	1.98
	Total tonne km	100.0	97.3	100.3	87.4	98.8	103.6	98.2	103.2	103.1	110.5	98.4	90.8	-0.77
	Rail cargo tonne km	100.0	103.3	97.8	81.1	87.3	90.7	90.4	88.5	92.4	96.7	99.0	100.4	0.03
	Road cargo tonne km	100.0	95.6	101.0	89.3	102.9	108.9	101.7	109.0	107.4	116.6	99.9	87.9	-1.01
	Water cargo tonne km	100.0	109.8	105.5	78.4	83.0	85.0	81.8	84.7	80.2	71.5	75.8	76.2	-1.99
	Air cargo tonne km	100.0	87.2	78.7	61.7	46.8	46.8	36.2	51.1	74.5	66.0	66.0	68.1	-2.66
	Pipe transport tonne km	100.0	90.7	101.0	94.1	95.6	85.3	83.2	84.4	90.0	88.3	69.3	94.5	-0.46
Passenger	Total passengers	100.0	100.3	102.3	99.5	99.6	95.1	97.6	95.6	95.0	95.7	99.4	100.7	0.06
	Rail passenger	100.0	100.7	96.9	90.1	90.0	91.8	94.4	95.3	96.2	96.5	97.9	100.1	0.01
	Road passegner	100.0	96.7	96.3	94.8	96.1	94.0	89.0	87.2	90.1	90.5	85.8	84.9	-1.26
	Air passenger	100.0	104.0	106.7	109.6	111.3	112.1	95.7	91.7	83.8	80.4	89.4	99.2	-0.07
	Water passenger	100.0	100.5	78.7	107.6	78.0	90.2	46.6	98.5	118.8	83.7	72.8	73.9	-2.17
	City public transport passenger	100.0	100.9	103.8	101.1	101.0	95.6	99.4	97.1	95.8	96.6	101.9	103.5	0.30
	Total passenger km	100.0	100.7	104.1	104.7	106.0	104.6	104.2	103.8	107.0	107.6	114.0	121.5	1.79
	Rail passenger km	100.0	99.7	98.3	93.9	95.2	97.0	105.0	109.8	112.6	119.9	127.8	137.5	3.12
	Road passenger km	100.0	100.2	97.0	99.9	108.8	97.5	94.9	95.0	105.4	105.2	108.0	117.1	1.42
	Air passenger km	100.0	102.4	105.0	110.7	106.5	113.2	103.7	93.9	95.3	94.8	99.7	110.7	0.89
	Water passenger km	100.0	146.2	130.8	76.9	100.0	115.4	130.8	123.1	161.5	107.7	92.3	100.0	0.00
	City public transport km	100.0	100.3	110.9	108.7	109.1	106.8	110.5	113.7	113.7	112.5	121.5	124.5	2.04

Note: 2006 = 100. Average yearly change was calculated as 2017 figure less 2006 figure divided by number of years.
Source: Author, based on data from Český statistický úřad (2019a)

Appendix B: Price Growth of Construction Works

Table 15: Price Growth of Construction Works

Year	Price index of construction works		Inflation	GDP growth
	Actual	SUDOP proposal		
2000	4.1		4.0	4.3
2001	4.0		4.1	2.9
2002	2.7		0.6	1.7
2003	2.2		1.0	3.6
2004	3.7		2.8	4.9
2005	3.0		2.2	6.5
2006	2.9		1.7	6.9
2007	4.1		5.4	5.6
2008	4.5		3.6	2.7
2009	1.2		1.0	-4.8
2010	-0.2		2.3	2.3
2011	-0.5		2.4	1.8
2012	-0.7		2.4	-0.8
2013	-1.1		1.4	-0.5
2014	0.5		0.1	2.7
2015	1.2	0	0.1	5.3
2016	1.1	0	2.0	2.5
2017	1.7	0	2.4	4.4
2018	3.2	0	2.0	2.9
Average	2.0		2.2	2.9
2050 (SUDOP proposal)		0	1.5	1.9

Source: Author, based on (SUDOP, 2018), Český statistický úřad (2019; 2019)

Bachelor's Thesis Proposal

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Proposed Topic:

Economic costs of unfinished highways in the Czech Republic

Preliminary Scope of Work:

The thesis will identify highways which are planned or under construction and attempt to quantify economic losses the region suffers from their incompleteness (deaths and injuries from car accidents, well-being of inhabitants suffering from noise and pollution, investing opportunities from firms and small businesses). Highways are known for "spillover effect", which causes a shift of economic activity from the region without highway to a region with the highway – this spillover effect would be another less documented economic loss of regions with unfinished highways, which the thesis aspires to investigate. The work will further discuss the economic loss of the whole Czech Republic stemming from highways not being connected to neighbouring countries. The thesis shall also investigate town bypasses of major cities as previous reading shows a potential for huge benefits per kilometer.

Contribution:

Synthesizing foreign and domestic research of various fields (economics, ecology, transportation safety) and using the latest data to produce detailed information for policy-makers. The author hopes to encourage more research and interest in cost-benefits analysis in the field of transportation.

Methodology:

The calculations will be using value of statistical life from the existing literature in combination with the data from the Czech Police. A part of the thesis will apply the existing research on well-being effects of transportation and the data from public institutions such as ČHMÚ, ŘSD and others. The data will be analysed in Excel and R. The Python language may be helpful in the visualisation or more complex operations with the data.

Outline:

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Abstract
Acknowledgments
Table of contents
1. Introduction
2. Literature and theory background:
Highways, bypasses (the theory and the situation in the Czech Republic)
Spillover effect of highways
Value of statistical life (compare various estimates for the Czech Republic)
Road accidents in the Czech Republic
Effects of noise and polution on well-being
3. Methodology
Areas and highways of interest (choices and reasoning behind them)
Economic loss due to road accidents (calculation formula)
Well-being reduction due to noise and polution (suggested ways to estimation)
Spillover effects (suggested ways to estimation)
Unfinished interstate highway connections (mainly from trade and toll)
4. Data
Road accidents data from the Czech Police
Air situation data from the ČHMÚ
(Economic data from regions) (not sure yet)
5. Results
Aggregated result for all the selected roads
Results for each area and highway
Limitations, other approaches and further research
6. Conclusion

Bibliography:

Howard J. Shatz, Karin E. Kitchens, Sandra Rosenbloom, Martin Wachs, "Highway Infrastructure and the Economy Implications for Federal Policy"

Egan, Petticrew, Ogilvie, Hamilton, "New Roads and Human Health: A Systematic Review"

Fernald, John G., "Roads to Prosperity? Assessing the Link Between Public Capital and Productivity"

Baum-Snow, Nathaniel, "Did Highways Cause Suburbanization?"

Flyvbjerg, Bent, Holm, and Buhl, "Underestimating Costs in Public Works Projects"