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FACULTY OF SOCIAL SCIENCES

Institute of Economic Studies

Bachelor thesis

2021 **Bc. Jan Mrkous**

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Transition to a low carbon transport system: including time as a decision factor in transport modal choice.

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Abstract

The aim of this bachelor thesis was to analyze the choice of transport modes depending on the value of travel time. For the purpose of this work, I limited the choice of travel modes to trains, buses and cars, as these modes of transport contribute to the transport of the population in the Czech Republic the most. This is a topic that can contribute to the optimization of transport at the national level. Through a robust literature search, I obtained data describing the value of travel time and then used it for modelling in the TIMES software. The model optimized people's use of various modes of transport based on their demands and the value of travel time.

Abstrakt

Cílem této bakalářské práce bylo zanalyzovat volbu dopravních modů v závislosti na hodnotě úspory cestovního času. V rámci této práce jsem volbu cestovních prstředků omezil na vlaky, autobusy a auta, jelikož tyto dopravní mody se podílejí na přepravě obyvatel v České republice nejvíce. Jedná se o téma, které muže přispět k optimalizaci v celostátní dopravě. Skrze robustní literírní rešerši jsem získal data popisující hodnotu cestovního čas a ta jsem následně použil k modelovaní v software TIMES. Tento model optimalizoval využívání různých druhů dopravy lidmi na základě jejich požadavků a hodnoty času cesty.

Klíčová slova

Dopravní prostředek, Cestovní čas, Hodnota cestovního času, TIMES model, Účel cesty, Způsob cestování

Keywords

Travel mode, Travel time, Value of travel time, TIMES model, Purpose of travel, Types of travel

Range of thesis: 39 pages, 63 263 symbols

Declaration of Authorship

1. The author hereby declares that he compiled this thesis independently, using only the listed resources and literature.

2. The author hereby declares that all the sources and literature used have been properly cited.

3. The author hereby declares that the thesis has not been used to obtain a different or the same degree.

Prague … **16.9.2021** **Bc. Jan Mrkous**

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Research question and motivation

I will try to analyze the travel time factors in the Czech Republic transport possibilities.
Travel time, being a crucial aspect of transport economics is worth being paid a lot more attention[1] to. It helps us to understand the pro and cons of travel decision making. That can later provide a reliable source of information for future transport policies.

In the last few years, there had been developed number of models to analyze the crucial aspect of the European Energy roadmap 2050[2] .Many of these studies the possibilities of new eco-friendly technologies or sources of renewable technology. However, the behavioural aspect of transport often does not play any significant part in these models[3] . Time is a crucial factor in the modal choice of transport. Therefore, I extend a standard energy model of the transport sector by including travel time budget and travel time investment in the model.
My motivation is to analyze the importance of travel time constraints (choosing between car/train/bus), and how it could affect the CO2, NOx and other undesired emission rates, together with the energy consumption.

Contribution

I will contribute to the development of a detailed transport sector module in of TIMES-CZ model ((Rečka & Ščasný 2017, 2018)). I will provide a robust literature review of the value of travel time and related aspects that can be applied in transport sector modelling.

Methodology

I will elaborate on the method developed by Daly et al., (2014), which applies travel time budget and travel time investment to model transport modal choice. Values on-time budget and travel time investment will be obtained from literature and will be included directly into the objective function of the model.

Outline

Abstract
Introduction
a. why is my topic interesting
b. a brief overview of existing knowledge
c. how I add to existing research
d. main results and what they mean
e. how is the thesis organized

Literature review
a. the literature on travel time, energy economics, modelling of the transport sector
Methodology and data
a. description of data
b. description of the model and implementation of travel time budget and travel time investments
c. how I analyzed the data
d. what hypotheses will be tested

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[1] Andrew Daly, Stephane Hess, 2019 " VTT or VTTS: a note on terminology for value of travel time Work" *Springer Science+Business Media, LLC, part of Springer Nature 2019*

[2]https://scholar.google.cz/scholar?hl=cs&scisbd=1&as_sdt=0%2C5&as_vis=1&q=European+Energy+roadmap+2050+&btnG=

[3] Hannah E. Daly, Kalai Ramea, Alessandro Chiodi, Sonia Yeh, Maurizio Gargiulo, Brian Ó Gallachóir 2014 "Incorporating travel behaviour and travel time into TIMES energy system Models" *Applied Energy*

Results
a. interpretation of the results

Conclusion
a. broader interpretation of results
b. implications for practice
c. topics for further research

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Content

Introduction

Travel time, as it directly implies, is time spent travelling. Every trip from point A to point B will consume some time. That means that every trip has its opportunity cost. In other words, the time consumed by travelling could have been used in a different, more effective, way. Also, the form of transportation can be modified to satisfy consumer's needs. All this brings the consumer of travel time to decide, what mode of transport will he use. With his final choice, he determines the amount of carbon consumption for his trip. In relationship with the development of travel and transport economics, the value of travel time is gaining more and more attention. The increasing popularity of the value of travel time savings is also related to the continuous development of infrastructure and the increasing importance of all types of transport. The value of travel time and time enter also advanced transport models [11].

In my work, I have focused on researching how time constraint and cost of travel time affect the choice of transport mode. This is the first application where the value of travel time and behavioural constraints, such as time budget constraints are integrated into a bottom-up model of the Czech transport sector. As a modelling platform, I have used the TIMES model generator. I have used a predefined DEMO model to work with simplified energy system and combine it with travel sector module from TIMES [30].

Through literature research, I have found sufficient data to create an exact transport model consisting of three main travel modes (car, bus, train). These travel modes have individual data depending on the distance travelled. The model had shown increasing travel costs and travel demands. The biggest growth had urban train travel (metro/tram) and intercity car and bus travel. These are expected to be increasing their comfort and efficiency over the years and decreasing the congestion risk. Overall, the value of travel time is increasing with the increasing distance and decreasing comfort.

In the first part od of the thesis, I focus on the literature review and listing the necessary data to satisfy the input requirements of TIMES model. Then I describe the main information source and data taken from it. After that, I present the results and model limitations that could be in the future used to improve and specify the obtained results.

1. Literature review

1.1 Travel time

There is no direct market for travel time. Its monetary value for travellers and businesses can be derived by indirect methods: a) analysis of business costs, b) traveller surveys, c) studying behavioural responses by consumers faced with a trade-off between time and money (pay extra for a faster trip, travel by train longer time, but be able to do some efficient work on the way).

The IFT [1] reviews six studies and surveys and concludes:

Personal travel time is estimated to have a value of 25% to 50% of consumers wages. This is dependent on the type of trip, type of trip and travelling conditions. With the increasing income of travellers, the unit cost tends to increase as well. Unemployed and under-age tend to have a lower unit cost of travel than employed (employed have a greater tendency to pay for travel time savings). The next factor affecting VTT is travel time variability and uncertainty. With increasing variability and arrival uncertainty, the unit cost of travel time tends to increase. It is particularly high for unexpected delays during activities with strict schedules (business trips, commuting). On the other hand, increased reliability of travel time creates additional value for the consumer. That is because uncertainty forces the travellers and freight operators to adjust their departure times, counting possible delays. The lesser possibility of delay there is, the more precisely can travellers plan their journey. That saves them some time for certain unit costs.

Value of travel time (VTT) refers to the cost of time used for travelling, which otherwise could be used in another way. It includes, all expenses connected with the time spent travelling. The cost of personal time spent travelling (unpaid time) is a crucial factor in deciding on which form of transport to choose (bus, train, car etc.). The choice of transport affects the number of carbon emissions since every form of transport has a different carbon intensity.

In a few cases, travel time has a low cost or positive value. These are the cases when people enjoy the experience of travelling (recreational travel, social aspects), or when they are extremely productive during the period of travel, in comparison to the productivity at the final destination (train, plane). When we consider walking, cycling, and waiting under pleasant conditions these modes of transport have a low or negative unit cost. On the other hand, under unpleasant conditions (rain, travelling nearby busy road) these forms of travel have two- or three-times higher unit cost than in-vehicle time. Overall we can say that there is a high level of variability in travel needs and preferences (some consumers place a higher unit cost of travel on transit travelling, some consumers place a higher cost on self-driving).

	GDP PPP per capita	Gross labour cost	Car Commute		Car Other			Car EB			Train EB	Bus Comm.	Air EB
			Urban free	Urban cong.	Urban Free	Urban cong.	Inter free	Urban Free	Urban cong.	Inter free	Inter	Urban	Inter
Austria	27925	28	8.04	11.43	7.07	10.06	9.79	15.89	22.59	21.97	32.06	6.09	58.83
Belgium	26290	35.3	7.54	10.72	6.64	9.44	9.18	14.84	21.10	20.52	22.99	5.72	55.02
Bulgaria	9733	3.1	2.64	3.75	2.33	3.31	3.22	4.80	6.83	6.64	9.95	2.06	18.26
Croatia	13499	8.6	3.73	5.3	3.38	4.67	4.54	6.96	9.90	9.63	14.31	2.88	26.25
Cyprus	22142	17.7	6.29	8.94	5.54	7.88	7.66	12.21	17.36	16.88	24.78	4.80	45.47
Czechia	17617	9.8	4.94	7.02	4.35	6.19	6.02	9.42	13.39	13.02	19.23	3.79	35.28
Denmark	28030	36.7	8.07	11.47	7.11	10.10	9.82	15.96	22.69	22.06	32.20	6.12	59.08
Estonia	14227	7.6	3.94	5.61	3.47	4.94	4.8	7.39	10.51	10.22	15.17	3.04	27.83
Finland	25461	28.8	7.29	10.36	6.42	9.13	8.88	14.31	20.34	19.78	28.94	5.54	53.10
France	23807	32.6	6.79	9.65	5.98	8.5	8.27	13.26	18.85	18.33	26.86	5.17	49.28
Germany	26107	28.8	7.48	10.64	6.59	9.37	9.11	14.72	20.93	20.35	29.75	5.68	54.60
Greece	19830	17	5.6	7.96	4.93	7.01	6.82	10.77	15.32	14.90	21.93	4.28	40.23
Hungary	14341	7	3.98	5.65	3.5	4.98	4.84	7.46	10.60	10.31	15.30	3.06	28.08
Ireland	28248	28.9	8.13	11.57	7.16	10.19	9.91	16.1	22.89	22.26	32.48	6.16	59.59
Italy	22263	26.8	6.33	8.99	5.57	7.92	7.70	12.29	17.47	16.99	24.93	4.82	45.75
Latvia	11366	5.5	3.11	4.42	2.74	3.90	3.79	5.73	8.15	7.92	11.82	2.41	21.69
Lithuania	12647	5.4	4.49	4.96	3.07	4.37	4.25	6.48	9.22	8.96	13.34	2.70	24.48
Luxemburg	60120	32.9	10.06	25.68	15.91	22.62	21.99	37.94	53.95	52.46	75.11	13.43	137.81
Macedonia	7852	3.3	2.1	2.99	1.85	2.64	2.56	3.76	5.35	5.20	7.84	1.65	14.39
Malta	18382	11.9	5.17	7.35	4.55	6.47	6.29	9.89	14.06	13.67	20.16	3.96	36.99
Netherlands	29432	31.1	8.49	12.08	7.48	10.64	10.34	16.87	23.98	23.32	33.99	6.43	62.37
Norway	39945	41.6	11.73	16.68	10.33	14.69	14.28	23.85	33.92	32.98	47.71	8.81	87.54
Poland	13890	7.2	3.84	5.47	3.39	4.81	4.68	7.19	10.23	9.94	14.77	2.97	27.10
Portugal	17751	12.6	4.98	7.08	4.39	6.24	6.06	9.50	13.51	13.14	19.39	3.82	35.58
Romania	10143	4.1	2.76	3.92	2.43	3.45	3.36	5.03	7.16	6.96	10.42	1.14	19.12
Serbia	7929	4.9	2.13	3.02	1.87	2.66	2.59	3.81	5.41	2.26	7.93	1.66	14.55
Slovakia	16230	7.7	4.53	6.44	3.99	5.67	5.52	8.58	12.20	11.87	17.55	4.48	32.21
Slovenia	18798	14.6	5.29	7.52	4.66	6.63	6.44	10.14	14.42	14.02	20.66	4.05	37.92
Spain	22259	20.7	6.32	8.99	5.57	7.92	7.70	12.28	17.47	16.98	24.93	4.82	45.74
Sweden	27449	33.6	7.89	11.22	6.95	9.88	9.61	15.58	22.16	21.55	31.46	5.99	57.72
Switzerland	32376	50.1	9.39	13.36	8.27	11.76	11.44	18.79	26.16	25.98	37.78	7.10	69.33
U.K.	24909	20	7.12	10.13	6.27	8.92	8.67	13.96	19.84	19.30	28.24	5.41	51.82
U.K. -39%	24909	20	4.34	6.18	2.82	5.44	5.29	8.52	12.10	11.77	17.23	3.30	31.61
%GLC			41%	58%	51%	50%	50%	78%	110%	107%	159%	31%	289%

Table 1: Implied Values of Time (€ per hour 2010 incomes and prices). Estimated EB stands for an employer's business [11]

The value of travel time savings (VTTS) is closely connected to the value of travel time. It describes the value gained from the decrease in travel time cost or duration, and it plays an important role in selecting the most economically efficient form of transport. It is essential for congestion relief projects since they are working with travel time reduction.

A good example of solving a congestion problem is adding a new lane to a freeway. That directly leads to increased traffic speed and therefore, decreasing travel delays. Another possibility would be to signal coordination strategy, to allow faster travel in a problematic sector of infrastructure. These both reduce travel time and increase travel effectiveness. The time gained from this reduction can be productively used to work or relax, depending on the characteristics of the traveller. Either way, additional time, saved by the travel time savings strategy, is transferred to an arbitrary form of value for the traveller [14].

Foreign studies and meta-analysis regarding the value of travel time savings

Most of the literature analyzing the value of travel time savings is focused on the USA, Great Britain, New Zealand and some Nordic countries like Norway or Sweden. It is necessary to mention that all of these countries are highly developed therefore their data are not relevant for countries in early developing stages [15].

Overall, the studies show that with the increase in travel distance, the value of travel time savings also increases (meaning that "the longer the travel distance is, the more is traveller willing to pay to reduce the travel time"). This effect is most profound in car travel (chapter 1.2). The objective reason for this result is the fatigue of the driver after a long continuous ride.

The results had shown a moderate connection between the value of travel time and net income. It is shown in table 2 below. The value of travel time shows considerable differences regarding the characteristics of the travel itself or the traveller [16]. Four socio-economic factors had the biggest impact on the value of travel time savings: income, employment, children in the household and the fact that the respondent lived in the main city (Stockholm). The last two were important mainly for the drivers. By comparison of different modes of transport, it was found that personal travel has the highest VTTS, followed by long-distance rail transport then was short-distance rail transport and the lowest VTTS had bus transport. Another factor affecting the VTTS is the purpose of the travel. Commute travel had a 30% higher value of travel time savings than other types (this study did not account for employer's business, which proved to have a higher price according to table 1). The explanation is that the time saved on the way can be directly transferred to money by having extra time for work.

Distance	Below 5 miles		5-25 miles		Above 25 miles	
Income						
Below 20 300 €	Commuting	1.88	Commuting	3.30	Commuting	7.17
	Other	2.31	Other	3.67	Other	7.12
20 300 € - 40 600 €	Commuting	2.57	Commuting	4.75	Commuting	10.13
	Other	2.75	Other	4.37	Other	8.71
Above 40 600 €	Commuting	3.32	Commuting	6.25	Commuting	13.23
	Other	3.09	Other	4.93	Other	9.85

Table 2: Values of travel time savings for Great Britain, divided based on the earnings and travel distance [2].

In the stated preference survey analyzing the usage of travel the rail travel time [18], 35% used a laptop, 56% used a Smartphone/Blackberry and 29% did other work related to employment. There has been a notable increase in the use of electronic devices for work-related activities on-train since 2009. These electronic devices help the traveller to effectively work or relax during travel.

For the time/cost trade-off the comparison of different studies supported the idea of the increasing value of travel time for the increasing distance of the trip, [18]. Table 3 also shows an average value of travel time for the car, bus, other public transport, and rail when the distance was unified. These results show that the most expensive is travelling by rail mode. The next highest VTT had the car travel mode. The „Other PT“ travel mode had very close values to car travel mode, except for the Employees' business SP re-weighted to NTS2010–2012 study that showed a significantly lower value 9.59 euro/hour compared to 19.55euro/hour when „Other PT“ compared to car travel mode. The lowest VTT was determined for bus travel mode.

Method	Distance	All modes	Car	Bus	Other PT	Rail
Previous WebTAG (2014 prices and values)	All distance	29.30	28.1	17.99	28.44	34.60
CSA estimate from NTS 2010–2012 data (2014 prices and values)	All distance	32.52	30.11	15.10	30.31	41.97
Employees' business SP re-weighted to NTS 2010–2012 (2014 prices and values)	All distance	20.97	19.25	N/A	9.59	31.78
	<5 miles	6.20	6.06	N/A	9.59	N/A
	5-20 miles	10.17	10.11	N/A	9.53	11.73
	>=20 miles	24.32	22.44	N/A	N/A	33.37
	>=50 miles	28.24	25.92	N/A	N/A	37.49
	>=100 miles	32.91	26.91	N/A	N/A	N/A

Table 3: Business values of travel time by the method of calculation, mode and distance (2014 perceived values of euro per hour) [18]

The study from New Zealand takes a closer look at the differences between individual modes of transport [22]. The difference in this study from the others is that it does not portrait the travel time as totally unproductive, so the primary goal of the traveller is not to shorten the duration of the travel. Its main hypothesis is that the savings of travel time are not the main motivation of all travellers. In some modes of transport, or under certain circumstances the trip can be perceived positively. The study mainly focused on commute travel due to its regularity.

The respondents then compared their usual time spent travelling with the preferred time spent travelling. Only 3% stated that their preferred time travelling is 0 minutes. 59% of respondents stated that their ideal travel time is between 10 and 20 minutes. Around 40% of respondents replied that they enjoy their time spent travelling because they have some space to listen to music, think or relax. The main reasons to not enjoy travel time was due to traffic jams and unnecessary loss of time. When comparing different travel modes, they found out that people who walk on foot enjoy their travel time more in comparison to commute travel or on-the-clock travel.

Czech studies regarding VTTS

The main resource for identifying the value of travel time savings was in the Czech Republic was the traffic journal number 11/2013 [4]. The results were based on the research conducted in 2006 and were initiated by the European Commission. Individual values were recalculated according to the conditions of the Czech Republic (GDP, inflation…). Results are shown in Table 4.

Item			**Specific cost in personal hours**			
			Cost 2002		Cost 2012	
			EUR	CZK	EUR	CZK
Work time	**Bus**		11,45	352,8	21,24	524,1
	Car, Train		14,27	439,7	26,47	653,2
Non-work time	**Short commute**	**Bus**	4,13	127,2	7,66	189,1
		Car, train	5,75	177,2	10,67	263,2
	Long commute	**Bus**	5,31	163,6	9,85	243,1
		Car, train	7,38	227,4	13,69	337,8
	Other-short-distance	**Bus**	3,46	106,6	6,42	158,4
		Car, train	4,82	148,5	8,94	220,6
	Other-long-distance	**Bus**	5,45	137,1	8,26	203,7
		Car, train	6,18	190,4	11,46	282,9

Table 4: Value of travel time savings for the Czech Republic [4]

We can see for work time the VTTS is significantly higher than for non-work related travels. The VTTS is increasing with the trip distance and the time comparison shows that over time the value of travel increases (this trend is closely analyzed in part 1.2). These results support the outcomes of previously presented studies.

The following study [20], is focusing on the value of travel time savings in the context of leisure travel. Results suggest that in the case of the most common type of long-distance leisure trips – weekend trips, estimated values of travel time savings are within the range of 25 % and 50 % of the average hourly wage. The study also confirms that the value of travel time increases together with a trip length.

The value of travel time savings for weekend leisure trips estimated by the study (using the stated preference survey) is 55.87 CZK/h. In the case of holiday travel, the value increases to 115.62 CZK/h. The downside of this study is that it didn't account for the socio-demographic characteristics of respondents, so the coefficient of determination was low for the estimated model. Such aspects can have a profound effect on the results.

A more recent study [23], conducted in 2018 supported the results from the previously mentioned one [20]. When looking at work-related trips, the specific value for travel time in the case of commuting by train and integrated bus transport is 600.34 CZK per person for one hour. The value for the bus is slightly lower and amounts to 481.70 CZK per person for one hour. Both values exceed the VTT for non-work-related trips. These were estimated for a short distance by IAD/Train 233 czk/hour and for long-distance to be 300 CZK /hour. For the bus travel mode, the estimations were 168 CZK/hour for short-distance trips and 216 for long-distance trips.

A complex meta-analysis of European value of travel time

The University of Leeds in the UK conducted a study regarding the values of travel time. For its purpose, they have used data from 389 European studies conducted between the years 1963 - 2011 in 26 European countries [11].

	Commute			Other			Business		
	Official	**Urban**	**Inter**	**Official**	**Urban**	**Inter**	**Official**	**Urban**	**Inter**
Norway (2009)	**Ramjerdi and Flugel (2010)**								
Car short (<100km)	11.7	11.73/16.68		10.01	10.33/14.69		49.40	23.85	
Car long (>100km)	26		16.22/23.06	18.98		14.28/20.31	49.40		32.98/46.9
PT(Bus, Train)short (<100km)	7.8	8.81		5.98	7.76/11.27		49.40	17.92/34.5	
Train long (>100km)	20.28		17.69	11.96		15.58	49.40		47.71
Bus Long (>100km)	13.39		12.18	9.49		10.73	49.40		24.78
Air	37.44		43.04	23.40		37.9	57.85		87.54
Netherlands (1997)	**Hague consulting group (1998)**								
Car	10.51	8.49/12.08	11.74/16.7	7.27	7.48/10.64	10.34/14.71	36.43	16.87/23.98	23.32/33.16
Train	10.58	9.34	12.91	6.52	8.22	11.37	22.4	24.58	33.99
Bus Tram	9.85	6.43/9.34		6.52	5.66/8.22		17.16	12.77/24.58	
Sweden (2008)	**Trafikverket (2012)**								
Car long (>100km)	10.96		10.91/15.51	10.96		9.61/13.66	29.54		21.55/30.64
Bus long (>100km)	3.96		8.28	3.96		7.29	29.54		16.34
Train long (>100km)	7.41		12.02	7.41		10.58	25.07		31.46
Air				17.56		29.23	29.54		57.72
Car short (<100km)	8.83	7.89/11.22		5.99	6.95/9.88		29.54	15.58/22.16	
Bus short (<100km)	5.38	5.99		3.35	5.27		29.54	11.82	
Train short(<100km)	7.00	8.69		5.38	7.65		25.07	22.75	
Denmark 2004	**Fosgerou et al. (2007)**								
Car	11.87	8.07/11.47	11.15/15.86	11.87	7.11/10.10	9.82/13.97			
PT (bus, train)	11.87	6.12/8.88		11.87	5.39/7.82				
Switzerland (2003)	**Swiss association of Road and transportation Experts (2009) for commuting and leisure, and Axhausen et al (2006) for business**								
Car	26.7	9.39/13.36		6.19	8.27/11.76		37.87	18.79/26.72	25.98/36.95
PT (bus, train)	16.19	7.1/10.3		8.72	6.25/9.07		35.31	14.19/27.33	
United Kingdom	**Mackie et al (2003)**								
Car	8.17	7.12/10.13	9.85/14.00	7.25	6.27/8.92	8.67/12.33	32.47	13.96/19/84	19.3/27.44
Train							38.35	20.43	28.24

Table 5: Official Values of Time from Studies Included in Meta-Data and Implied Meta-Model Values of Time (€ per hour 2010 incomes and prices). For car and PT, there are two given values. The first one represents the free flow time and the second one the congested time [11]

	Official	*Meta*
Commuting	13.29 (1.86) [20]	12.43(1.78) [20]
Other Trips	9.94 (1.12) [21]	11.82(1.72) [21]
Business	36.13(2.50) [20]	29.59(3.89) [20]
All	19.49(1.86) [61]	17.86(1.83) [61]

Table 6: Summary of Official and Meta-Model Values of travel time (€ per hour 2010 incomes and prices). Figures are mean value, standard error of the mean ( ) and the number of observations [11]

Regression models for Value of travel time savings

In 2009 J.D. Shires and G.C. Jong conducted an international meta-analysis of values of travel time savings. These values are often used in cost-benefit analysis of transport projects and policies, and also to compute generalized travel costs. With the analyzed data they managed to construct a regression model expressing the relationship between a range of different variables and the value of travel time savings [12].

The results of the analysis for the OLS model analyzing employer's business showed that for dummy variable describing travel by aeroplane has a positive influence of 0.32 on the value of travel time savings (increases the VTTS). The dummy variable describing travel by bus has a negative effect of -0.22 on VTTS (that means there is a lower benefit from reducing the travel time if the traveller is using the bus). With increasing GDP per capita (2003, €) the VTTS increases by a coefficient of 0.47. For countries outside Europe, the VTTS is decreasing by -0.33. It is important to mention that this estimated model had a coefficient of determination of only 0.36 (74% of the influence on VTTS is not expressed by the selected variables).

The OLS model describing VTTS for commute form of travel showed the following. Bus dummy variable has a negative effect of -0.19 on VTTS. The dummy for long-distance trips has a coefficient of 0.17 which indicates a positive effect on decreasing the travel time. With increasing GDP per capita (2003, €) the VTTS increases by 0.68. In countries from Southern Europe, the value of travel time savings increases by 0.22. For countries from Eastern Europe, the value increases by 0.59. This estimated model has a coefficient of determination of 0.55, which is moderate and better than the model estimated of employer's business travel.

For the OLS model capturing the leisure travel alternative the influential coefficients for certain variables were captured as follows. The dummy variable for travel by aeroplane has a coefficient of 0.34, which indicates increasing VTTS. The opposite effect of -0.35, has the dummy for bus travel. For long-distance travel (also dummy) the coefficient is 0.30, which again increases the value of travel time savings. For variable capturing GDP per capita (2003, €) the effect is 0.53, increasing the VTTS by the largest amount. Countries from southern Europe have slightly bigger VTTS in comparison to the countries from eastern Europe, 0.37 to 0.36.

We can see that there is a large amount of variation in the estimation of the value of travel time savings. According to the coefficient of determination, the models can explain 36% (employers' model), 55% (commute model) and 45% (leisure model) of that variation. The rest of the model is dependent on other attributes of the countries and the methods used in the individual studies, for which there are no variables to include in the model.

The next important findings from these regressions are the income elasticities of the VTTS: 0.47 for business, 0.67 for commuting and 0.52 for other purposes. That reflects how the demand for certain modes of travel changes according to the supply. We see that the most elastic value of travel time savings is for commuting and the least elastic is business travel.

Transport mode choice

Mode choice models have been used extensively to evaluate policy implications and level-of-service changes, providing a powerful transportation planning tool for developing effective travel demand forecasts. The following study shows the results for modal choices concerning distance or travel time [13]. It works with a representative sample of Austrian workers. The analysis reveals population-weighted median VTTS estimates for the car (12.3 Euro/h), public transportation (PT; 8.1 Euro/h), bike (11.7 Euro/h) and walk (10.2 Euro/h).

Attributes	Observations	mean	std	skewness
Shortest path street distance SPDS [km]	17 392	9.8	12.9	2.6
SPDS if choice = walk [km]	2 374	0.8	1	5
SPDS if choice = bike [km]	1 036	3.4	3.5	2.8
SPDS if choice = car driver [km]	10 673	11.3	13.1	2.4
SPDS if choice = car passenger [km]	1 429	13.6	16.6	2.5
SPDS if choice = PT [km]	1 880	12.9	13.5	2
Purpose =work/education	17 293	0.2	0.4	1.3
Purpose =leisure	17 293	0.1	0.3	2.4
Purpose =shopping	17 293	0.1	0.3	2.2
Purpose =other	17 293	0.5	0.5	-0.1
Weekend trip	17 293	0.2	0.4	1.3
Travel time walk [min]	17 293	107	140.5	2.8
Travel time bike [min]	15 501	53.1	63.4	2.9
Travel time car (driver/passenger)	16 014	14.4	13.1	1.7
Travel cost (driver/passenger) [Euro]	16 014	0.8	1	2.8
Parking cost car (driver/passenger) [Euro]	16 014	0.2	0.8	4.7
Acces time+egress time (driver nad passenger) [min]	16 014	4.9	1.5	0.3

Table 7: statistics of transport mode choice RP attributes (for available alternatives) [13]

Table 7, constructed according to the regression model, identified the mean SPSD (shortest path street distance of travelling subjects) to be 9.8 km, with a standard deviation of 12.9km. That means that the collected data concerning SPSD are highly spread out.

The results regarding the purpose of travel showed that out of 17 392 respondents 20% has the main purpose of travel commuting, 10% leisure travelling, 10% shopping, and 50% other purposes.

The travel time of walking was estimated to be 107 min and of cycling 53.1 min. Travel time of car driver/passenger was approximated as 14.4, and access/egress time of driver/passenger was 4.9min. The car travel cost was estimated to be 0.8 euro and parking cost 0.2 euro. These results describing car travel have high std.

Attributes	Observations	Mean	Standart deviation	Skweness
Parking management in force	16 014	0.1	0.3	2.5
Parking space at home	16 014	0.9	0.3	-2.7
Parking space at work place	16 014	0.6	0.5	-0.6
Travel time PT [min]	10 942	16.5	13.5	1.7
Travel cost PT [CZK]	10 942	67.5	69.8	1.7
Access + egress time PT [min]	10 942	14.7	7.9	1.3
Headway PT [min]	10 942	16.9	21.8	3.3
Transfers PT	10 942	0.9	1.0	1.0
Main mode – heavy rail	10 942	0.3	0.4	1.1
Main mode – bus	10 942	0.5	0.5	0.0
Main mode – tram	10 942	0.1	0.3	2.4
Main mode – light rail	10 942	0.1	0.3	2.6

Table 8: statistics of transport mode choice RP attributes (for available alternatives) [13]

Table 8 shows us that 90% of respondents using cars have parking space at home, 60% of respondents have parking space at work and only 10% have officially managed parking area around work.

We can see that the travel time spent in public transport is 16,5 min on average, but it has a standard deviation of 13.5 which could mean moderate inaccuracy in the result. The same inaccuracy could be seen for the travel cost that has an estimated mean of 67.5 CZK and a standard deviation of 69.8 CZK
(there is a high variability of the public transport travel costs).

The percentages of individual transport modes resulted to be 30% for heavy rail, 50% for bus, 10% for tram and 10% for the light trail. With the average amount of transfers equal to 1.

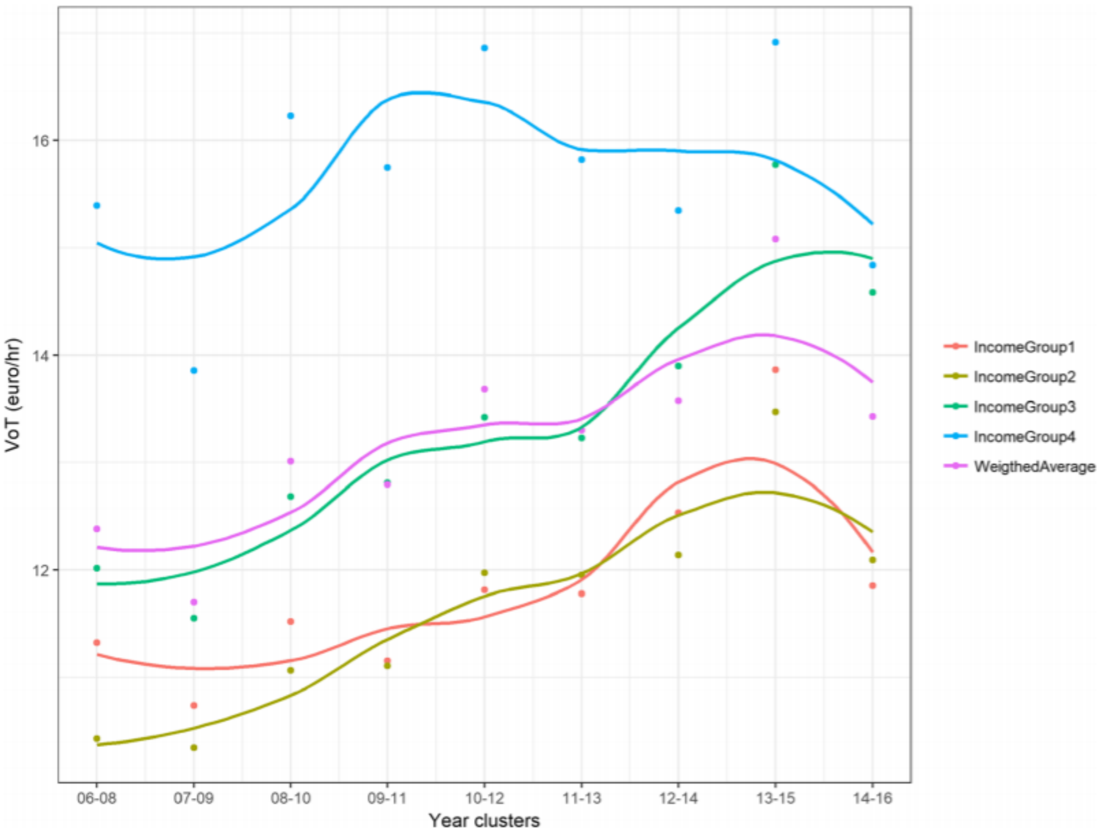
1.2 Trend analysis of travel time

In the case of rich western countries such as Denmark and Australia, the marginal utility of earned income approaches zero (this is an extreme case where everyone has a considerable amount of wealth). In this situation, because transport costs are part of the budget constraint, the preference with respect to transport costs will be weakened as well. This will cause the VTTS to increase and in particular for those with high incomes.

The counterargument could be that due to the significant enhancement of transport technology the travel is becoming a lot more comfortable. More comfortable cars and public transport services could indeed mean that the time spent in these modes of transport is less “painful”. Hence, the discomfort or VTTS should decrease.

Another technology impact that decreases the VTTS is the fact that before 2005, people used to read books and newspapers while travelling on public transport. Nowadays, there are more opportunities, and it is possible to respond to emails and work while travelling. For car users, it is also possible to talk while driving (handheld communication and Bluetooth) and all of this points in the direction of a lower VTTS simply because transport becomes less of a waste of time.

If we look beyond the fact that new technologies may partly provide some relief in how travel time is perceived, congestion will point in the other direction. This is mostly concerning cars and public transport. The truth is that high traffic level is starting to be a big problem even in highly developed countries, where the infrastructure and public transport is well functioning. It is an increasing concern due to the escalation in urbanisation in most cities around the world. Being productive while travelling in the morning or afternoon congestion peak is highly improbable, as the roads are stuck, and trains and buses are fully packed.



Picture 1: Estimate of VTTS for each income group across the years 2006-2016. (Income group 1 represents the 25% of individuals with the lowest annual personal income whereas group 4 represents the 25% of individuals with the highest incomes) [19]

[19] strongly indicated that there is no sign of declining VTTS for the mentioned period. Even though in the last year cluster we can see a small declining tendency, it is not more profound than the overall trend. Furthermore, a significant driver of increasing VTTS is that of increased congestion and travel distances.

1.3 Types of travel

To construct a relevant analysis of travel time, we have to account for the type of travel that is happening (on-the-clock travel, commute travel, personal travel, bus and rail transit travel, aeroplane travel, non-motorised travel), because each type has different characteristics and conditions.

On-the-clock travel

On-the-clock travel consists of trips made by workers during a workday as a part of their job. A considerable part of these work trips is made by truck drivers or workers attending meetings. Delivery services are also counted in this category. The main modes used for this type of transport are trucks, cars and vans. The value of such a travel time should include workers' wages and overhead costs. The US Department of transport suggests using $21.20 per hour for on-the-clock transport.

There are situations in on-the-clock travel, where travellers are passengers rather than drivers. That means that they can conduct some productive work during their trip (working on the bus, train aeroplane) and reduce the unit cost of travel. This is often not accounted for in the calculation of the value of time savings, because it is highly dependent on the characteristics of the traveller.

Commute travel

Commute travel is described as periodically recurring travel trips that are connecting travellers place of residence and place of work or study. Studies mainly refer to peak-period commuting (morning, when travellers are going to work and late afternoon, when they are returning from work) and distinguish commute travel from non-work (personal) travel. The value of commute travel time is usually calculated as a fraction of the wage rate. The US Department of travel suggests taking a 50% value of travellers wages.

The problem with commute travel is its variability. The travel time can profoundly change according to the traffic situation. In the calculation of the unit cost of commute travelling, we need to account for variability under congested road conditions. A survey conducted in California showed a strong aversion of travellers to unpredictable travel times. It stated that a minute of saving under congested conditions is valued 2,5 times more than a minute in a non-problematic traffic environment (few other studies redefined this multiplier in a range of 1,4-2,3, depending on the level of congestion) [5]. Studies of tool-roads show that commuters make trade-offs between time and cost, where they value their time 1,4-1,8 times more. Travel time cost should also account for the stress of driving under high traffic conditions.

Here we assign the value of travel time (as a percentage of wage) according to the level-of-service (with a range from A to F, where A fluent transport and F is extreme congestion). At level-of-service A, B, C we take the travel time unit cost as 50% of the wage. That increases to 67% at level-of-service D, to 87% of wage at level-of-service E and to 100% at level-of-service F. This describes the travel time unit cost of a driver. In passenger cases, the increase in congestion is not that significant [5].

Personal travel

Personal travel includes non-work-oriented trips like leisure time trips. Across different conducted studies [17] the unit cost of personal travel varies from one third to half of the average wage rate. The tendency is that for long-distance travelling the unit cost increases, in comparison to the short-distance trip. The recommended price by the US Department of transportation is half of the average wage rate and for long-distance trips, it increases to 70%.

1.4 Travel modes

Bus and rail transit travel

Passenger unit cost of travel time is a combination of the unit cost of work and non-work trip, depending on the individual traveller. In conservative studies after averaging work and non-work trips, they value passengers travel time as 50% of the average wage rate [5].

For the bus and rail transit travel there is a not negligible amount of off-vehicle time included during the travelling (walking to stations, waiting for arrival). To make our estimation accurate a separated value is used for an off-vehicle time, depending on the surrounding conditions (rain, hot sun, crowded station). If the conditions are unpleasant higher rate is set for the off-vehicle time than for the in-vehicle. The price recommended by the US Department of transport is 100% of the average wage rate for time spent walking and waiting.

1.5 Modelling of the transport sector

Modelling in the transport sector is a process where a model of the energy system is created through the usage of a computer program. This model is then used for further analysis of the energy system. To create an accurate energy model, we need to use detailed scenario analysis, to study a wide range of assumptions connected to the conditions (economical, structural, technical) at play. Outcomes of the model can be the practicability, financial aspects, natural resources used, emissions or energy efficiency of the analysed system.

The main contribution of energy models is to the creation of energy policies (governments create energy policies based on national energy models) or engineering designs (creating a functional process or product). With an increasing danger of climate change energy models gained a lot more attention, since the energy supply sector is the largest producer of global greenhouse gas emissions [9]. According to IPCC (Intergovernmental Panel on Climate Change), climate change mitigation can be achieved by reconstructing the energy supply sector and substituting the consumption of fossil fuel with different low-greenhouse gas options.

Energy models

Energy Models include heat, electricity, gas, mobility and other relevant sectors, based on the purpose of the created model. Mostly demanded are national energy models since they help governments to establish efficient energy policies. Primarily we distinguish between top-down and bottom-up models:

- **Top-down models** approach modelling by breaking down a composite system to gain insight into its sub-systems. They are broadly economic and are working with achieving general equilibrium (takes into account the whole system) or partial equilibrium (takes into consideration only a part of the whole system). Since in mathematical modelling partial equilibrium is easier to handle, it is used more often than the general equilibrium.

- **Bottom-up** models work the other way around than top-down models. In modelling, they combine individual simple systems to create more complex systems. In this method, we use the collected data from the targeted environment to form a relevant conclusion. Smaller sub-systems are studied in detail, so the predictions of more complex systems are sufficiently accurate.

Existing models

For effective energy modelling, there are already a few established energy models (LEAP, NEMS, TIMES) [28].

LEAP (Long-range Energy Alternatives Planning System) is a tool to help us address the issues of energy development including energy production, distribution, and consumption together with the issue of climate change. It is used to analyse a wide range of desired systems from the size of a city to national energy systems. It is used in more than 190 countries by government agencies, academics, energy utilities etc. Its primary purpose is to help with integrated resource planning, greenhouse gas mitigation evaluation and Low Emission Development Strategies (LEDS).

LEAP is a device to create models of different energy systems. Its methodology is built around the concept of scenario analysis. Each scenario represents a storyline of how an energy system can evolve. With LEAP analysts can evaluate individual scenarios based on the comparison of their energy requirements, social costs and benefits, carbon footprint and environmental impact. It is compatible with both bottom-up and top-down modelling. It usually works with medium- to long-term time frames with most of its calculations being based on annual-time steps. The main benefit of using LEAP is low requirements on initial data. Many other models use very complex and particular solution algorithms, therefore, have very rigid requirements on input data. LEAP provides a choice between different modelling methodologies and many of its aspects are optional. This allows users to start with relatively simple data structures and therefore saves the analyst a lot of time and work.

NEMS (National energy modelling system) is regional energy, economy and environmental model used for the energy markets of the United States. It was developed by a section of the US government called EIA (Energy Information Administration). Every year version of NEMS is updated to the current situation of energy markets. It helps analysts to project the production, import, export, conversion and conservation of energy. In principle, NEMS annually represents the behaviour of energy markets and their interactions with the economy of the United States. The model calculates a balance between supply and demand by solving for prices of each energy product that will balance the quantities produced with the quantities consumed.
NEMS consists of:

Four supply modules – oil and gas, natural gas transmission and distribution, coal, renewable resources

Two conversion modules - electricity, petroleum refineries

Four end-use demand modules – transportation, commercial, residential, industrial

Module to simulate energy-economy interactions – macroeconomic activity

Module to simulate the world oil market – international energy activity

Module calculating general market equilibrium – integrating module

NEMS design provides a high level of working flexibility. For each component of the U.S. energy system, it uses the most appropriate calculation. It can execute each section individually or in a collection to create accurate assumptions about the future development of desired energy section.

TIMES (The Integrated MARKAL-EFOM System) is an economic model generator (evolution of MARKAL). It covers scales from local, national and multi-regional up to global energy systems. It provides a basis for describing energy dynamics over the desired time horizon. TIMES can be used to analyse single parts of the energy market such as electricity/heat distribution or to analyse the entire energy sector.

The user of TIMES needs to provide the estimates of end-use energy service demands (car road travel, residential lightning) for each studied region, to drive the reference scenario. Other necessary estimates for the TIMES are the characteristics of future technologies, the number of existing stocks of energy-related equipment and present/future sources of energy supply. After estimating all of these inputs, the TIMES model calculates the supply of energy services at a minimum loss of total surplus (minimum global costs). The results of TIMES help the user to make decisions on equipment investment and operation (energy supply and trade for each region). TIMES can be used also to analyse the environmental emissions or materials related to energy systems.

Example: If we experience an increase in residential energy service relative to the reference scenario, due to the decrease in the cost of electricity, either the existing equipment must be used more intensively or be exchanged for a more efficient one. The choice of light generation equipment (by the model) is calculated using the characteristics of alternative light generation technologies together with the economics of energy supply and environmental criteria.

2. Data

The main data source of data is the stated preference survey "Česko v pohybu" conducted in the Czech Republic during the years 2017-2019 [25].

For accurate modelling in VEDA, I had to calculate a time budget for travelling that would give model information about how much time can be spent by travelling during the day. The calculation was done using the information about the travel time budget form [25]. That was averaged on one traveller and multiplied by the number of people in the Czech Republic to get the total travel time budget. The travel time budget for long and short personal kilometres was calculated using the percentual amount of short and long trips. The results were then compared to the transport yearbook [27].

To account for the difference in preferences in between travel modes I have created a commodity time-comfort-gasoline. It considers the value of travel time in different travel modes and on different distances. For the model, the input unit for this commodity is million-euro per hour. It was calculated by taking the weighted average of values of travel times (cleaned up from inflation) from [4].

2.1 Summary of the primary data source

During 2017-2019 a stated preference survey was conducted in the Czech Republic [25]. It gathered responses from 9219 households across Czechia (that contained information from 22 122 people describing the aspects of their 51 434 travels). The survey provided the following results:

Household equipment with cars and bicycles

In households that participated in the survey, 28% reported that they don't have a car in their possession. 51.1% have one car for the whole household. 16.9% have two cars and 3.75% have more than 3 cars. If we consider bicycles, 46% of households have none. 17% have one bike, 18.1% have two bikes 6.6% have three bikes and 10.2% have four or more bicycles. We can see that more than 70% of households are equipped by car, which has a direct effect on their transport preference. Close to half of households do not have a bicycle in their possession so are reliant on the car or public transport.

Access to modes of transport (car, public transport bonus)

If we consider overall access to car 64% can travel by car. If we take into account the economical activity (active or inactive) 76% of economically active respondents have access to a car and 49.1% of economically inactive can travel by car. 32% of respondents have access to a form of public transport benefits and therefore have the incentive to travel by public transport. In the case of economical activity, 28.4% of economically active participants have public transport benefits and 38.1% of economically inactive have public transport benefits. We see that with economical activity the percentage of trips by car grows. That could be connected to the fact that they value the travel time more than the economically inactive part of respondents.

Number of trips during the workday

The number of trips in one randomly selected day was 0 for 18.5% of participants. 1 trip was completed by 3.4% of respondents. 2 trips were completed by 42.2% of respondents. 3 trips were completed by 12.8% of respondents. 4 trips by 15.4%, 5 trips by 3.2%, 6 trips by 2.9% and 7 trips by 1.6%. We can see that the most common number of trips is 2 since it reflects the journey to work and then back from work. For economically active participants the percentage for 0 trips reduces to 13.1% and the percentage for 2 trips increases to 44%. From the other perspective for economically inactive people, the percentage for 0 trips increases to 25.7% and the percentage for 2 trips decreases to 39.4% since they have one less reason to travel during the day in comparison to the active ones.

Purpose of travel

On the overall average, 40.8% of respondents reported that the reason for the trip was accessing their place of residence. Survey options for the travel purposes that could be considered non/work-related are related to free time, shopping, resolving non-work-related responsibilities, food, education and other. The percentages for these options were 11.9% free time, 10.1% shopping, 7.4% resolving non-work-related responsibilities, 1.1% food, 6% education and 1.9% other. The work-related trips consumed 20.9%.

If we divide the samples into economically active and inactive the percentage significantly differ. For economically active respondents the work-related trips percentage increases to 33.1% and education purpose shrink down to 0.6%. Economically inactive respondents spend 16.7% of their travels on free time and 14.8% on education. The percentage for work-related trips reduces to 0.7%. This change can be justified by the fact that economically inactive people are mainly students who do not work but study instead or the elderly that do not work but spend more of their travel on free-time activities.

Travel modes used

The question “what mode of transport was used for the trip” brought the following results. Overall 35.4% of people participating in the survey travel by foot. A bicycle uses 4.5%. Public transport (combined with train and bus) is used by 20.2% and the car (as a passenger or driver) is used by 39.1%. These results account for all the travel purposes combined.

It is interesting to look at some separate travel purposes. If we examine the trips that are connected to a place of residence we see that 33.8% walks, 4.8% uses bike, public transport (combined with train and bus) is used by 21.5% and 39,5% of participants use a car (as a passenger or driver).
If we take a closer look at work-related trips 19.6% of people travel by foot, 4.4% use bike, 24.3% use public transport (combined with train and bus) and 50.8% use car (as a passenger or driver).

Trip duration

For each trip survey asked for the time of initiation and end. From that, it was possible to derivate the trip duration. Overall people walk 20.89min. Bike trips take 27.31. There is a significant difference between bus, train and public transport that we cannot overlook. For Public transport, people travel 27.84min, when travelling bus the trip duration is usually 43.43min long and when using train it is 65.27 min long. Car trips (as a passenger of driver) take 31.53 min.

Travel distance

Travel distances were derived from the estimation of travel distances by respondents and individual coordinates calculation according to the road network. On average when people walk, they travel 0.81km. When using a bicycle, people drive 3.08 km on average. In public transport, the trip is usually 6.53 km long. Bus trips are 17.31 km long and train trips are 35.63 km long. In a car (as a driver or passenger) people usually drive 15.93 km.

3. Times model

I use a predefined model DEMO model as simplification of the energy system and a travel sector module from the TIMES-CZ model [30]. I developed the transport module into more detail to allow to incorporate the travel time budget to model transport modal choice Daly et al., (2014).

The dividing distance between long person kilometres and short person kilometres was 20 kilometres. Short kilometres are describing the distance travelled inside cities and long kilometres are describing intercity travel.

To create a logical growth of demand for short and long person kilometres I have calculated a coefficient of growth using [29]. The demand for short person kilometres grows form the demand for short person kilometres grew from 47000 mil SPKM to 63000 mil SPKM. The demand for long person kilometres grew from 69000 mil LPKM to 93000 LPKM.

To create an accurate model, I have applied regulatory conditions to the model so that the model would not calculate using only the most efficient modes of travel. For car travel, the lower bound for long person kilometre production is 62% in 2017 and decreases to 50% in 2050. The upper bound for long car travel was 68% in 2017 and decreases to 55% in 2050. Lower bounds for short car travel are 14% in 2017 and 11% in 2050. The upper bounds for short car travel are 17% in 2017 and 13% in 2050. The lower bounds for long bus travel are 6% in 2017 and 5% in 2050. The upper bounds for long bus travel are 8% in 2017 and 6% in 2050. The lower bounds for short us travel are 8% in 2017 and 6% in 2050 and the upper bounds are 10% in 2017 and 8% in 2050. For long train travel, the lower bound is 6% in 2017 and 5% in 2050 and the upper bound is 8% in 2017 and 6% in 2050. For short and long train travel the lower bounds are 1% in 2017 and 2% in 2050. Another necessary limitation was concerning individual car travel. I had to fix the portion of LPKM supply of each type of car to be 70% and for SPKM to be 30%. Otherwise, the model would select only the most beneficial car ale left out the other types. Since travelling by cars with electrical engines is quite a new phenomenon, I had to introduce this technology only from 2020 and not earlier.

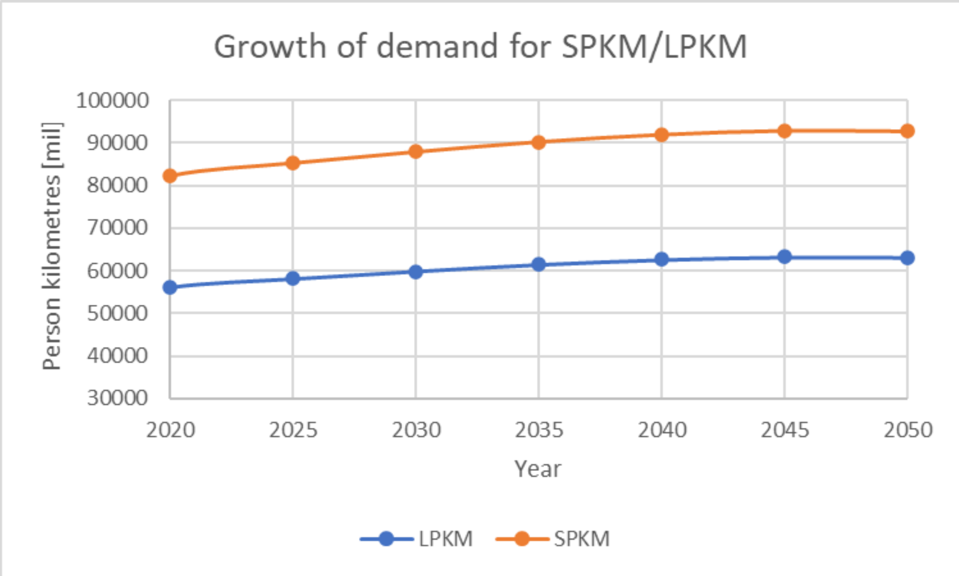
4. Scenarios

I have created two scenarios.
The baseline scenario (**BL**) has no time budget limitation and no cost of travel time.

The timebudget scenario (**TB**) introduces limitations on the overall time budget and travel mode-specific travel time cost. The travel time budget was calculated from the Czech Republic travel information [25] to fit the population of Czechia.

I have then compared the results from these two scenarios in terms of total costs and short/long person kilometre demand. Each travel mode (bus/train/car) has a coefficient that accounts for the commodity time-comfort-gasoline, which is crucial in the decision-making process of travellers.

Both scenarios have common exogenous demand for travelled short/long person kilometres (Graph1).



Graph 1: Evolution of demand for short/long person kilometres over years 2020-2050

According to the calculations, there is a 34% growth in demand for short and log person kilometres. That could be caused by the increase in the overall population and increased production and effectiveness of travel modes.

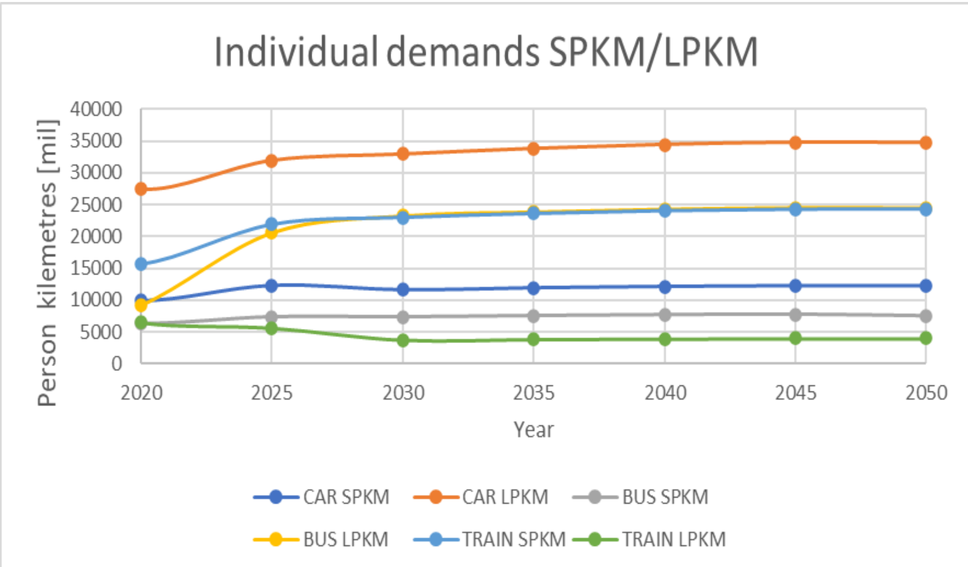
5. Results

I have used two different scenarios with a different approach towards the overall calculated time budget for the Czech Republic. I planned to compare the two overall results and create a logical conclusion. The overall results had no profound difference between each other. The individual differences between these two scenarios remained on the level of basic calculations.

Using the researched value of travel time to determine the costs of travelling by individual modes I derived the following results. The most expensive was the urban travel by bus, due to low comfort and average speed. Urban bus consumed 22.01 l/km time-comfort-gasoline per kilometre, which means that one kilometre travelled costs the traveller 22.01 CZK. Next was intercity travel by bus consuming 11.99 l/km. Long distance travel by car consumed 5.54 l/km and short distance consumed 9.19 l/km. The train had the highest effectivity on urban travel consuming 5.46 l/km and 8.36 l/km on long distance trips.

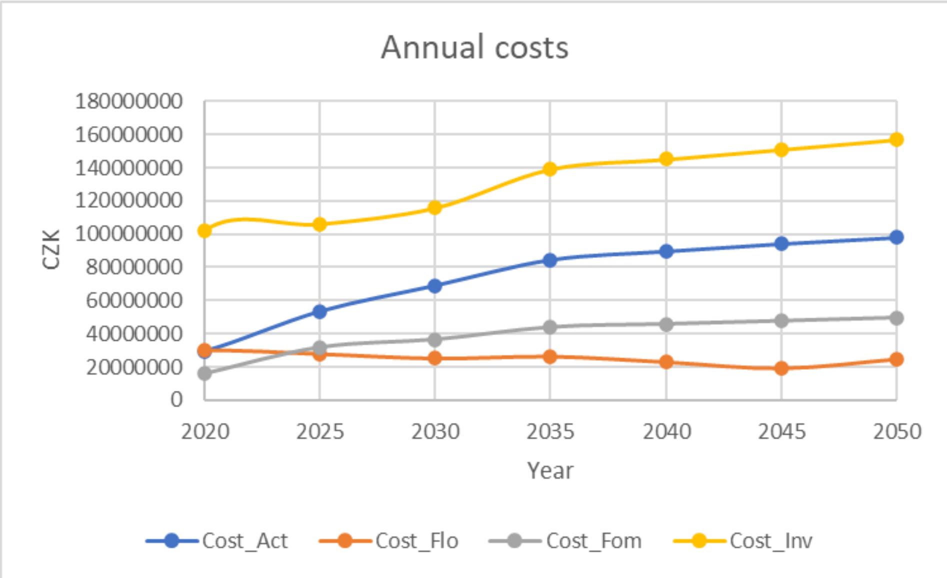
The baseline scenario (with no time budget restriction) had no difference from the timebudget scenario up to the year 2030. In between years, 2030-2040 baseline scenario started to prefer regular diesel engine cars over hybrid engines. That is due to the difference in fuel consumption and overall stock of available cars. Hybrid cars were more regulated in the model. Without time regulation the model used more diesel cars to produce long person kilometres (intercity travel over 20km). Another difference in car travel mode selection between BL and TB is in urban travel (distance below 20 km). The travel budget scenario is using more LPG engine cars over regular diesel engine cars. That is due to the fuel cost and consumption during urban travel. LPG are in these conditions more effectively and therefore have a lower value of travel time.

The low amount of difference between the two scenarios could be caused by the high number of regulations issued onto the modelling process. These regulations are necessary due to the simplicity of the created scenarios. If the model would have more complex scenarios to work with, it would have looser manipulating space and therefore give more profound differences in results.



Graph 2: Individual demands for short/long person kilometres divided by mode and travel distance (LPKM>20km, short<20km)

Graph 2 demonstrates the evolution of demand for individual modes of transport based on travel distance. There is an increase in demand for a long-distance car travelling since the car technology is rapidly improving and therefore the travel comfort with it. The same conclusion can be applied to long-distance bus travel since is more effective and beneficial for lower-income groups. Another major increase is in the short distance train travel (urban). That is the most efficient travel mode to be used in these defined conditions and therefore its use is going to increase in future years. Urban travel by bus is facing a mild decrease since a lot of travellers that were using the intercity bus are going to transfer to urban train (metro/tram). The same theory can be applied to urban car travel. There is a danger of congestion problem and therefore decreased comfort. Train or tram in this scenario is a lot less risky and therefore travellers prioritize metro/tram before urban car travel. The model shows s slight decrease in train travel on long-distance, that can be the case since cars and buses are increasing their comfort and effectivity over time, but there is also a factor of subsidies that incentivizes train travel and was not included in the model calculations. That could change the trend of long-distance train travel from decreasing to slightly increasing.



Graph 4: Evolution of annual travel costs (Cost_Act- activity costs, Cost_Flo – annual flow costs including import and export prices, Cost_Fom – fixed operating and maintenance costs, Cost_Inv – investment costs).

Graph 4 demonstrates the overall growth in annual costs. That is logical since the demand for travelling is increasing. A moderate increase is visible in investment costs. Demand for innovations in transport technologies is growing and therefore the investment into transport modes is also going to grow. The next visible increase is connected to activity costs. That is logical since the overall use of travel modes and overloading of Czech infrastructure is going to increase and the activity costs with it. Flow costs are following a constant trend. They include the import and export prices of fuel. Since the model is counting with the increase of electric and LPG cars the fuel costs decrease. Fixed operating and maintenance costs increase. That is logical because the overall distance travelled increases and that is connected to amortization and needs for repairs.

6. Model Limitations

To increase the accuracy of the developed model, many additional aspects could be taken into account. I have limited the travel modes to bus, rail and car. In real transport management, there are a lot more modes that could be taken into account.

For example, aeroplane travel for which the US Department of travel estimates the unit cost of travel for intercity on-the-clock air travel as $41.10 per hour, $23.30 per hour for personal air travel and $28.60 per hour as a blended average. Another example is Non-motorised travel. That can be narrowed down to walking and cycling. As a lot of the previous modes of transport modes, this transport mode is dependent on the surrounding conditions. Under unpleasant conditions unit cost is high, but under favourable conditions, unit cost decreases drastically. It can be even negative since some travellers enjoy the time spent outside in nice weather or doing some exercise (it usually substitutes travellers free time reserved for exercise). So, traveller will choose this mode of transport even if it takes more time.

Next, we can take into account pollution. Each mode has a different level of carbon/noise/light pollution. In future, the model can provide information about how to efficiently transfer to a low carbon transport system. The means to find a transport mode that leaves the smallest carbon footprint (total greenhouse gas emissions produced, expressed in the amount of carbon dioxide produced). Low-carbon transport development is necessary to reduce the adverse effects of climate change.

Another factor that could be included in the calculations is the valuation of transport externalities. Negative externalities include local air pollution, noise pollution, light pollution, safety hazards and community severance. The contribution of transport systems to potentially hazardous climate change is a significantly negative externality. Congestion is also considered a negative externality and as we have shown in the previous studies, it increases the VTTS. Valuation of health impacts according to studies carried out in the Czech Republic costs Czech medical care 490 000 CZK per year [24]. The additional cost that could be accounted for is the decreased production of the agricultural sector due to acidic rains or the accelerated corrosion of construction materials that need to be repaired.

The next limitation is the fact that inside the calculations, I was not able to include the incentives and subsidies for bus and train modes of transport and therefore the model views the less efficient than they are in the reality, therefore decreases their portion in the optimization result. In reality, more people would choose to travel by bus and train.

7. Conclusion

The main aspect of the research was to determine the value of travel time and from it derive the modal choice of transport. This information was used to run TIMES modelling software and create the optimal transport scenario for the Czech Republic. The model consisted of three main travel modes (car, bus and train).

In stated preference surveys, responses were mixed. It is important to value the travel time because it is a commodity that has a finite supply and therefore certain value. Many aspects affect the value of travel time like the trip duration, comfort, congestion or trip purpose. The results from conducted surveys differ but most studies agreed on the fact that the value of travel time is increasing with the distance of the trip, since the traveller is getting uncomfortable with the travel itself, and there is a higher probability of congestion problems.

For the purpose of modelling, I have represented the value of travel time by introducing a new commodity nicknamed "time-comfort-gasoline". This allows the model to represent people's preferences for travelling different distances by different modes of transport. Using this, I used TIMES software to create the travel scenario of the Czech Republic. Based on people's demands for travel and many other variables, the model outputs the distribution of person-kilometres travelled by the various modes of transport (bus, car, train) and create an ideal travel scenario.

In the two scenarios (baseline scenario, timebudget scenario), differences remained on the level of basic calculations and had no profound effect on the summarizing results. The results were inside the individual model choices. Base-scenario used more hybrid engine and LPG engine cars, due to their short efficiency and low fuel consumption. Time-budget scenario preferred classical diesel engine due to its effectivity on long-distance travel. The final growth of demand for a person kilometre was 34%. There was a moderate increase in activity/innovation and fixed operations and maintenance costs. All of these are connected to the fact that the travel demand in the Czech Republic is going to increase and therefore the previously mentioned cost must increase too. Flow costs remained constant. That can be justified by the fact that the percentage of electric and LPG cars used will increase and therefore the fuel expenses will decrease. Demands for urban metro/tram will possibly increase since this is the most effective mode of transport (from these I have examined) since has the lowest risk of congestion and highest comfort and speed. Car and bus long-distance travelling will increase since the improving new technology will bring more comfort and the congestion problem on intercity travel is lower. Bus and car intercity travel will decrease since travellers will prefer tram/metro. Results are showing a decrease in intercity train travel. That is because travellers prefer car and bus modes. The model also is not taking into account the train travel subsidies that help decreases the travel costs of traveller and therefore affect his decision-making.

The model I have created has still a lot of limitations and could be improved in many ways (add more transport modes, account for pollution costs, count with the subsidies for train and bus travel etc.). The results bring us a rough estimation of how people are going to travel with regard to the value of travel time as a deciding factor between cars, trains and buses and what are going to be the connected costs.

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